Signa® MR/i with Signa Select™ (ASP2)
Learning and Reference Guide
Volume 2: Concepts of Specific Pulse Sequences

2292262-100 Rev. 0 (03/01)

Medical Device Directive

These products conform with the requirements of council directive 93/42/EEC concerning medical devices, when they bear the following CE Mark of Conformity:

0459

This equipment generates, uses, and can radiate radio frequency energy. The equipment may cause radio frequency interference with other medical and non-medical devices and radio communications. To provide reasonable protection against such interference, the:

GE Signa MR/*i* Systems

comply with emissions limits for (Group 2, Class A) Medical Devices as stated in EN 60601-1-2. However, there is no guarantee that interference will not occur in a particular installation.

If this equipment is found to cause interference (which may be determined by turning the equipment on and off), the user (or qualified service personnel) should attempt to correct the problem by one or more of the following measure(s):

- reorient or relocate the affected device(s);
- increase the separation between the equipment and the affected device;
- power the equipment from a source different from that of the affected device; and/or
- consult the point of purchase or service representative for further suggestions.

The manufacturer is not responsible for any interference caused by using interconnect cables that are not recommended or by unauthorized changes or modifications to this equipment. Unauthorized changes or modifications could void the user’s authority to operate the equipment.

Do not use devices that transmit RF Signals (**cellular phones**, transceivers, or radio controlled products) in the vicinity of this equipment as they may cause performance outside the published specifications. Keep the power to these types of devices turned off when near this equipment.

The medical staff in charge of this equipment is required to instruct technicians, patients, and other people who may be around this equipment to fully comply with the above requirement.

Immunity/Emissions Exceptions: Note the exceptions from the EMC test results. Check with the business EMC engineer for this information.

In accordance with the international safety standard IEC 601-1, this system is a Class I device, acceptable for Continous Operation, having ordignary protection against ingress of water with type B applied parts and is not for use in the presence of flammable anesthetics.

CAUTION: User to call or contact the local authorities for disposal of the MR System at the end of its useful life.

Table of Contents

Volume 2

About This Guide

Introduction

This chapter explains the purpose and design of the Pulse Sequence Database (PSD) Learning and Reference Guide. It provides the information necessary to understand the layout of the material in this guide.

Purpose of This Guide

This guide is written to aid health care professionals (namely, MR technologists) in making proper selection of each PSD and its associated components relating to the proper operation of the scanner. This guide is intended to teach you the features necessary to use the scanner to its maximum potential. It is not intended to teach magnetic resonance imaging or to make any type of clinical diagnosis.

This guide should be kept with the equipment at all times. It is important for you to periodically review the procedures and safety precautions. **It is important for you to read and understand the contents of this guide before attempting to use this product.**

Prerequisite Skills

Since this guide is not intended to teach magnetic resonance imaging, it is necessary for you to have sufficient knowledge to pass the ARRT Magnetic Resonance Imaging Examination. This knowledge is gained through a variety of educational methods including clinical working experience, hospital based programs, and as part of many college and university Radiologic Technology programs.

Chapter Format

Each chapter contains a consistent format. This consistency provides uniformity for content delivery and a better learning environment for you. Listed below are the components for each chapter.

Introduction

The **Introduction** provides a short introduction to the chapter and a list of tasks to be presented. There are pre-questions related to the concepts and tasks of the chapter. These pre-questions help you think about the concepts and tasks as you go through a particular chapter and help reinforce the learning of the material covered.

About...

The **About...** section lists and explains concepts necessary to perform the pulse sequences within the chapter.

This section also provides examples, in the form of a decision matrix, of the PSDs for a particular application.

The decision matrix is only for prescribing a specific scan. The purpose of the decision matrix is to help you understand the trade-offs that occur when you change the values for a particular parameter and to provide a framework with which you may build you own unique protocol.

NOTE: The selected values are only an example of what could be used for a given PSD and are not to be considered recommendations by GE Medical Systems. For specific protocols, refer to the protocols on your system.

In addition to listing the information you need to select on the system, the "What You Select" column of the matrix uses two other conventions.

- N/A refers to not applicable to that particular sequence example.
- N/S refers to not selectable in that particular sequence example.

Glossary of Terms and Acronyms

Appendix A contains a list of terms and acronyms commonly used in Magnetic Resonance Imaging.

Graphic Conventions and Legend

Table About-1 describes the terminology used for the various mouse functions. Table About-2 describes the conventions used when working with menus, buttons, text boxes and keyboard keys.

Table About-1 Conventions for mouse actions

Mouse Action	Description
Click	Clicking the left mouse button to select a button or icon. The button can be pressed in, not pressed in, or popped in/out.
Right-click	Clicking the right mouse button.
Middle-click	Clicking the middle mouse button.
Click and drag	Clicking and holding the left mouse button down while dragging the cursor to the desired location.
Right-click and drag	Clicking and holding the right mouse button down while dragging the cursor to the desired location.
Middle-click and drag	Clicking and holding the middle mouse button down while dragging the cursor to the desired location.
Double-click	Clicking the left mouse button twice in rapid succession.
Triple-click	Clicking the left mouse button three times in rapid succession.

Table About-2 Conventions for menus, buttons, text boxes, and keyboard keys

Example	Describes
Select	Selecting an option in a check box or radial button and selecting a tab.
Press **Enter**	Pressing a hard key on the keyboard.
Press and hold **Shift**	Pressing and holding down a hard key on the keyboard.
Click **[Viewer]**	A button label or Interface button name.
Click  (Exam prior)	Selecting an icon-based button.
In the **Matrix** text box,...	The name of text box in which you can select or type text.
Type **`supine`** in the Patient Position text box (different font and bold)	Text you enter into a text box.
Select **Sort** > **Sort by date**	The pathway of selecting option(s) in a pull-down menu.

Safety Notices

The following safety notices are used to emphasize certain safety instructions. This guide uses the international symbol along with the danger, warning, or caution message.

DANGER: **Danger is used to identify conditions or actions for which a specific hazard is known to exist which will cause severe personal injury, death, or substantial property damage if the instructions are ignored.**

WARNING: **Warning is used to identify conditions or actions for which a specific hazard is known to exist which may cause severe personal injury, death, or substantial property damage if the instructions are ignored.**

CAUTION: **Caution is used to identify conditions or actions for which a potential hazard may exist which will or can cause minor personal injury or property damage if the instructions are ignored.**

NOTE: A Note provides additional information that is helpful to you. It may emphasize certain information regarding special tools or techniques, items to check before proceeding, or factors to consider about a concept or task.

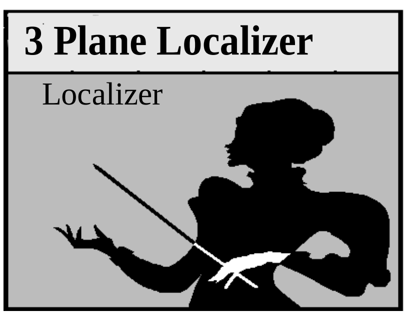
This page intentionally left blank.

Volume 2

Chapter 1

Imaging with 3 Plane Localizer

Where Am I?



Introduction

This chapter explains the pulsing components and timing factors directly related to 3 Plane Localizer. This chapter explains the concepts of each, and the step-by-step instructions to help you learn how to:

- Set up a 3 Plane Localizer

In addition, this chapter answers the following questions:

1. When would you want to use a 3 Plane Localizer?
2. What pulses sequences is it compatible with?
3. What imaging options can be used with 3 Plane Localizer?

About... 3 Plane Localizer

This section presents the concepts necessary to understand 3-Plane Localizer. Specifically you need to understand:

- 3-Plane Localizer
  - Description
  - Background
  - Associated imaging options
  - Applications for 3 Plane Localizer

3-Plane Localizer

Description

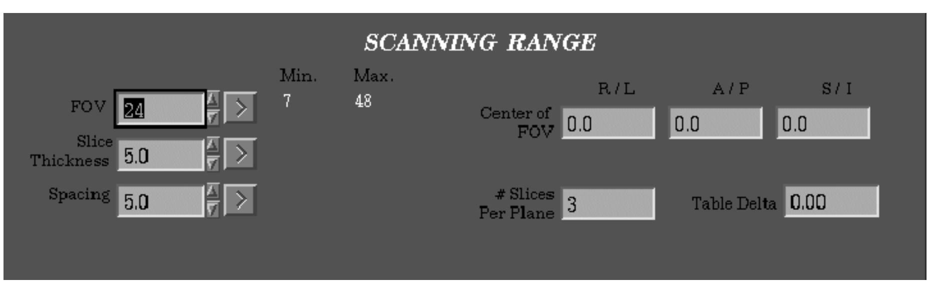
3-Plane Localizer allows the sequential acquisition of three orthogonal scan planes which are scanned in a single series with one scan prescription. 3-Plane Localizer uses a Fast Gradient Echo pulse sequence and can obtain the three planes in a single breath-hold. Two new selections are present within the Imaging Parameters area:

3-Plane is found in the Plane pull-down menu, and Localizer is new on the Pulse Sequence menu.

Background

3-Plane Localizer is launched when 3-Plane is selected from the Plane pull-down menu in the Imaging Parameters area. Once 3-Plane is selected, Localizer must be selected from the Pulse Sequence menu. The only valid mode is 2D.

The Scanning Range area is new for 3-Plane Localizer.



FOV, Slice Thickness and spacing are entered as usual. Enter a Center of FOV for each plane plus the number of slices desired for each plane. The number of slices must be an odd number between 1 – 85. Each plane will have the same number of slice locations. If more than the allowed slices for the gradient platform are programmed, the system automatically increases the # of acquisitions.

Images are acquired in the following order:

1. Axial
2. Sagittal
3. Coronal

3-Plane Localizer images are valid images for Graphic RX, SAT and SmartPrep tracker pulse prescriptions. In Graphic Rx, the system makes available for use only those images appropriate for the plane selected. For example, if the prescribed series plane is Axial, only the Sagittal and Coronal images from the 3-Plane Localizer scan are available for Graphic Rx.

3-Plane Localizer images are annotated LOC. The image plane annotation reflects the plane of acquisition for that image: Ax, Sag or Cor.

The type-in option is `L` and is not case sensitive.

Something to Think About...

- The following scan parameters are not programmable:
  - TR (the minimum value is automatically selected)
  - TE (the minimum value is automatically selected)
  - Flip Angle (a 30° flip angle is used)
  - Receive Bandwidth (32Khz is used)
  - Turn on No Phase Wrap any time a 3-Plane Localizer acquisition contains anatomy outside the selected FOV in any direction.
  - As the number of Slices per Plane increases, scan time increases.
- Each plane is acquired in a different pass.
- No Phase Wrap is the only available Imaging Option with 3-Plane Localizer. NPW is needed if anatomy falls outside the FOV in the phase direction in any one of the three planes.
- If the Center of FOV, for any of the prescribed slices, falls outside of the scan range of the selected coil, a message is posted. Change the Center of FOV location or decrease the number of slices per plane.

Associated Imaging Options

In the following table the X's indicate the option available for use with the 3 Plane Localizer.

Imaging Options			
X	None		Variable Bandwidth
	Flow Compensation	X	No Phase Wrap
	POMP		Extended Dynamic Range
	Square Pixel		Surface Coil Intensity Correction
	Respiratory Compensation		Classic
	Magnetization Transfer		Sequential
	Cardiac Gating/Triggering		Respiratory Gating/Triggering
	Tailored RF		IR Prepared
	DE Prepared		Multi-Phase
	Full Echo Train		CCOMP
	ZIP 1024		ZIP 512
	Zip x 2		ZIP x 4
	SmartPrep		Blood Suppression
	Multi Station		Real Time

Applications

Acquiring a localizer series with all three orthogonal planes, eliminating the need to prescribe and scan three separate series.

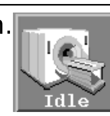
CAUTION: **Provide all patients with ear protection prior to any scan to help avoid possible hearing impairment.** Acoustic noise levels can exceed 99 dBA in the magnet bore.

Setting up a 3 Plane Localizer

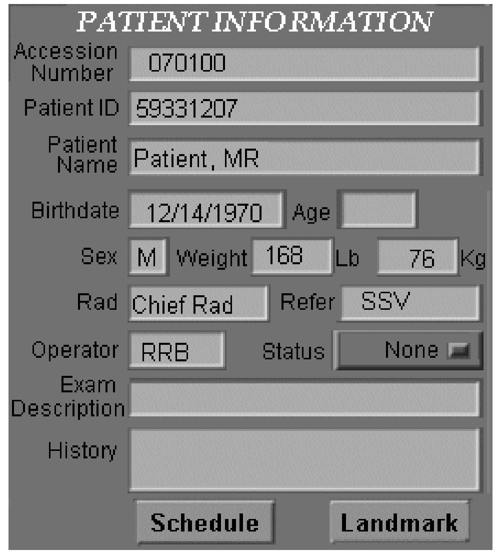
The decision matrix is only for prescribing a 3 Plane scan. The purpose of the decision matrix to help you understand the trade-offs that occur when you change the values for a particular parameter and to provide a framework with which you may build you own unique protocol.

The selected values are only an example of what could be used for a 3 Plane Localizer acquisition and is not to be considered a recommendation by GE Medical Systems. For specific protocols, refer to the protocols on your system.

.

3 Plane Localizer- What you select	Selection Notes
SCAN DESKTOP screen	
	Select **Scan Desktop** icon. 

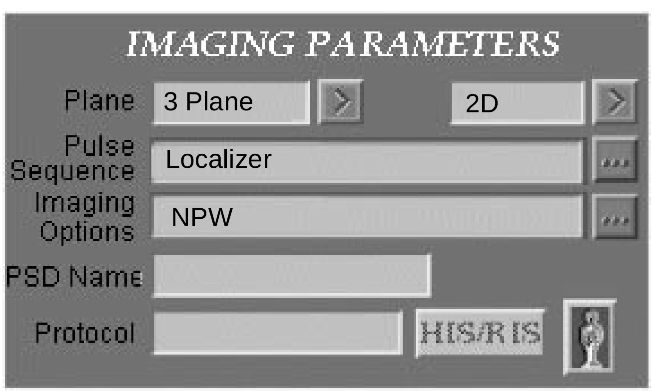
3 Plane Localizer- What you select	Selection Notes
	Click on **[New Patient]** and fill in the patient information.



PATIENT POSITION area

Patient Position	**[Supine]**	**Position and Entry:** 3 Plane Localizer is compatible with any patient position and entry.
Patient Entry	**[Head First]**	**Patient Entry:** 3 Plane Localizer is compatible with any patient position and entry.
Coil	**[Head]**	**Coil:** Select the coil that produces the optimum coverage and SNR.
Series Description		**Series Description:** Enter a suitable series description. If you don not enter a description, the system enters one for you. The series description default is the selected scan mode, PSD, and imaging options.

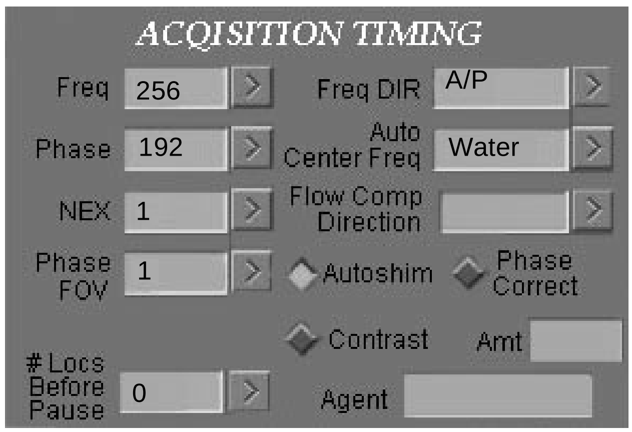
IMAGING PARAMETERS area



3 Plane Localizer- What you select		Selection Notes
Plane	**[3 Plane]**	**Plane:** Select 3 Plane.
Mode	**[2D]**	**Mode:** 2D is the only valid mode.
Pulse Seq	**[Localizer]**	**Pulse Seq:** Localizer is the only available Pulse Sequence when 3 Plane is the selected plane. Click the **[Accept]** button to register the selection.
Imaging Options	**[NPW]**	**Imaging Options:** No Phase Wrap is the only available Imaging Option with 3-Plane Localizer. Use NPW to prevent aliasing or wraparound artifact if anatomy falls outside the FOV in any of the three planes. Click the **[Accept]** button to register the selections.
PSD Name	**N/A**	**PSD Name:** The type-in PSD Name is `L`. Type and enter `L` in the text field as an alternative to selecting Localizer from the Pulse Sequence menu.
Protocol	**N/A**	
SCAN TIMING area		
# of echoes	**[1]**	**# of echoes:** Only 1 echo is allowed.
TE	**N/A**	**TE:** The minimum available TE is set by the system.
TR	**N/A**	**TR:** The minimum available TR is set by the system.
TI	**N/A**	
Flip Angle	**N/A**	
Echo Train Length	**N/A**	
Bandwidth	**N/A**	**Bandwidth:** The Bandwidth is set to 32Khz and cannot be changed.
Bandwidth 2	**N/A**	
SCANNING RANGE area		
FOV	**[24]**	**FOV:** Select a FOV that covers the anatomy of interest. Anatomy outside the FOV in the phase direction results in aliasing. Small FOVs produce: increased resolution, decreased SNR, and can increase the minimum TE value.
Slice Thickness	**[5]**	**Slice Thickness:** Thin slices produce: increased resolution and decreased SNR.
Spacing	**[2.5]**	**Spacing:** Interslice cross-talk is eliminated on sequential gradient echoes. Typical spacing is 0-20% of the slice thickness.
Center of FOV	**R/L: R0** **A/P: A0** **S/I: I0**	**Center of FOV:** Enter the FOV center for each plane. If the value entered is outside the scannable range of the coil, a message is posted.

3 Plane Localizer- What you select		Selection Notes
# Slices per Plane	**[3]**	**# Slices per Plane:** If more than one slice per plane is prescribed, the Center of FOV coordinates entered designate the middle slice, not the first or starting slice location. Only an odd number of slices can be prescribed. Observe the Advisory panel to note the number of acquisitions that have been prescribed. As the number of Slices per Plane increases, scan time increases.

ACQUISITION TIMING area



Freq	**[256]**	**Freq:** Increasing the frequency matrix produces: increased minimum TE and TR, increased resolution and decreased SNR.
Phase	**[192]**	**Phase:** Phase controls scan time and may control resolution.
NEX	**[1]**	**NEX:** Select a NEX value that produces sufficient SNR.
Phase FOV	**[1]**	**Phase FOV:** Select 0.75 or 0.5 to reduce phase steps and thus decrease scan time, decrease FOV in the phase direction, and decrease SNR slightly. The phase FOV dimension is displayed next to the phase FOV factor. The Phase FOV value is applied to all three planes.
Freq DIR	**[A/P]**	**Freq DIR:** 3-Plane Localizer does not follow the normal convention for determining frequency direction. Turn on No Phase Wrap any time a 3-Plane Localizer acquisition contains anatomy outside the selected FOV in any direction.
Auto Center Freq	**[Water]**	**Auto Center Freq:** Water is generally the center frequency selected.
Flow Comp DIR	**N/A**	
Autoshim	**[On]**	**Autoshim:** Click the Autoshim button when using an FOV off center and on the first series of each exam.

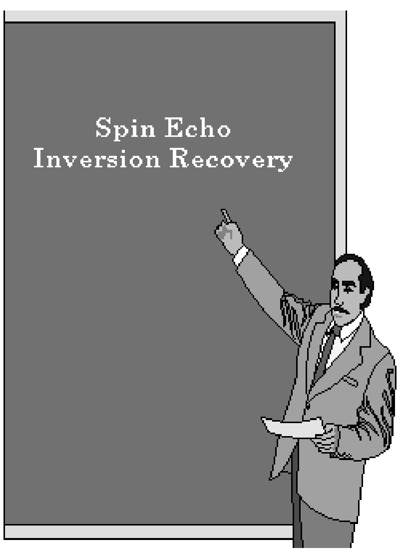
3 Plane Localizer- What you select		Selection Notes
Phase Correct	**N/A**	
# of Acqs/Locs Before Pause	**N/A**	
Additional Parameters **SAT Screen**		
SAT	**None**	**SAT:** SAT pulses are not allowed in 3-Plane Localizer.
SCAN OPERATIONS area		
	[Save Series] **[Prep to Scan]** **[Auto Prescan]** **[Scan]**	Enter data in all the fields and click on **[Save Series]**. The series is saved as RXD.

Volume 2

Chapter 2

Imaging with Spin Echo Pulse Sequences

Where Am I?



Introduction

This chapter explains the pulsing components and timing factors directly related to the Spin Echo (SE) and IR pulse sequences. This chapter explains the concepts of each, and the step-by-step instructions to help you learn how to:

- Optimize Spin Echo images
- Optimize Inversion Recovery images
- Set up a Spin Echo pulse sequence
- Set up a Inversion Recovery pulse sequence

In addition, this chapter answers the following questions:

1. What are the pulsing components and timing factors for SE, and IR sequences?
2. What is the correct TR and the regulation of saturation effects?
3. What is the correct TE and the regulation of dephasing effects?
4. What is the null point as well as the TI regulation of saturation and /or signal suppression?
5. What are the imaging characteristics of a SE and IR pulse sequence?
6. Which imaging options can be used with SE and IR pulse sequences?
7. What are some applications for SE and IR pulse sequences?

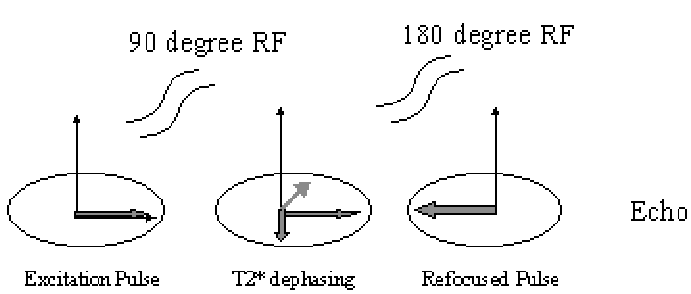
About... Spin Echo Pulse Sequences

This section presents the concepts necessary to understand SE and IR pulse sequences. Specifically you need to understand:

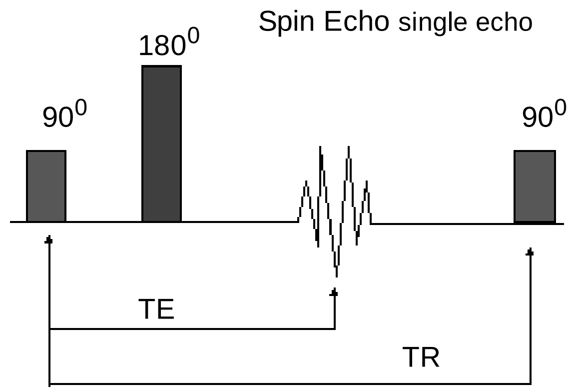
- Spin Echo
  - SE image characteristics
  - Associated imaging options
  - Applications for SE
- Inversion Recovery (IR)
  - Null point
  - TI time
  - IR image characteristics
  - Associated imaging options
  - Applications for IR

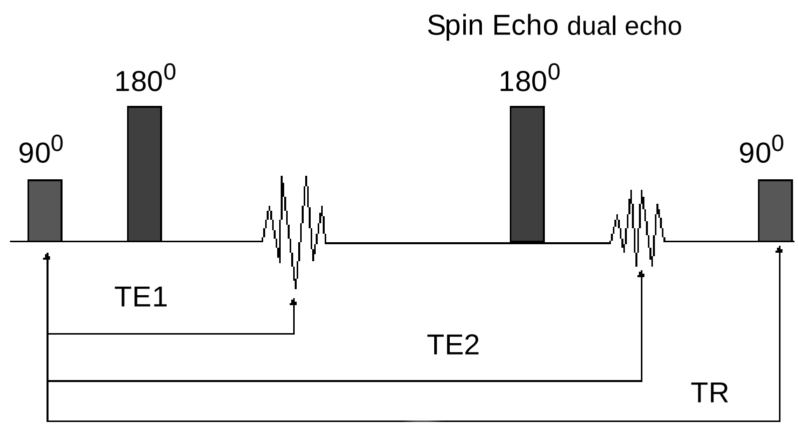
Spin Echo (SE)

Spin Echo is a 2D pulse sequence which consists of an initial 90-degree excitation pulse followed by at least one 180-degree refocusing pulse in one TR period. The 90-degree excitation pulse creates magnetization in the transverse plane. This is followed by the 180-degree pulse which rephrases the magnetization to produce spin echo signals.

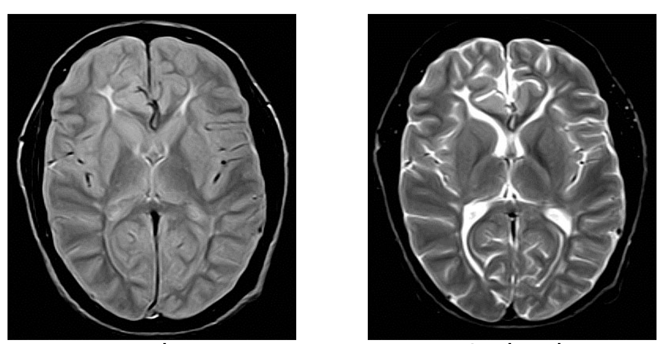


Variable echo is a two echo acquisition where the second echo has to be a multiple of the first echo. A diagram of how SE is played out for both a single echo and a variable echo sequence is displayed as follows:





With variable echo either one, two or four echoes can be acquired in a single acquisition. Each echo is used to create a different image, usually displaying different image contrast.



1st Echo 2nd Echo

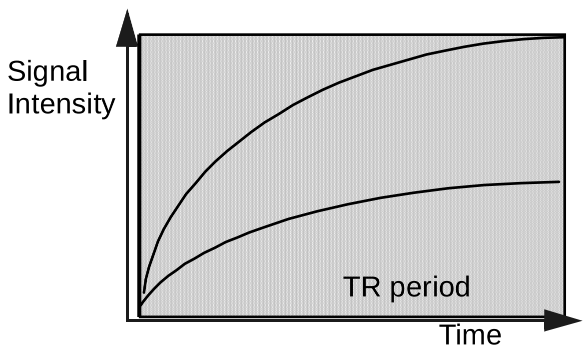
Images were acquired using a Spin Echo dual echo sequence. 1st Echo displays PD-weighting. 2nd Echo displays T2-weighting.

Spin Echo Image Characteristics

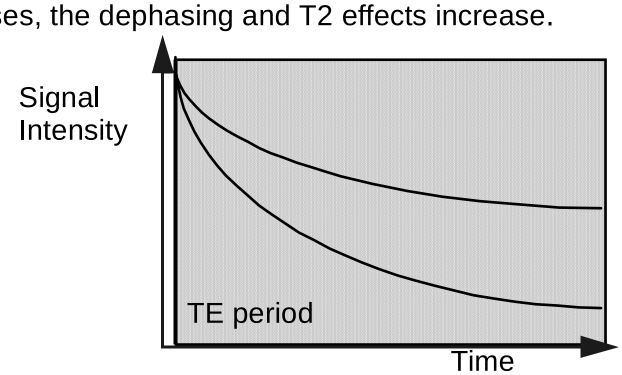
Spin Echo images are generally less sensitive to magnetic field inhomogeneties and paramagnetics than most other pulse sequences. This is due to the RF rephasing of protons.

Less geometric blurring is seen on spin echo images than Fast Spin Echo (FSE) images, therefore producing sharper image edges. The one drawback of SE sequences is that when comparing SE images with FSE images longer scan times for sequences with the same TR values are seen.

To control SE image characteristics, imaging parameters TE and TR play important roles. TR regulates the level of saturation or T1 contribution. The repetition rate of the excitation pulse and the T1 relaxation time of the tissue affect the amount of recovery that occurs between each excitation pulse. As a rule, when TR decreases, saturation and T1 effects increase. Therefore when TR increases, saturation and T1 effects decrease.



TE regulates the level of dephasing or T2 contribution. The timing of the rephasing pulse and the T2 relaxation time of the tissue affect the amount of dephasing that occurs before the echo signal is read. The rule for TE is, as the TE decreases, dephasing and T2 effects decrease. Therefore as the TE increases, the dephasing and T2 effects increase.

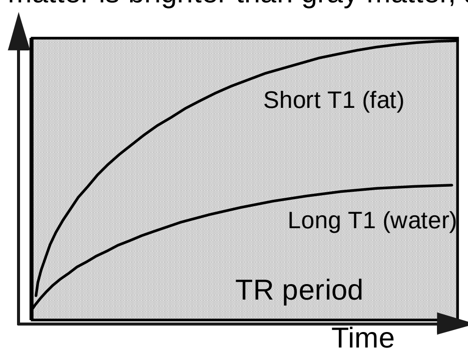


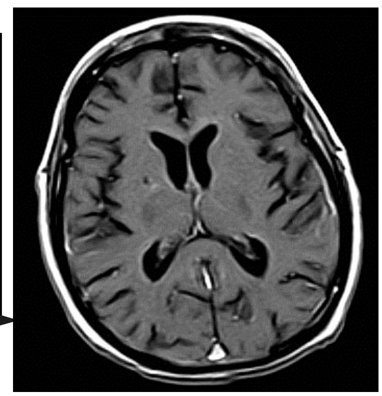
Spin Echo contrast is determined by the varying combinations of TR and TE times.

Timing	PD Weighting	T2 Weighting	T1* Weighting
TR	Long, >2000 ms	Long, >2000 ms	Short, <600 ms
TE	Short, <30 ms	Long, >90 ms	Short, <25 ms

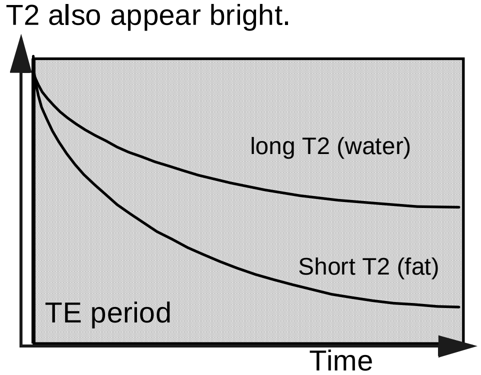
As field strength decreases, TR & TE decrease.

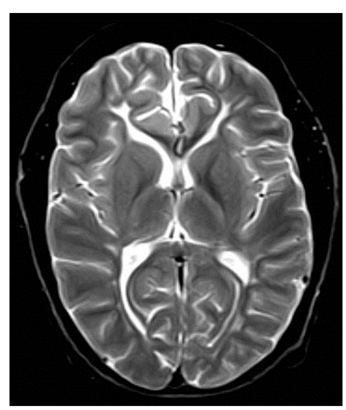
T1 is the time constant for longitudinal relaxation and thermal or spin lattice relaxation. Scan protocols that allow the T1 effects to predominate over the other relaxation effects produce T1 weighted images In T1 weighted images, tissues with short T1 are bright and tissues with long T1 are dark. In the brain, white matter is brighter than gray matter, and CSF is dark.



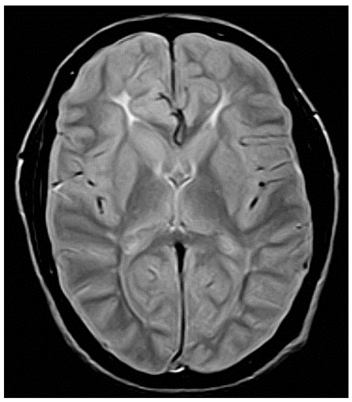


T2 is the time constant that measures the transverse magnetization decay and spin-spin effects. Scan protocols that allow the T2 effects to predominate over the other contrast effects produce T2 weighted images. In T2 weighted images, tissues with short T2 are dark and tissues with long T2 are bright. In the brain, CSF produces the brightest signal on moderate to late TE images; pathology that alters and delays T2 also appear bright.





Proton Density weighted images have contrast that is primarily due to the density of protons in the structures. PD weighted images result when you select scan timing parameters that minimize the T1 (long TR) and the T2 (short TE) contrast effects. With PD weighted images, tissues with a greater number of protons are bright and tissues with fewer protons are dark. In the brain, gray matter is brighter than white matter, due to the amount of protons it contains.



Something to Think About...

- The effects of changing TR and TE on PD/T2 images:

	CNR	SNR	Scan Time	# of Slices
As TR increase	Increases	Increases	Increases	Increases
As TE increase	Increases	Decreases	----	Decreases

Table 1-1 TR and TE changes on PD/T2 images

- The effects of changing TR and TE on T1 images:

	CNR	SNR	Scan Time	# of Slices
As TR increase	Decreases	Increases	Increases	Increases
As TE increase	Decreases	Decreases	----	Decreases

Table 1-2 TR and TE changes onT1 images

- Tissues with long T2 times, such as CSF, are darker on SE proton density weighted images than on FSE proton density weighted images. This is due to SE typically using a TR of 2000 ms, which produces saturation in CSF.
- Standard vs. Classic 2D Spin Echo can be substituted for T2 studies. It offers greater signal-to-noise and is less sensitive to center frequency adjustment when

compared to classic. Its echoes are more uniform, and demonstrates images with more shades of grey than classic.

- Classic 2D Spin Echo SNR is lower. Classic is recommended when you're looking for a larger variance between muscle and fat signal. Its effects can be emphasized via center frequency adjustment. Classic images are annotated with a "CL".
- For T1 weighting - selecting short TR and short TE so that T1 saturation effects dominate contrast; TR should be at or below 600 ms for 1.5T, 500 ms for 1.0T or 300 ms for 0.2T. TE should fall below 25 ms.
- For T2 weighting - selecting a long TR and long TE so that T2 dephasing effects dominate contrast; TR should be at or above 2000 ms and at or above 40 ms for the TE.
- For PD weighting - selecting a long TR and short TE so that proton density dominates contrast; TR should be at or above 2000 ms and at or below 45 ms for TE.
- T1 weighted images cannot be produced in conjunction with PD weighted or T2 weighted images, because the TR requirements are not compatible.
- PD and T2 weighted images can be produced in the same acquisition using 2 echoes because the TR requirements are compatible.
- Changes made to Spin Echo timing factors are likely to result in a decrease in the maximum number of slice locations allowed per TR (as compared to pre-8.3 software). As a result, you may see SE protocols which are forced to a double acquisition when the number of slices exceeds the allowed maximum per TR. Increase the TR, or decrease the number of slice locations, to avoid a double acquisition. In most instances, decreasing the number of slices by one location will suffice.

Associated Imaging Options

In the following table the X's indicate the option available for use with the Spin Echo pulse sequence.

Imaging Options			
X	None	X	Variable Bandwidth

Imaging Options			
X	Flow Compensation	**X**	No Phase Wrap
X	POMP	**X**	Extended Dynamic Range
X	Square Pixel	**X**	Surface Coil Intensity Correction
	Respiratory Compensation	**X**	Classic
X	Magnetization Transfer		Sequential
	Cardiac Gating/Triggering		Respiratory Gating/Triggering
	Tailored RF		IR Prepared
	DE Prepared		Multi-Phase
	Full Echo Train		CCOMP
	ZIP 1024		ZIP 512
	Zip x 2		ZIP x 4
	SmartPrep		Blood Suppression
	Multi Station		Real Time

Applications

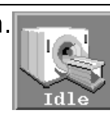
Spin Echo sequences are used to acquire images throughout the body. It is used for T1, T2 and PD contrast weighting. When too much geometric and/or edge blurring is produced in FSE images, the Spin Echo sequence is often used. Use SE instead of GRE to decrease magnetic susceptibility effects, for example, when using in the vicinity of air-tissue or tissue-bone interfaces.

Setting up a Spin Echo pulse sequence

The decision matrix is only for prescribing a Spin Echo scan. The purpose of the decision matrix to help you understand the trade-offs that occur when you change the values for a particular parameter and to provide a framework with which you may build you own unique protocol.

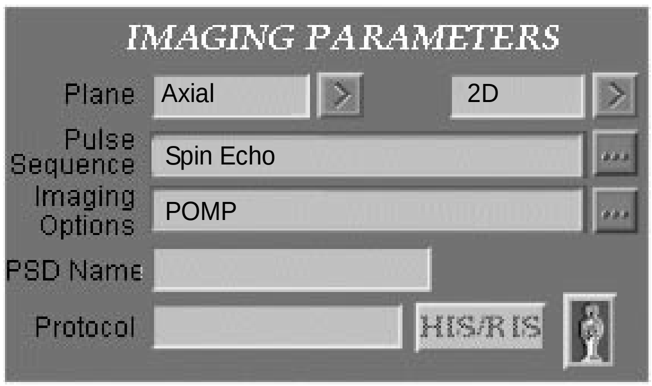
The selected values are only an example of what could be used for T1-weighted Spin Echo acquisition and are not to be considered recommendations by GE Medical Systems. For specific protocols, refer to the protocols on your system.

.

Spin Echo - What you select	Selection Notes
SCAN DESKTOP screen	
	Select **Scan Desktop** icon.  Click on **[New Patient]** and fill in the patient information. 
PATIENT POSITION area	
Patient Position **[Supine]** Patient Entry **[Head First]**	**Position and Entry:** An SE pulse sequence is compatible with any patient position and entry.

Spin Echo - What you select		Selection Notes
Coil	**[Head]**	**Coil:** Select the coil that produces the optimum coverage and SNR.
Series Description		**Series Description:** Enter a suitable series description. If you don not enter a description, the system enters one for you. The series description default is the selected scan mode, PSD, and imaging options.

IMAGING PARAMETERS area



Plane	**[Axial]**	**Plane:** SE is compatible with any scan plane; select the plane that best meets the clinical need.
Mode	**[2D]**	**Mode:** Select [2D].
Pulse Seq	**[Spin Echo]**	**Pulse Seq:** Select [Spin Echo]. Click on the [Accept] button in the window to register the selection.
Imaging Options	**[POMP]**	**Imaging Options:** Select imaging options that optimizes SNR, spatial resolution, # of slices and reduce motion artifacts. Click on the [Accept] button to register the selections.
PSD Name	**N/A**	**PSD Name:** Not applicable for Spin Echo.
Protocol	**N/A**	

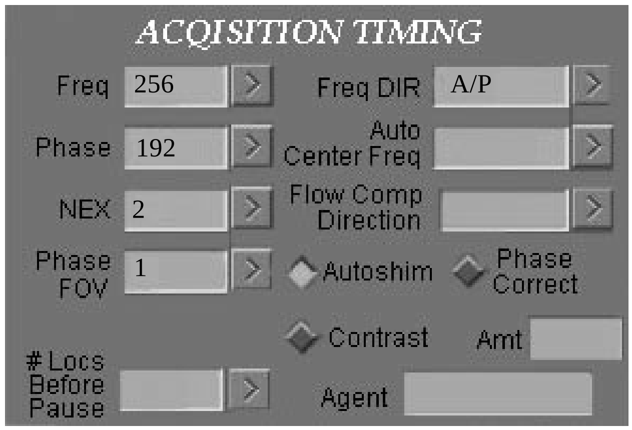
SCAN TIMING area

# of echoes	**[1]**	**# of echoes:** Select 1 echo for a T1-weighted acquisition. Select 2 echoes for a PD/T2-weighted acquisition.
TE	**[Min Full]**	**TE:** Short TEs produce: increased T1 and PD contrast, increased SNR, and with multi-planar acquisitions, increased # of slices. Minimum TE changes as RBw changes. Minimum is a fractional echo and may compromise SNR.

Spin Echo - What you select		Selection Notes
TR	**[400]**	**TR:** Short TRs produce: decreased SNR, decreased # of slices in multi-planar acquisitions, increased T1 contrast, decreased scan time. In a SE T1-weighted acquisition, don't exceed the following TR: 1.5T 700 ms, 1.0T 600 ms. Long TRs produce: increased SNR, increased # of slices, increased PD/T2 contrast, increased scan time. TR is not selectable with gated scans. The TR is determined by the RR intervals on the Gating Additional Parameters screen. **NOTE:** Changes made to SE timing factors are likely to result in a decrease in the max. number of slice locations allowed per TR. As a result, acquisitions may double, if the number of slices exceed the max. TR. To avoid double acquisition decrease the number of slices by one.
TI	**N/A**	
Flip Angle	**N/A**	
Echo Train Length	**N/A**	
Bandwidth	**[16]**	**Bandwidth:** RBw can only be changed if it was selected from the Imaging Options window. As the RBw decreases, the following occurs: increased SNR, increased chemical shift artifact, increased minimum TE which can potentially decreases # of slices and increased motion artifact.
Bandwidth 2	**N/A**	**Bandwidth2:** RBw2 is only selectable with a 2 echo Spin Echo acquisition. The value for RBw2 is for the second echo and typically lower than RBw1.
SCANNING RANGE area		
FOV	**[22]**	**FOV:** Select a FOV that covers the anatomy of interest. Anatomy outside the FOV in the phase direction results in aliasing. Small FOVs produce: increased resolution, decreased SNR, and can increase the minimum TE value.
Slice Thickness	**[5]**	**Slice Thickness:** Thin slices produce: increased resolution and decreased SNR.
Spacing	**[2.5]**	**Spacing:** Select a spacing that reduces cross-talk between slices (typically 20% of the slice thickness) If your scan is a dual acquisition with no concantenated SAT pulse, 0 spacing is allowed.
Start, End Locations		**Start, End Locations:** Typically the start and end locations are programmed from the Graphic Rx program.

Spin Echo - What you select		Selection Notes
# Slices	**[16]**	**# Slices:** The maximum number of slices available is determined by the TR, TE, SAR, and gradient stress.

ACQUISITION TIMING area



Freq	**[256]**	**Freq:** Increasing the frequency matrix produces: increased resolution, decreased SNR, and decreased # of slices.
Phase	**[192]**	**Phase:** Phase controls scan time and may control resolution.
NEX	**[2]**	**NEX:** Select a NEX value that produces sufficient SNR.
Phase FOV	**[1]**	**Phase FOV:** Select .75 or .5 to reduce phase steps and thus decrease scan time, decreasing FOV in the phase direction, and decreasing SNR slightly. The phase FOV dimension is displayed next to the phase FOV factor.
Freq DIR	**[A/P]**	**Freq DIR:** The direction displayed is the default frequency direction which is typically the long axis of the image. To swap phase and frequency, select the other direction.
Auto Center Freq	**[Water]**	**Auto Center Freq:** Select the CF peak that is set during prescan.
Flow Comp DIR	**N/A**	
Autoshim	**[Off]**	**Autoshim:** Select Autoshim when using fat SAT or an FOV off center, and on the first series of each exam.
Phase Correct	**N/A**	
# of Acqs/Locs Before Pause	**N/A**	

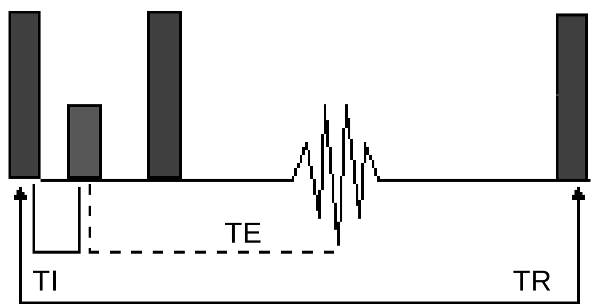
Additional Parameters
SAT Screen

I	**[80]**	SAT pulses may decrease the # of slices/acquisition.
S	**[80]**	

Spin Echo - What you select	Selection Notes
Additional Parameters	To prescribe oblique slices you must select **[Oblique]** in the Plane pull-down menu.
GRAPHIC RX Screen	
Click on the image to display the line cursor for Graphic Rx.	The SAT band function can be accessed from the GRAPHIC Rx window and vice versa. If you had graphically prescribed the previous axial series the same prescription can be copied using the **[Copy RX]** button. Consider using an offset to center the anatomy in the middle of the screen so that you can use a PFOV less than 1 and therefore reduce the scan time. View the Advisory panel to note the Max # of slices/Acq and the # of Acqs you are prescribing. The scan time increases as the # of Acquisitions increase.
SCAN OPERATIONS area	
[Save Series] **[Prep to Scan]** **[Auto Prescan]** **[Scan]**	Enter data in all the text boxes and click on **[Save Series]**. The series is saved as RXD.

Inversion Recovery (IR)

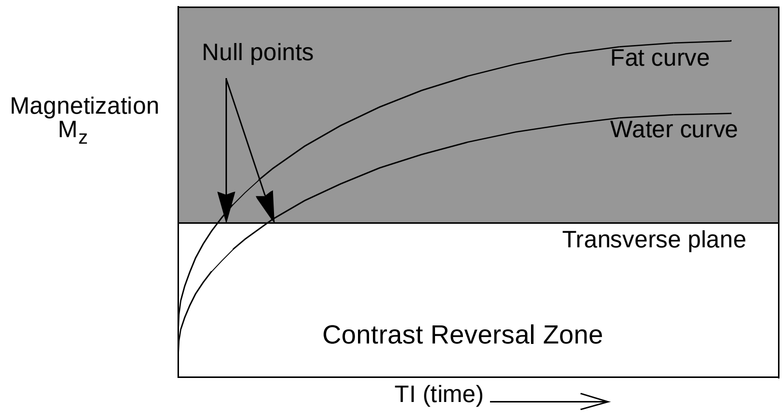
Inversion Recovery is a Spin Echo pulse sequence with an initial 180-degree inversion pulse prior to the 90-degree pulse. This sequence is used to produce T1-weighted or fat-suppressed images. The initial 180-degree pulse is used to create magnetization in the negative Z axis. There is a brief period between the 180-degree and the 90-degree pulse, this period is called TI, or inversion time. The time between the 90-degree excitation and the middle of the readout is called TE; similar to a Spin Echo sequence. A diagram of the sequence is as follows:



With Inversion Recovery images, the relative intensities are determined by timing parameters of TI, TR, and TE, where TI is the primary contrast controller. Recommended TI times are listed below to better demonstrate various structures in the brain. These times vary based on field strength.

Contrast	***TI***	***Structures in Brain***
Fat Suppressed	1.0T = 140 to 150 ms 1.5T = 160 to 170 ms	CSF is bright. Gray matter is brighter than white matter. Fat is dark. Muscle is dark.
T1-weighted	1.0T = 700 ms 1.5T = 800 ms	CSF is dark. Grey matter is grey. White matter is brighter than gray matter. Fat is bright. Muscle is intermediate.

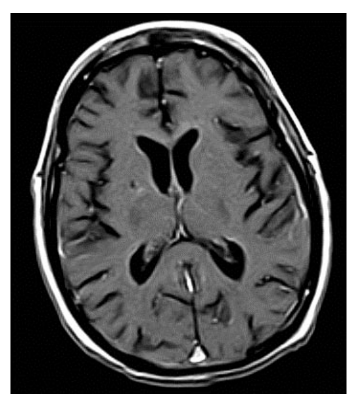
The T1 recovery curve and timing of the inversion pulse determine the results of T1-weighted or fat suppressed contrast. The time required for a tissue to recover from the negative longitudinal axis to the transverse plane is the null point.



The null point is defined as the point in time when the magnetization vector is flipped into the transverse plane and no signal is being received. This is why images can be produced demonstrating no signal from fat or water.

Inversion Recovery Image Characteristics

Inversion Recovery produces T1-weighted images with better contrast and more SNR than SE T1-weighted images, but the the drawback is that the scan time is longer.



The image on the left is an inversion recovery image. The image on the right is a spin echo image. Notice the brighter signal of the brain white matter in the inversion recovery image.

Inversion Recovery fat suppressed, or STIR (Short TI-Inversion Recovery), images have more uniform fat suppression than chemical saturation because IR is less sensitive to magnetic field inhomogeneties and off-center FOV effects.

Something to Think About...

- Short-TI IR images have low SNR due to reduced transverse magnetization. Plan for this loss in SNR by varying other scan parameters that increase SNR (e.g., lower resolution, increase NEX, or narrow the receive bandwidth).
- As the slice spacing gets smaller, expect to see greater change in signal intensity from one slice to the next. The signal variation is due to cross-talk effects and can be minimized by using a spacing between 20-50% of the slice thickness.
- Consider using the FSE-IR pulse sequence to decrease scan time.
- The system offers choices in how it collects images for Multi-planar IR: sequentially or non-sequential interleaved.
- The effectiveness of the IR fat suppression technique varies based on changes in magnetic field homogeneity.
- IR may produce contrast reversal depending on TI selection where tissues with long T1 times may be brighter than or isointense with tissues with short T1 times.
- SAT pulses can result in reduced number of slices due to the time it takes to apply the SAT pulses.
- Do not use IR techniques with gadolinium because enhancing pathology could be suppressed if the shorted T1 corresponds to the null point.

Associated Imaging Options

In the following table the X's indicate the option available for use with the Inversion Recovery pulse sequence.

Imaging Options			
X	None	**X**	Variable Bandwidth
X	Flow Compensation	**X**	No Phase Wrap
X	POMP	**X**	Extended Dynamic Range
X	Square Pixel	**X**	Surface Coil Intensity Correction
X	Respiratory Compensation	**X**	Classic
X	Magnetization Transfer	**X**	Sequential
	Cardiac Gating/Triggering		Respiratory Gating/Triggering
	Tailored RF	**X**	IR Prepared
	DE Prepared		Multi-Phase
	Full Echo Train		CCOMP
	ZIP 1024		ZIP 512
	Zip x 2		ZIP x 4
	SmartPrep		Blood Suppression
	Multi Station		Real Time

Applications

Some suggested fat suppression applications are Orbits for better optic nerve imaging, abdominal imaging to reduce respiratory artifacts by suppressing abdominal fat, and extremities when the anatomy of interest is off center from isocenter.

Use Flow Comp with T1 or pathology -weighted IR images to minimize flow motion.

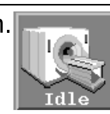
To achieve T1-weighted images use a long TR (2000 ms or greater), short TE (approx. 25 ms), and moderate TI (400 to 700 ms). For fat suppressed images use a long TR (2000 ms or greater), short TE (approx. 25 ms), and short TI (140 to 170 ms). Pathology-weighted images use a long TR, moderate TE (40 to 60 ms), and short TI (140 to 170 ms).

CAUTION: **Provide all patients with ear protection prior to any scan to help avoid possible hearing impairment.** Acoustic noise levels can exceed 99dBA in the magnet bore.

Setting up an Inversion Recovery pulse sequence

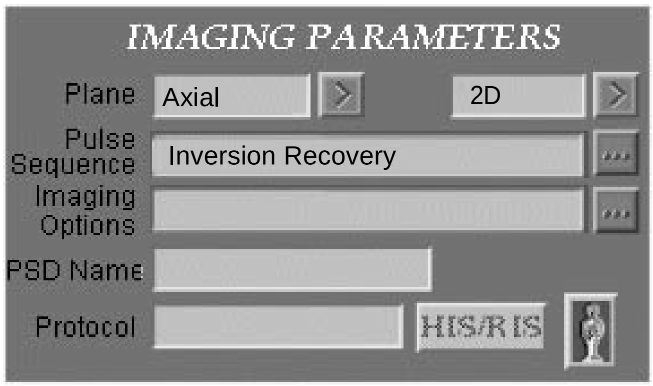
The decision matrix is only for prescribing a Inversion Recovery scan. The purpose of the decision matrix to help you understand the trade-offs that occur when you change the values for a particular parameter and to provide a framework with which you may build you own unique protocol.

The selected values in the left hand column are only an example of what could be used for a short TI, IR (fat suppressed) scan and are not to be considered recommendations by GE Medical Systems. For specific protocols, refer to the protocols on your system.

Inversion Recovery - What you select		Selection Notes
	SCAN DESKTOP screen	
		Select **Scan Desktop** icon.  Click on **[New Patient]** and fill in the patient information. 
	PATIENT POSITION area	
Patient Position	**[Supine]**	**Position and Entry:** An IR pulse sequence is compatible with any patient position and entry.
Patient Entry	**[Head First]**	

Inversion Recovery - What you select		Selection Notes
Coil	**[Head]**	**Coil:** Select the coil that produces the optimum coverage and SNR.
Series Description		**Series Description:** Enter a suitable series description. If you do not enter a description, the system enters one for you. The series description default is the selected scan mode, PSD, and imaging options.

IMAGING PARAMETERS area



Plane	**[Axial]**	**Plane:** IR is compatible with any scan plane; select the plane that best meets the clinical need.
Mode	**[2D]**	**Mode:** Select [2D].
Pulse Seq	**[Inversion Recovery]**	**Pulse Seq:** Select [Inversion Recovery]. Click on the [Accept] button in the window to register the selection.
Imaging Options		**Imaging Options:** Select imaging options that optimizes SNR, spatial resolution, # of slices and reduce motion artifacts. Click on the [Accept] button to register the selections.
PSD Name	**N/A**	**PSD Name:** Not applicable for Inversion Recovery.
Protocol	**N/A**	

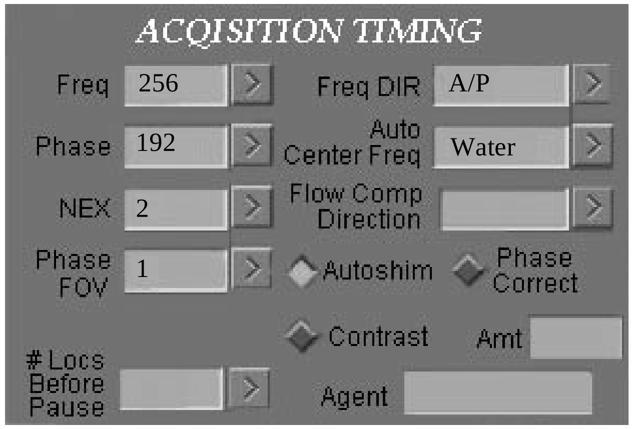
SCAN TIMING area

# of echoes	**[1]**	**# of echoes:** Select 1 echo for a T1-weighted acquisition. Select 2 echoes for a PD/T2-weighted acquisition.
TE	**[40]**	**TE:** Short TEs produce: increased T1, increased SNR, and with multi-planar acquisitions, increased # of slices. Minimum TE changes as RBw changes. Minimum is a fractional echo and may compromise SNR.A slightly longer TE (~ 40ms) allows for more fat to decay and thus reduces the signal from fat.
TE2	**N/A**	Not selectable.

Inversion Recovery - What you select		Selection Notes
TR	**[2000]**	**TR:** Long TRs produce: increased SNR, increased # of slices, increased scan time. The TR is determined by the RR intervals on the Gating Additional Parameters screen. Long TRs produce: increased SNR, increased # of slices, increased scan time. TR is not selectable with gated scans. The TR is determined by the RR intervals on the Gating Additional Parameters screen.
TI	**[110]**	**TI:** TI affects the fat suppression contrast. Typical values: • 1.0T is 140 ms • 1.5T is 170 ms TI affects # of slices and T1 contrast. Typical values: • 1.0T is 600-800 ms • 1.5T is 700-900 ms
Flip Angle	**N/A**	
Echo Train Length	**N/A**	
Bandwidth	**[16]**	**Bandwidth:** RBw can only be changed if it was selected from the Imaging Options window. As the RBw decreases, the following occurs: increased SNR, increased chemical shift artifact, increased minimum TE which can potentially decreases # of slices and increased motion artifact.
Bandwidth 2	**N/A**	
SCANNING RANGE area		
FOV	**[25]**	**FOV:** Select a FOV that covers the anatomy of interest. Anatomy outside the FOV in the phase direction results in aliasing. Small FOVs produce: increased resolution, decreased SNR, and can increase the minimum TE value.
Slice Thickness	**[5]**	**Slice Thickness:** Thin slices produce: increased resolution and decreased SNR.
Spacing	**[2.0]**	**Spacing:** Select a spacing that reduces cross-talk between slices (typically 20% of the slice thickness) If your scan is a dual acquisition with no concantenated SAT pulse, 0 spacing is allowed.
Start, End Locations		**Start, End Locations:** Typically the start and end locations are programmed from the Graphic Rx program.
# Slices	**[16]**	**# Slices:** The maximum number of slices available is determined by the TR, TE, SAR, and gradient stress.

Inversion Recovery - What you select		Selection Notes

ACQUISITION TIMING area



Freq	**[256]**	**Freq:** Increasing the frequency matrix produces: increased resolution, decreased SNR, and decreased # of slices.
Phase	**[192]**	**Phase:** Phase controls scan time and may control resolution.
NEX	**[2]**	**NEX:** Select a NEX value that produces sufficient SNR.
Phase FOV	**[1]**	**Phase FOV:** Select .75 or .5 to reduce phase steps and thus decrease scan time, decreasing FOV in the phase direction, and decreasing SNR slightly. The phase FOV dimension is displayed next to the phase FOV factor.
Freq DIR	**[A/P]**	**Freq DIR:** The direction displayed is the default frequency direction which is typically the long axis of the image. To swap phase and frequency, select the other direction.
Auto Center Freq	**[Water]**	**Auto Center Freq:** Select the CF peak that is set during prescan.
Flow Comp DIR	**N/A**	
Autoshim	**[Off]**	**Autoshim:** Select Autoshim when using fat SAT or an FOV off center, and on the first series of each exam.
Phase Correct	**N/A**	
# of Acqs/Locs Before Pause	**N/A**	

Additional Parameters
SAT Screen

I	**[80]**	SAT pulses may decrease the # of slices/acquisition.
S	**[80]**	

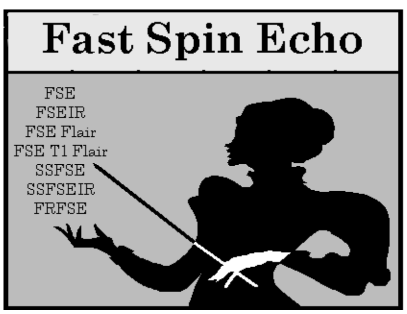
Inversion Recovery - What you select	Selection Notes
Additional Parameters	To prescribe oblique slices you must select **[Oblique]** in the Plane pull-down menu.
GRAPHIC RX Screen	
Click on the image to display the line cursor for Graphic Rx.	To prescribe oblique slices you must select **[Oblique]** in the Plane pull-down menu. The SAT band function can be accessed from the GRAPHIC Rx window and vice versa. If you had graphically prescribed the previous axial series the same prescription can be copied using the **[Copy RX]** button. Consider using an offset to center the anatomy in the middle of the screen so that you can use a PFOV less than 1 and therefore reduce the scan time. View the Advisory panel to note the Max # of slices/Acq and the # of Acqs you are prescribing. The scan time increases as the # of Acquisitions increase.
SCAN OPERATIONS area	
[Save Series] **[Prep to Scan]** **[Auto Prescan]** **[Scan]**	Enter data in all the text boxes and click on **[Save Series]**. The series is saved as RXD.

Volume 2

Chapter 3

Imaging with Fast Spin Echo Pulse Sequences

Where Am I?



Introduction

This chapter explains the pulsing components and timing factors directly related to the Fast Spine Echo (FSE) pulse sequences. There are several pulse sequences that stem from FSE. This chapter explains the concepts of each, and the step-by-step instructions to help you learn how to:

- Optimize all FSE images
- Set up a FSE T1 Flair pulse sequence using Picture This
- Set up a FRFSE pulse sequence using Picture This

In addition, this chapter answers the following questions:

1. What are the pulsing components and timing factors for FSE, FSEIR, FSE Flair, FSE T1 Flair, SSFSE, SSFSEIR and FRFSE?
2. What is the correct TR and the regulation of saturation effects?
3. What is the correct TE and the regulation of dephasing effects?
4. What is the null point as it applies to FSEIR, FSE Flair, FSE T1 Flair and SSFSEIR pulse sequences?
5. What is the TI and the regulation of saturation and/or signal suppression as it applies to FSEIR, FSE Flair, FSE T1 Flair and SSFSEIR pulse sequences?
6. What is a 3D FSE acquisition?
7. What are the imaging characteristics of each FSE pulse sequence?
8. Which imaging options can be used with each FSE pulse sequence?
9. What are some applications for FSE pulse sequences?

About... Fast Spin Echo Pulse Sequences

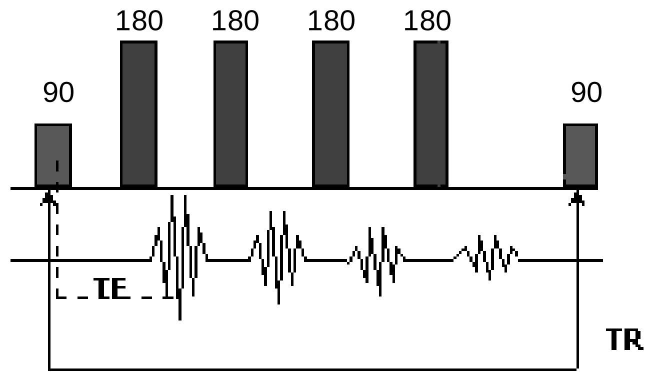
This section presents the concepts necessary to understand all FSE pulse sequences. Specifically you need to understand:

- Fast Spin Echo
  - FSE image characteristics
  - Associated imaging options
  - Applications for FSE
- Fast Recovery Fast Spin Echo (FRFSE)
  - FRFSE image characteristics
  - Associated imaging options
  - Application for FRFSE
- FSE Inversion Recovery (FSEIR)
  - Null point
  - TI time
  - FSEIR image characteristics
  - Associated imaging options
  - Applications for FSEIR
- FSE Flair and T1 Flair
  - Null point
  - TI time
  - FSE Flair and T1 Flair image characteristics
  - Associated imaging options
  - Applications for FSE Flair and T1 Flair
- Single Shot Fast Spin Echo (SSFSE) and Single Shot Fast Spin Echo Inversion Recovery (SSFSEIR)
  - SSFSE and SSFSEIR image characteristics
  - Null point
  - TI time
  - Associated imaging options
  - Applications for SSFSE and SSFSEIR

Fast Spin Echo (FSE)

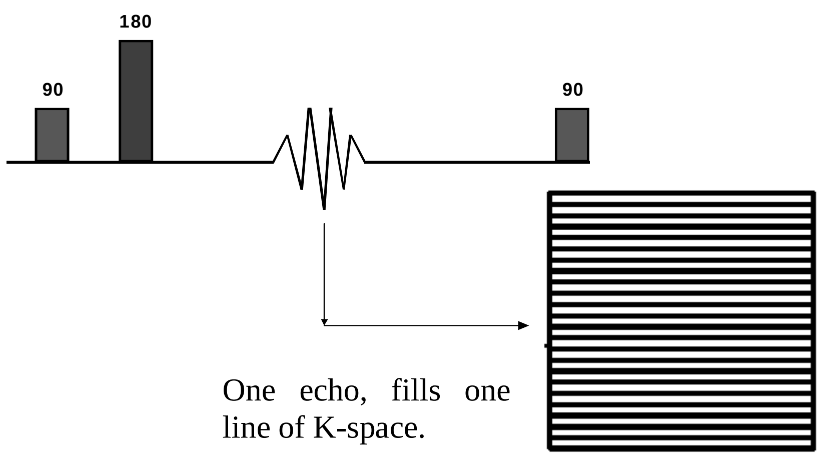
Fast Spin Echo is a 2D or 3D pulse sequence which consists of an initial 90-degree excitation pulse followed by multiple 180-degree refocusing pulses in one TR period. In order to completely understand Fast Spin Echo (FSE), a brief review of Spin Echo is helpful.

A diagram of how FSE is played out is as follows:



FSE Diagram

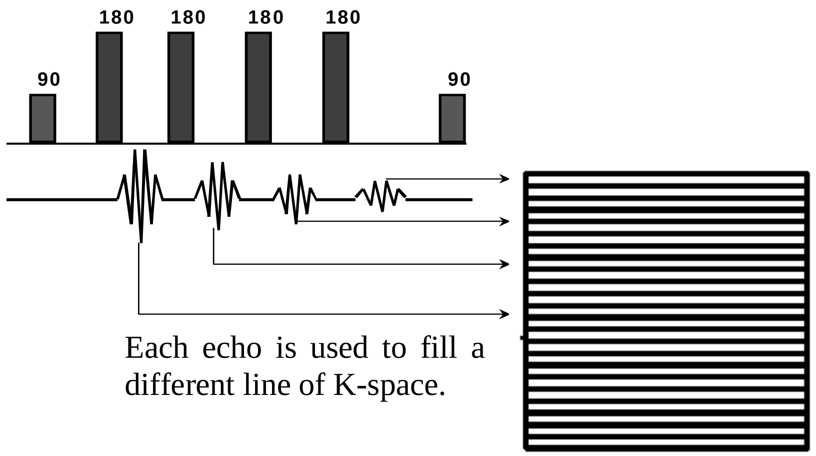
During a Spin Echo pulse sequence, we note that in a single TR period the 180-degree refocusing pulse produced one echo. Thus filling only one line of K-space during one TR period.



Spin Echo diagram filling K-space

When using a Fast Spin Echo pulse sequence, we note that in a single TR period multiple 180-degree refocusing pulses can be used. Thus filling multiple lines of K-space in one TR period. Your Signa® system allows 2 to 128 refocusing pulses to be prescribed. Prescribing these pulse are done by manipulating the Echo Train Length (ETL).

Let’s look at an example to further explain this concept. In the diagram below you can see that four 180-degree pulses follow the initial 90-degree pulse. Using this example you would fill four lines of K-space in one TR period.

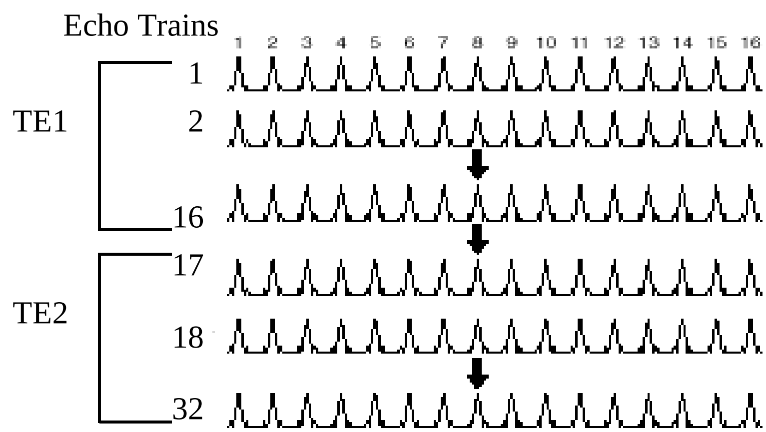


FSE Diagram filling K-space

- FSE also makes it practical to conduct high resolution exams with a variety of frequency and phase combinations. By filling multiple lines of K-space you can drastically reduce you overall acquisition time, as compared to SE acquisition time.

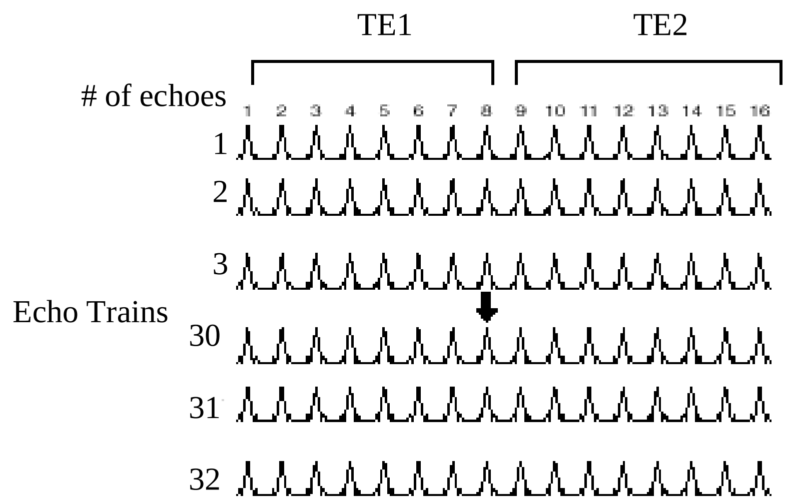
One or two effective TEs may be acquired and scan time is directly related to the number of echoes acquired. A single echo acquisition is twice as fast as a dual echo acquisition. A dual echo acquisition may be acquired with either a full echo train or a split echo train.

The full echo train method completes all echo trains for Effective TE1 before Effective TE2 is initiated. The phase encoding process is altered to place the central phase encodings at the selected Effective TE1 or TE2. If a 16 ETL was used, all 16 echoes would contribute to the effective TE1 or TE2. The full echo train method allows flexible selection of both Effective TE1 and TE2 and any multiple of the minimum echo space can be used for either TE. The resulting image contrast is similar to that a a single echo acquisition for a long TR/short TE and long TR/long TE. The term "effective" is used because the phase encoding producing the echoes with the largest signal occur at this echo time.



FSE dual echo acquisition with a Full Echo Train

The split echo train method used the same number of echoes in the same total acquisition time as an equal full echo train, however, each echo train is halved. The echoes in the first half of the echo train contribute to K-space for the Effective TE1 and the echoes in the second half contribute to the Effective TE2. A phase encoding scheme is employed so that the central phase encodes occur at the selected echo time (Effective TE1) for the first half and then are re-centered for the selected echo time (Effective TE2) for the second half of the echo train. If a 16 ETL was used, only 8 echoes contribute to the effective T1 or T2.



FSE2: split echo train

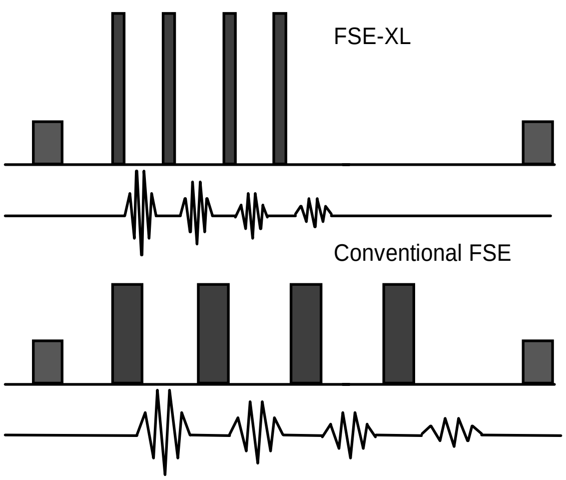
Generally, the contrast with a split echo train sequence is closer to the contrast in a conventional variable echo pulse sequence rather than a full echo train. The split echo train sequence combines data from fewer echoes to form the image.

Fast Spin Echo can also be used to obtain a 3D volume acquisition. A 3D volume acquisition excites the entire imaging volume, not just a single slice. A slice encoding gradient is applied separating the volume into slices, thus allowing thin contiguous slices.

NOTE: For more information on 3D volumetric imaging, see Volume 1, Chapter 3.

An adaptation of the FSE pulse sequence is FSE-XL. It is an enhanced 2D Fast Spin Echo and Fast Spin Echo Inversion Recovery (FSE-IR) pulse sequence designed to reduce exam times and improve FSE image quality. This is accomplished by:

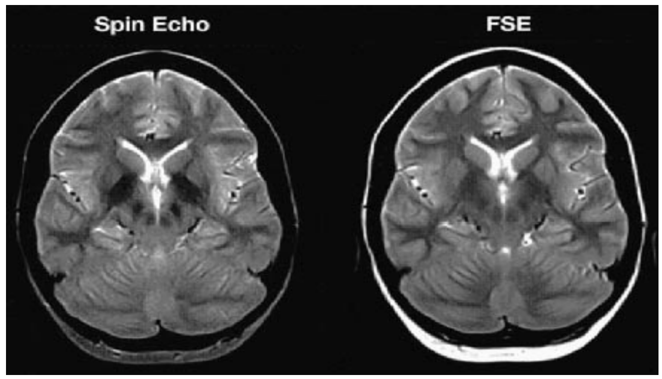
- RF modification techniques which decrease the echo space, resulting in reduced edge blurring and improved tissue contrast,
- the ability to prescribe, and acquire in one series, multiple groups in sequential acquisitions, at different angles,
- the availability of ZIP 512 reconstruction.



Fast Spin Echo Image Characteristics

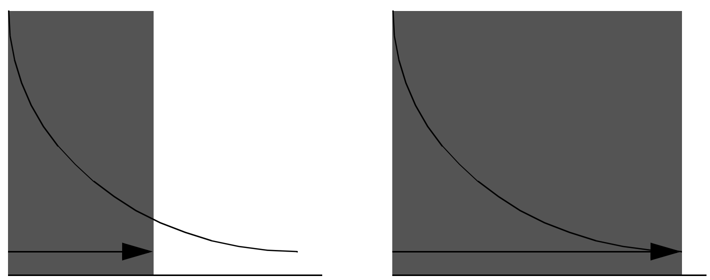
Fast Spin Echo images are less sensitive to magnetic field inhomogeneities and paramagnetics than SE images, because of the multiple 180º pulse so areas of the brain that contain iron are darker on SE than FSE.

Fat is brighter on FSE images because of an effect called J-coupling. Also CSF and other long T2 tissues are brighter on T2 and PD FSE images than on SE images.



Spin Echo (left) and FSE (right) images displaying CSF and Fat differences.

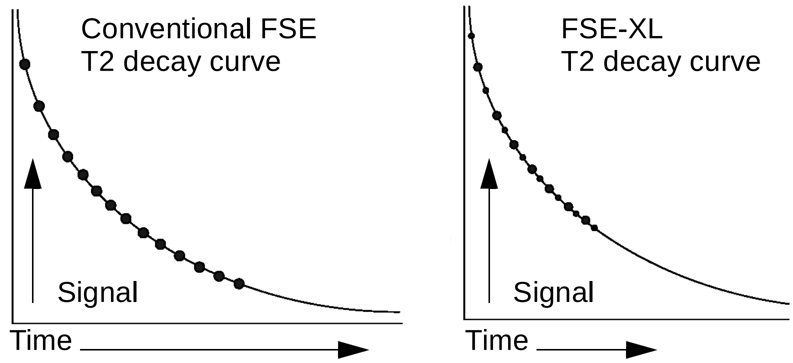
The drawback to using an FSE sequence instead of an SE sequence is FSE images are affected by edge blurring related to the echo spacing and echo train.



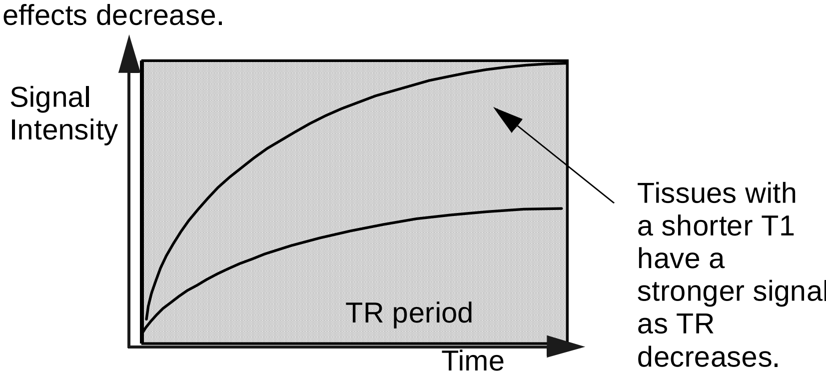
Short ETL captures less of the T2 decay curve and motion. Short ETL (left). Long ETL (right).

T2 decay and geometric/edge blurring affect FSE images as a result of the ETL.

One option to help reduce edge blurring would be to keep ETLs short. Another would be to use FSE-XL, to help minimize echo spacing. Echo spacing (ESP) is how far apart the echoes are spread out along the T2 decay curve. As the ESP increases, the echoes spread further across the decay curve, resulting in a greater variation of signal intensities that contribute to the image. FSE-XL improves tissue contrast from the decreased variation in signal collected across the T2 decay curve as ESP is reduced. This allows for use of longer ETLs for PD and T2 imaging and improves T1 contrast for short TR/TE acquisitions.

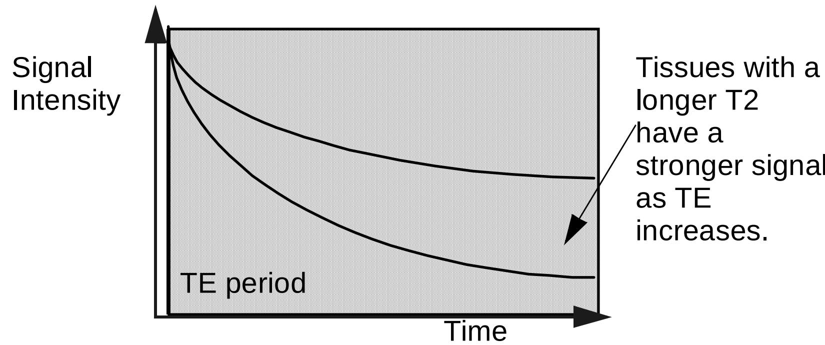


To control FSE image characteristics, imaging parameters TE, TR and ETL play important roles. TR regulates the level of saturation or T1 contribution. The repetition rate of the excitation pulse and the T1 relaxation time of the tissue affect the amount of recovery that occurs between each excitation pulse. As a rule, when TR decreases, saturation and T1 effects increase. Therefore when TR increases, saturation and T1 effects decrease.



Effective TE and ETL regulate the level of dephasing or T2 contribution. The timing of the rephasing pulse and the T2 relaxation time of the tissue affect the amount of dephasing that occurs before the echo signal is read. The rule for TE is, as the effective TE increases dephasing and T2 effects increase.

Therefore as the ETL increases dephasing and T2 effects increase.



Fast Spin Echo contrast is determined by the varying combinations of TE, TR and ETL times.

Timing	PD Weighting	T2 Weighting	T1 Weighting
TR	Long, >2000 ms	Long, >2000 ms	Short, <500 ms
TE	Short, <30 ms	Long, >90 ms	Short, <20 ms
ETL	Short, <8 ETL	Up to Maximum system allowed.	Short, <4 ETL
***As field strength decreases, TR & TE decrease.** ***As field strength increases T1 time increase.**			

Something to Think About...

- Fast Spin Echo with ETL > 4 may not be effective for T1-weighted images since the middle lines of K-space are acquired during the greatest period of T2 decay; the lines with the most signal have the most variation due to decay, producing blurring. Further, as the selected train length (ETL) increases, the number of echoes contributing to T2 decay increases.
- Since FSE can have 2 to 128 180 degree pulses with varied phase encoding, each phase encoding echo exhibits different T2 decay. This can increase signal in late echo images due to contribution from phase encoded echoes occurring early in T2 decay.
- Phase encoding across T2 decay can also produce image blurring, especially when the selected TE is short. This occurs where the T2 decay curve is the steepest. The blurring decreases as the number of phase

encodings is increased. It is practically unnoticeable at 512 phase encodings.

- Increasing the number of refocusing RF pulses increases the SAR to the patient, which can limit the number of slices allowable for any given TR.
- Concatenated acquisitions can be used with FSE.
- On a 1.5T system, the receive bandwidth is not reset on Fast Spin Echo scans from series to series. That means if a +/-8 kHz bandwidth is used on the first series, the next series defaults to +/-8 kHz. Manually change the bandwidth if another value is desired for the next sequence.
- Unlike conventional Spin Echo with Flow Comp (FC), which increases the minimum TE, FSE, with FC maintains the minimum echo spacing so the effective TEs are unaffected. The echo spacing decreases for FSE with FC due to FC being applied to only one axis for FSE acquisitions. When FC is selected, crusher gradient pulses on one of the axes are replaced by a flow compensation lobe in order to maintain sequence time and minimum echo spacing. You must select the axes on which FC is applied.
- The following scan parameters may produce signal loss and/or ghosting in spine images:
  - Fast Spin Echo PSD,
  - Sagittal Plane,
  - Use of the CTL Array and other spine coils,
  - When Flow Comp is selected, and
  - When Swap Phase and Frequency is selected.

  Keep in mind, Flow Comp can only be applied in the slice select or frequency direction with Fast Spin Echo. Swapping phase and Frequency on a sagittal spine places frequency in the A/P direction. Flow, in the form of a pulsatile CSF, takes place in the S/I direction of the sagittal spine, and therefore if frequency is in the A/P direction, it is ineffective. Also it is applied in only one direction, frequency or slice.
- The selection of Effective TE is not as flexible with the split train method as it is with a full echo train since the Effective TE1 must occur during the first half of the echo train and the Effective TE2 during the second half. Although, with all scan parameters the same, the

Effective TE1 should exhibit less blurring and increased relative proton density weighting in the split echo train method.

- Increasing the echo train length decreases acquisition time, affects the resulting contrast for the selected Effective TE, and decreases the number of slices available. As the echo train lengthens (increased number of echoes), the time per slice is increased since it increases the number of echoes generated and takes up more of the TR time.
- Fast Spin Echo can be used for T2 weighted body images, although the times may be adequate for breath hold it does not freeze cardiac motion or peristalsis.
- Fast Spin Echo with FC does not correct for pulsatile flow and may not provide benefits to the degree seen with conventional FC Spin Echo. Swapping phase and frequency with FSE may be the best alternative for sagittal spine imaging. ETL, TR, Receive Bandwidth, and echo spacing affect the CSF signal intensity and motion artifacts. If echo spacing remains short (for example, 16 msec), then Swapping phase and frequency may not be necessary.
- With FSE-XL the number of acquisitions in a series is determined by the number of angles prescribed and the number of slices allowed in each group.
- FSE-XL cannot be used with SS-FSE or FLAIR.
- Fractional echo is not allowed with FSE-XL, if the selected TE is less than the ESP, the effective TE increases to the ESP value.
- The duration of the RF pulse application has been decreased with FSE-XL which allows for shorter ESP. This has resulted in an increase of RF power to obtain the proper flip angles which are calculated in the prescan program. This is reflected in an increase in Flip Angle TR (TG gain) values during prescan.
- When using FSE-XL with sequential oblique group acquisitions, concatenated SAT can be used for placing SAT pulses in the slice direction without the trade-off of cross-talk because slice groups are acquired sequentially.
- When FSE-XL is used to prescribe two orthogonal images, e.g., axial and coronal, the coronal images may appear flipped upside down and /or sideways. This

orientation occurs because the system views the coronal images as an angled axial plane. To view the coronal in the normal manner, use the Flip/Rotate key on the Viewer or Mini Viewer desktop.

In addition, the slice locations on the flipped images represent the center of the FOV and will not change from image to image. To find the correct slice location for the flipped image, bring up a crosshair cursor and view the cursor annotation. The cursor annotation notes the correct slice position, which changes from image to image.

- Images from FSE-XL sequences may exhibit a fine line artifact. The suspected cause of this artifact is production of a FID outside the FOV. The FID is generated by echoes that cannot be completely rephased following the 180 refocusing pulses. Because multiple 180° pulses are utilized in FSE-XL, the FID created is strong compared to a standard Spin Echo sequence.

  Using an even NEX (2, 4, 6, etc.) can decrease, and often eliminate, the artifact. However, 2 NEX with No Phase Wrap (NPW) is truly a 1 NEX acquisition. It is recommended the NPW be turned off whenever possible. When not possible, other parameter changes can be made to obtain an even NEX scan with NPW on. For example: a protocol for a shoulder might be: FSE-XL, NPW, TRF, TR 3100, TE 51, 8 ETL, 12.5 kHz RBw, 12x12 FOV, 4mm thick, 1mm spacing, SAT I and Fat, 256x256 and 2 NEX. Changes to this could be: 20.83 RBw, 12 ETL, 4 NEX and NPW can remain on.

  The ETL increases, but the RBw is also increased, which decreases echo spacing. This results in similar T2 decay (even though the ETL is longer), and image contrast is similar in both sequences. The increased RBw decreases SNR, but it is offset by the increased NEX. And finally, scan time changes are minimal, but this is offset by the elimination of the fine line artifact.

- Use of the Classic imaging option helps to reduce artifact in some FSE images. Since Classic is sensitive to your center frequency choice, performing manual prescan insures proper center frequency placement.

Associated Imaging Options

In the following table the X's indicate the option available for use with the Fast Spin Echo pulse sequence.

Imaging Options			
X	None	**X**	Variable Bandwidth
X	Flow Compensation	**X**	No Phase Wrap
	POMP	**X**	Extended Dynamic Range
X	Square Pixel	**X**	Surface Coil Intensity Correction
	Respiratory Compensation		Classic
	Magnetization Transfer	**X**	Sequential
X	Cardiac Gating/Triggering	**X**	Respiratory Gating/Triggering
X	Tailored RF		IR Prepared
	DE Prepared		Multi-Phase
X	Full Echo Train		CCOMP
X	ZIP 1024	**X**	ZIP 512
	Zip x 2		ZIP x 4
	SmartPrep		Blood Suppression
	Multi Station		Real Time

NOTE: Multi-Slice Multi-Angle is compatible with FSE-XL. If multiple slices with multiple angles are acquired using a FSE-XL pulse sequence, a user CV becomes available. Selecting [Sequential] results in a Multi-Slice Multi-Angle (MSMA) acquisition and selecting [Interleaved] results in a Multi-Slice Multi-Group (MSMG) acquisition.

Applications

Fast Spin Echo can be used for various imaging acquisitions. It main use is to shorten the acquisition timing for long TR T2 weighted sequences. Use of a 3D FSE can be for volumetric data sets resulting in less magnetic susceptibility than GRE and FGRE.

Use FSE-XL in any area where FSE is normally used to obtain PD and T2 images in less time than it takes to acquire FSE images. Also to acquire dual bi-lateral planes simultaneously.

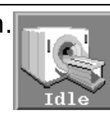
CAUTION: **Provide all patients with ear protection prior to any scan to help avoid possible hearing impairment.** Acoustic noise levels can exceed 99 dBA in the magnet bore.

Setting up a Fast Spin Echo Pulse Sequence

The decision matrix is only for prescribing a Fast Spin Echo/Fast Spin Echo-XL scan. The purpose of the decision matrix to help you understand the trade-offs that occur when you change the values for a particular parameter and to provide a framework with which you may build you own unique protocol.

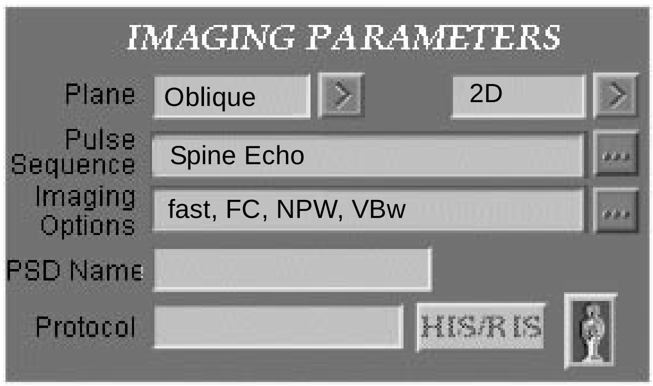
The selected values are only an example of what could be used for PD/T2-weighted Spin Echo acquisition and are not to be considered recommendations by GE Medical Systems. For specific protocols, refer to the protocols on your system.

.

Fast Spin Echo - What you select	Selection Notes
SCAN DESKTOP screen	
	Select **Scan Desktop** icon.  Click on **[New Patient]** and fill in the patient information. 
PATIENT POSITION area	
Patient Position **[Supine]**	**Position and Entry:** An FSE pulse sequence is compatible with any patient position and entry.
Patient Entry **[Feet First]**	

Fast Spin Echo - What you select		Selection Notes
Coil	**[Spine Array]**	**Coil:** Select the coil that produces the optimum coverage and SNR.
Series Description		**Series Description:** Enter a suitable series description. If you don not enter a description, the system enters one for you. The series description default is the selected scan mode, PSD, and imaging options.

IMAGING PARAMETERS area



Plane	**[Oblique]**	**Plane:** FSE is compatible with any scan plane (except 3 plane); select the plane that best meets the clinical need.
Mode	**[2D]**	**Mode:** Select [2D]. FSE-XL is only compatible with 2D.
Pulse Seq	**[FSE]**	**Pulse Seq:** Select [FSE]. Click on the [Accept] button in the window to register the selection.
Imaging Options	**[FC, NPW, VBw]**	**Imaging Options:** Select imaging options that optimizes SNR, spatial resolution, # of slices and reduce motion artifacts. Click on the [Accept] button to register the selections.[Full Echo Train] is for a dual echo FSE scan only. The [Full Echo Train] option completes all echo trains for Effective TE1 before Effective TE2 is initiated. If you are acquiring a dual echo acquisition and do NOT select [Full Echo Train], the system uses a split echo train method.
PSD Name	**N/A**	**PSD Name:** Not applicable for Fast Spin Echo.
Protocol	**N/A**	

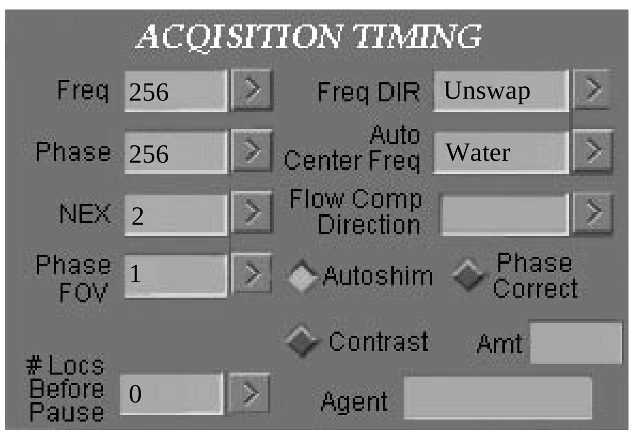
SCAN TIMING area

# of echoes	**[2]**	**# of echoes:** Select 1 echo for a T1-weighted acquisition. Select 2 echoes for a PD/T2-weighted acquisition.
TE	**[17]**	**TE:** Short TEs produce: increased T1 and PD contrast, increased SNR, and with multi-planar acquisitions, increased # of slices. Minimum TE changes as RBw changes. The minimum TE is the echo space.

Fast Spin Echo - What you select		Selection Notes
TE2	**[116]**	**TE2:** Long TEs produce decreased # of slices, increased T2 contrast and decreased SNR.
TR	**[3000]**	**TR:** Short TRs produce: decreased SNR, decreased # of slices in multi-planar acquisitions, increased T1 contrast, decreased scan time. In a SE T1-weighted acquisition, don't exceed the following TR: 1.5T 700 ms, 1.0T 600 ms. Long TRs produce: increased SNR, increased # of slices, increased PD/T2 contrast, increased scan time. TR is not selectable with gated scans. The TR is determined by the RR intervals on the Gating Additional Parameters screen. **NOTE:** Changes made to FSE timing factors are likely to result in a decrease in the max. number of slice locations allowed per TR. As a result, acquisitions may double, if the number of slices exceed the max. TR. To avoid double acquisition decrease the number of slices by one.
TI	**N/A**	
Flip Angle	**N/A**	
Echo Train Length	**[8]**	**Echo Train Length:** Long ETLs produce decreased scan time, increased edge blurring, increased signal from fat and decreased # of slices. • The value selected is dependent on whether or not the [Full Echo Train] key is selected and if you are acquiring a dual echo FSE or two single echo FSE scans. • Typically 2-4 ETL is used with a T1 weighted acquisition. • Odd numbered ETLs can be collected only when doing a single echo acquisition or when using the [Full Echo Train] imaging option. This is because an odd number od echoes cannot be evenly distributed between two images.
Bandwidth	**[16]**	**Bandwidth:** RBw can only be changed if it was selected from the Imaging Options window. As the RBw decreases, the following occurs: increased SNR, increased chemical shift artifact, increased minimum TE which can potentially decreases # of slices and increased motion artifact.
Bandwidth 2	**N/A**	**Bandwidth2:** Only 1 RBw is allowed with FSE.
SCANNING RANGE area		

Fast Spin Echo - What you select		Selection Notes
FOV	**[20]**	**FOV:** Select a FOV that covers the anatomy of interest. Anatomy outside the FOV in the phase direction results in aliasing. Small FOVs produce: increased resolution, decreased SNR, and can increase the minimum TE value.
Slice Thickness	**[4]**	**Slice Thickness:** Thin slices produce: increased resolution and decreased SNR.
Spacing	**[1.0]**	**Spacing:** Select a spacing that reduces cross-talk between slices (typically 20% of the slice thickness) If your scan is a dual acquisition with no concantenated SAT pulse, 0 spacing is allowed.
Start, End Locations		**Start, End Locations:** Typically the start and end locations are programmed from the Graphic Rx program.
# Slices	**[18]**	**# Slices:** The maximum number of slices available is determined by the TR, TE, ETL, SAR, and gradient stress.

ACQUISITION TIMING area



Freq	**[256]**	**Freq:** Increasing the frequency matrix produces: increased resolution, decreased SNR, and decreased # of slices.
Phase	**[256]**	**Phase:** Phase controls scan time and may control resolution. Increasing phase steps may decrease edge blurring. Valid phase matrix values are from 128 to 512 in increments of 32 with echo train lengths between 16 and 8.
NEX	**[2]**	**NEX:** Select a NEX value that produces sufficient SNR.
Phase FOV	**[1]**	**Phase FOV:** Select 0.75 or 0.5 to reduce phase steps and thus decrease scan time, decreasing FOV in the phase direction, and decreasing SNR slightly. The phase FOV dimension is displayed next to the phase FOV factor.

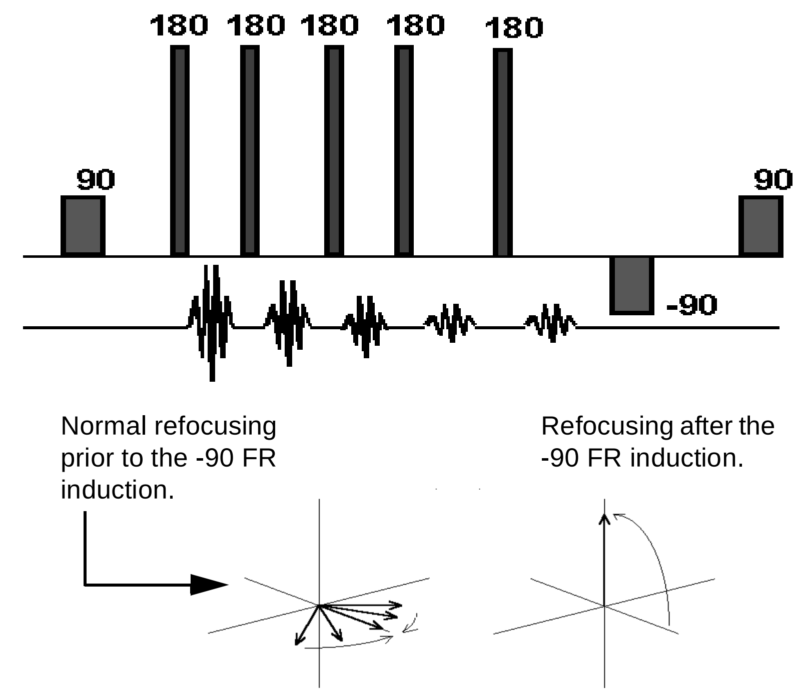
Fast Spin Echo - What you select		Selection Notes
Freq DIR	**[Unswap]**	**Freq DIR:** The direction displayed is the default frequency direction which is typically the long axis of the image. To swap phase and frequency, select the other direction.
Auto Center Freq	**[Water]**	**Auto Center Freq:** Select the CF peak that is set during prescan.
Flow Comp DIR	**[Freq]**	**Flow Comp DIR:** Flow Comp direction can only be selected when Flow Comp is active. The default direction is based on the selected scan plane except with oblique which has no default.
Autoshim	**[Off]**	**Autoshim:** Select Autoshim when using fat SAT or an FOV off center, and on the first series of each exam.
Phase Correct	**[On]**	**Phase Correct:** By turning phase correct on this helps to correct any artifact occurring in the phase direction.
# of Acqs/Locs Before Pause	**N/A**	
Additional Parameters **SAT Screen**		
I	**[80]**	SAT pulses may decrease the # of slices/acquisition. Fat SAT is frequently used with T2 weighted scans acquired with long ETLs.
S	**[80]**	
Additional Parameters		To prescribe oblique slices you must select **[Oblique]** in the Plane pull-down menu.
GRAPHIC RX Screen		
Click on the image to display the line cursor for Graphic Rx.		The SAT band function can be accessed from the GRAPHIC Rx window and vice versa. If you had graphically prescribed the previous axial series the same prescription can be copied using the **[Copy RX]** button. Consider using an offset to center the anatomy in the middle of the screen so that you can use a PFOV less than 1 and therefore reduce the scan time. View the Advisory panel to note the Max # of slices/Acq and the # of Acqs you are prescribing. The scan time increases as the # of Acquisitions increase.
SCAN OPERATIONS area		

Fast Spin Echo - What you select	Selection Notes
[Save Series] **[Prep to Scan]** **[Auto Prescan]** **[Scan]**	Enter data in all the fields and click on **[Save Series]**. The series is saved as RXD.

Fast Recovery Fast Spin Echo (FRFSE)

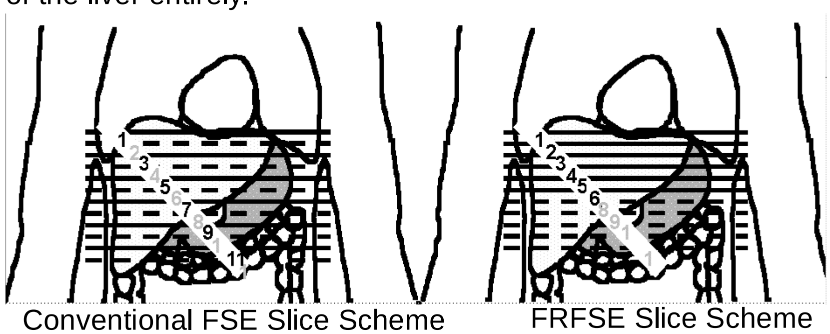
The FRFSE pulse sequence is a modified version of FSE-XL. As a refresher the FSE-XL pulse sequence uses RF pulses with higher amplitude with a shorter duration which result in shorter echo spacing and ETL, than an FSE pulse sequence.

The basis of a FRFSE sequence is that the transverse magnetization is still present at the end of the echo train. In FRFSE this magnetization is refocused back into the longitudinal axis by applying a -90° pulse, during the time when normal refocusing is occurring. By refocusing transverse magnetization into the longitudinal axis with a -90 RF, this effectively shortens the apparent T1 effect in protons consisting of long T2 characteristics.



NOTE: An odd number of ETL must be prescribed.

Another characteristic of this PSD is the slice ordering scheme. With conventional FSE, if multiple acquisitions are being acquired the system defaults to acquiring slices in an interleaved fashion. (e.g. if two acquisitions are acquired for twenty slices, slices 1, 3, 5...19 are acquired in the first acquisition and slices 2, 4, 6...20 are acquired in the second acquisition.) Normally, two acquisitions are required to collect axial slices of the liver with appropriate slice thicknesses. If the patient holds their breath such that one acquisition is completed per breath-hold, the default slice acquisition scheme acquires axial slices covering the entire liver in each breath-hold, interleaving the slices from subsequent breath-holds. Because it is impossible for the patient to hold their breath at exactly the same location on each breath-hold, the liver will be at different actual locations in the scanner during each breath-hold. This means that axial slices from subsequent breath-holds are not correctly interleaved relative to the slices acquired in the first breath-hold. In this scheme, it is even possible to miss portions of the liver entirely.



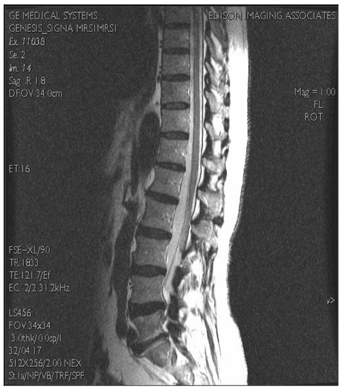
The improved acquisition scheme for liver imaging.

With this new method, axial slices are acquired in groups of contiguous slices, starting with the first group located at the top of the liver, with each subsequent group located progressively more inferiorly until the entire liver is cover.

NOTE: The groups can also be acquired starting from the bottom of the liver and progressing to the top over subsequent breath-holds if preferred).

Fast Recovery FSE Image Characteristics

FRFSE produces images that are T2 weighted with enhanced T2 components compared to conventional FSE images. Images can be acquired with long ETLs, thus reducing the overall image time. For images acquired with long echo trains, signal from fluid can be dramatically enhanced.



Compare the contrast-to-noise in the CSF areas of the spine. Image on the left is conventional FSE, image on the right FRFSE.

With the introduction of the -90 RF, resulting images have less saturation effects and therefore more T2 weighting and improved SNR.

Blurring cancellation can also be implemented in this PSD to cut down on image ghosting. This feature can be turned on under the User CV. This feature acquires K-space twice, in reverse order, this can add to acquisition time in some cases.

Something to Think About...

- Blurring cancellation can be turned on under the User CV. If shorter breath-holds are desired, this User CV can be turned off, but ghosting is increased.
- PSD, FSE must be selected from menu and FRFSEOPT, should be typed in on the PSD name line in order to turn on the FRFSE sequence.

- Acqs Before Pause must be set to 1 to enable breath-hold slice ordering. This allows a pause between groups of slices for free breathing.
- Always use 0.75 FOV to maximize efficiency.
- For SAT bands, both S and I sats, also concatenated should be selected in order to place a group of SAT bands at the limits of each group of slices.
- Overlapping groups of slices are done in the Graphics Prescription window by:
  - defining the first group of slices with the maximum number of slices per acquisition;
  - placing the cursor over the last slice then holding down the SHIFT key, left click and defining the second group of slices. Again with the maximum number of slices per acquisition.
  - It is recommended to move the second group to overlap with the first group of slices. Do not define two groups of slices by clicking and dragging once only—this results in uneven contrast throughout the group of slices.

Associated Imaging Options

In the following table the X's indicate the options available for use with the FRFSE pulse sequence.

Imaging Options			
X	None	**X**	Variable Bandwidth
X	Flow Compensation	**X**	No Phase Wrap
	POMP	**X**	Extended Dynamic Range
	Square Pixel	**X**	Surface Coil Intensity Correction
	Respiratory Compensation		Classic
	Magnetization Transfer		Sequential
	Cardiac Gating/Triggering		Respiratory Gating/Triggering
X	Tailored RF		IR Prepared
X	DE Prepared		Multi-Phase
X	Full Echo Train		CCOMP

Imaging Options			
	ZIP 1024	**X**	ZIP 512
	Zip x 2		ZIP x 4
	SmartPrep		Blood Suppression
	Multi Station		Real Time

Applications

Some suggested applications for FRFSE are breath-held abdominal imaging, as well as any area were rapid T2 weighting is desired.

Use blurring cancellation to minimize image ghosting. Lower TRs can be used at no expense to contrast-to-noise; this helps to also reduce overall scan timing.

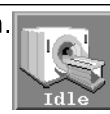
CAUTION: **Provide all patients with ear protection prior to any scan to help avoid possible hearing impairment.** Acoustic noise levels can exceed 99 dBA in the magnet bore.

Setting up a FRFSE pulse sequence

The decision matrix is only for prescribing a Fast Recovery Fast Spin Echo sequence. The purpose of the decision matrix to help you understand the trade-offs that occur when you change the values for a particular parameter and to provide a framework with which you may build you own unique protocol.

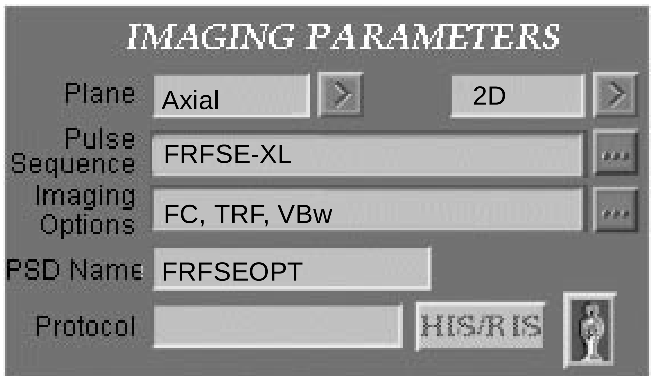
The selected values are only an example of what could be used for a FRFSE acquisition and are not to be considered recommendations by GE Medical Systems. For specific protocols, refer to the protocols on your system.

.

FRFSE - What you select		Selection Notes
	SCAN DESKTOP screen	
		Select **Scan Desktop** icon.  Click on **[New Patient]** and fill in the patient information. 
	PATIENT POSITION area	
Patient Position	**[Supine]**	**Position and Entry:** An FRFSE pulse sequence is compatible with any patient position and entry.
Patient Entry	**[Feet First]**	
Coil	**[Torso Array]**	**Coil:** Select the coil that produces the optimum coverage and SNR.

FRFSE - What you select		Selection Notes
Series Description		**Series Description:** Enter a suitable series description. If you don not enter a description, the system enters one for you. The series description default is the selected scan mode, PSD, and imaging options.

IMAGING PARAMETERS area



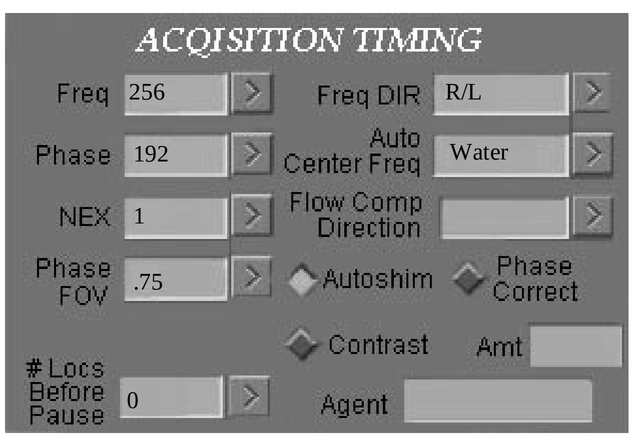
Plane	**[Axial]**	**Plane:** FRFSE is compatible with any scan plane (except 3 plane); select the plane that best meets the clinical need.
Mode	**[2D]**	**Mode:** Select [2D]. FRFSE is only compatible with 2D.
Pulse Seq	**[FRFSE-XL]**	**Pulse Seq:** Select [FRFSE-XL]. Click on the [Accept] button in the window to register the selection.
Imaging Options	**[FC, TRF, VBw]**	**Imaging Options:** Select imaging options that optimizes SNR, spatial resolution, # of slices and reduce motion artifacts. Click on the [Accept] button to register the selections.
PSD Name	**[FRFSEOPT]**	**PSD Name:** Type in [FRFSEOPT].
Protocol	**N/A**	

SCAN TIMING area

# of echoes	**[1]**	**# of echoes:** Select 1 echo.
TE	**[90]**	**TE:** Short TEs produce: increased T1 and increased SNR. Minimum TE changes as RBw changes.
TE2	**N/A**	
TR	**[2500]**	**TR:** Long TRs produce: increased SNR, increased # of slices, and increased scan time. TR is not selectable with gated scans. The TR is determined by the RR intervals on the Gating Additional Parameters screen.
TI	**N/A**	
Flip Angle	**N/A**	

FRFSE - What you select		Selection Notes
Echo Train Length	**[17]**	**Echo Train Length:** Long ETLs produce decreased scan time, increased edge blurring, increased signal from fat and decreased # of slices.
Bandwidth	**[41]**	**Bandwidth:** RBw can only be changed if it was selected from the Imaging Options window. As the RBw decreases, the following occurs: increased SNR, increased chemical shift artifact, increased minimum TE which can potentially decreases # of slices and increased motion artifact.
Bandwidth 2	**N/A**	**Bandwidth2:** RBW2 is only selectable with a 2 echo Spin Echo acquisition.
SCANNING RANGE area		
FOV	**[32]**	**FOV:** Select a FOV that covers the anatomy of interest. Anatomy outside the FOV in the phase direction results in aliasing. Small FOVs produce: increased resolution, decreased SNR, and can increase the minimum TE value.
Slice Thickness	**[7]**	**Slice Thickness:** Thin slices produce: increased resolution and decreased SNR.
Spacing	**[1.0]**	**Spacing:** Select a spacing that reduces cross-talk between slices (typically 20% of the slice thickness) If your scan is a dual acquisition with no concantenated SAT pulse, 0 spacing is allowed.
Start, End Locations		**Start, End Locations:** Typically the start and end locations are programmed from the Graphic Rx program.
# Slices	**[9]**	**# Slices:** The maximum number of slices available is determined by the TR, TE, SAR, and gradient stress.

ACQUISITION TIMING area



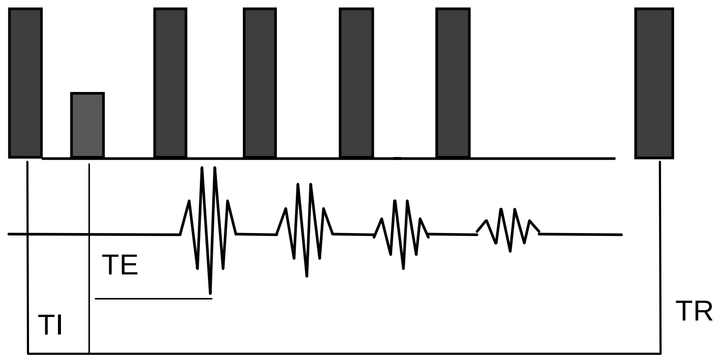
FRFSE - What you select		Selection Notes
Freq	**[256]**	**Freq:** Increasing the frequency matrix produces: increased echo space, increased resolution, decreased SNR, and decreased # of slices.
Phase	**[192]**	**Phase:** Phase controls scan time and may control resolution. Increasing phase steps may decrease edge blurring.
NEX	**[1]**	**NEX:** Select a NEX value that produces sufficient SNR.
Phase FOV	**[.75]**	**Phase FOV:** Select 0.75 or 0.5 to reduce phase steps and thus decrease scan time, decreasing FOV in the phase direction, and decreasing SNR slightly. The phase FOV dimension is displayed next to the phase FOV factor.
Freq DIR	**[R/L]**	**Freq DIR:** The direction displayed is the default frequency direction which is typically the long axis of the image. To swap phase and frequency, select the other direction.
Auto Center Freq	**[Water]**	**Auto Center Freq:** Select the CF peak that is set during prescan.
Flow Comp DIR	**[Slice]**	**Flow Comp DIR:** Flow Comp direction can only be selected when Flow Comp is active. The default direction is based on the selected scan plane except with oblique which has no default.
Autoshim	**[On]**	**Autoshim:** Select Autoshim when using fat SAT or an FOV off center, and on the first series of each exam.
Phase Correct	**[Off]**	
# of Acqs/Locs Before Pause	**N/A**	
Additional Parameters SAT Screen		
I	**[80]**	SAT pulses may decrease the # of slices/acquisition. Fat SAT is frequently used with T2 weighted scans acquired with long ETLs.
S	**[80]**	Select the [Concat] option in the SAT parameters screen.
Additional Parameters		To prescribe oblique slices you must select **[Oblique]** in the Plane pull-down menu.
GRAPHIC RX Screen		

FRFSE - What you select	Selection Notes
Click on the image to display the line cursor for Graphic Rx.	The SAT band function can be accessed from the GRAPHIC Rx window and vice versa. If you had graphically prescribed the previous axial series the same prescription can be copied using the **[Copy RX]** button. Consider using an offset to center the anatomy in the middle of the screen so that you can use a PFOV less than 1 and therefore reduce the scan time. View the Advisory panel to note the Max # of slices/Acq and the # of Acqs you are prescribing. The scan time increases as the # of Acquisitions increase.
SCAN OPERATIONS area	
[Save Series] **[Prep to Scan]** **[Auto Prescan]** **[Scan]**	Enter data in all the fields and click on **[Save Series]**. The series is saved as RXD.

Fast Spin Echo-Inversion Recovery (FSE-IR)

The FSE-IR pulse sequence is a modified version of FSE. FSE-IR employs the same technique used in FSE to speed up scan time, with an added Inversion Recovery technique that is primarily used for nulling the signal from fat. Typically a short TE (40ms), short TI (140ms), and a long TR (3000ms) is used to nullify fat signal. Just like with conventional IR the TI value is based on the recovery of fat to the null point and changes as the field strength changes. As a reminder, as the field strength gets larger, the TI gets longer. A sample TI value for 1.5T = 170ms, and a sample TI time for 1.0T = 145ms.

A diagram of how the FSE-IR pulse sequence is as follows:



FSE-IR Image Characteristics

FSE-IR has the same general image characteristics as FSE. T1 weighted images have improved contrast and more SNR than FSE images, fat suppressed images have more uniform fat suppression than chemical saturation because FSE-IR is less sensitive to magnetic field inhomogeneities and off-center FOV effects.

Something to Think About...

- The Echo Train selected for FSE-IR affects the image contrast as does the echo space, the Effective TE, TR, motion, chemical shift, flow, SNR, and resolution.
- Since FSE-IR can have 2 to 128, 180° pulses with varied phase encoding, each phase encoding echo exhibits different T2 decay. This can increase signal in late echo images due to contribution from phase encoded echoes occurring early in T2 decay.
- Increasing the number of refocusing RF pulses, increases the SAR to the patient, which can limit the number of slices allowable for any given TR.
- Phase encoding across T2 decay can also produce image blurring, especially when the selected TE is short. This occurs where the T2 decay curve is the steepest. The blurring decreases as the number of phase encodings is increased. It is practically undetectable at 512 phase encodings.
- Concatenated acquisitions can be used with FSE-IR.
- On a 1.5T system, the receive bandwidth is not reset on FSE-IR scans from series to series. That means if a

+/-8kHz bandwidth is used in the first series, the next series defaults to +/-8kHz. Manually change he bandwidth if another value is desired for the next sequence.

- Unlike conventional Spin Echo with FC, which increases the minimum TE, FSE-IR with FC maintains the minimum echo spacing so the effective TEs are unaffected. The echo spacing decreases for FSE with FC due to FC being applied to only one axis for FSE acquisitions. When FC is selected, crusher gradient pulses on one of the axes are replaced by a flow compensation lobe in order to maintain sequence time and minimum echo spacing. You must select the axes on which FC are applied.
- Increasing the echo train length decreases acquisition time, affects the resulting contrast for the selected Effective TE, and decreases the number of slices available. As the echo train lengthens (increased number of echoes), the time per slice is increased since it increases the number of echoes generated and takes up more of the TR time.
- FSE-IR with FC may not provide benefits to the degree seen with conventional FC Spin Echo. Therefore, swapping phase and frequency may be desirable to minimize motion artifact. If echo spacing remains short (for example, 16msec), then swapping phase and frequency may not be necessary.
- When FSE-IR is selected in the Imaging Parameters area, the TI field becomes active in the Scan Timing area.
- Sequential is automatically selected with FSE-IR.
- The maximum allowed value for TE2 is a FSE-IR sequence may not match the maximum shown adjacent to the TE text box in the Scan Timing area. This is due to the fact that the system cannot allow for all possible parameter selections which affect the maximum TE for FSE-IR. Therefore, you may find that the actual TE2 exceeds the posted maximum.

Associated Imaging Options

In the following table the X's indicate the option available for use with the FSE-IR pulse sequence.

Imaging Options			
X	None	X	Variable Bandwidth
X	Flow Compensation	X	No Phase Wrap
	POMP	X	Extended Dynamic Range
X	Square Pixel	X	Surface Coil Intensity Correction
	Respiratory Compensation		Classic
	Magnetization Transfer	X	Sequential
X	Cardiac Gating/Triggering		Respiratory Gating/Triggering
X	Tailored RF		IR Prepared
	DE Prepared		Multi-Phase
X	Full Echo Train		CCOMP
X	ZIP 1024	X	ZIP 512
	Zip x 2		ZIP x 4
	SmartPrep		Blood Suppression
	Multi Station		Real Time

Applications

FSE-IR is used to suppress competing signal from tissues that obscure pathology or structures of interest. FSE-IR has shorter scan times and more efficient slice interleaving than IR.

Also when you desire a more uniform fat suppression for large FOV or off-center FOV, FSE-IR is an excellent alternative. Do not use IR techniques with contrast studies, enhancing pathology could be suppressed if the contrast shortened T1 corresponds to the null point.

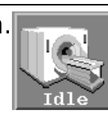
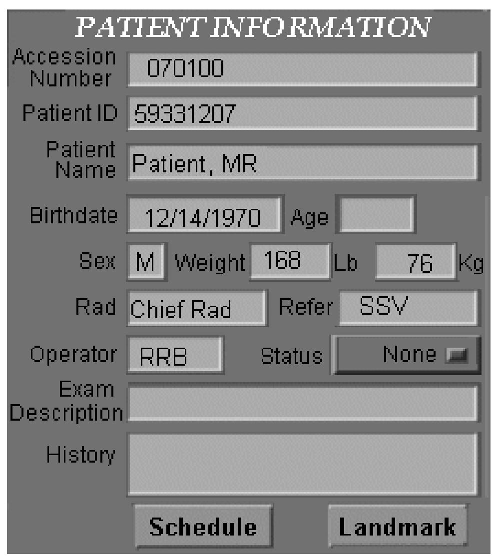
CAUTION: **Provide all patients with ear protection prior to any scan to help avoid possible hearing impairment.** Acoustic noise levels can exceed 99 dBA in the magnet bore.

Setting up a FSE-IR Pulse Sequence

The decision matrix is only for prescribing a Fast Spin Echo-Inversion Recovery sequence. The purpose of the decision matrix to help you understand the trade-offs that occur when you change the values for a particular parameter and to provide a framework with which you may build you own unique protocol.

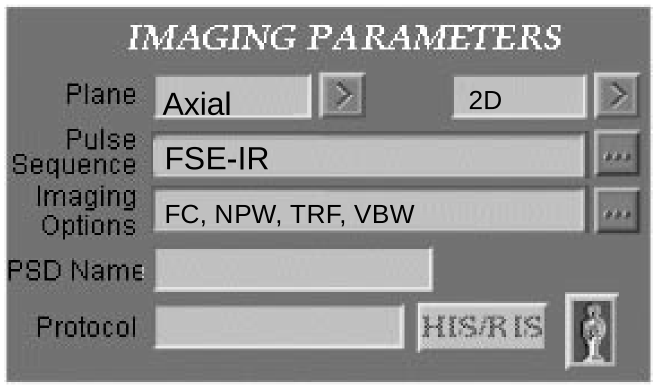
The selected values are only an example of what could be used for a short TI-IR, fat suppression acquisition and are not to be considered recommendations by GE Medical Systems. For specific protocols, refer to the protocols on your system.

.

FSE-IR - What you select		Selection Notes
SCAN DESKTOP screen		
		Select **Scan Desktop** icon.  Click on **[New Patient]** and fill in the patient information. 
PATIENT POSITION area		
Patient Position	**[Supine]**	**Position and Entry:** An FSE-IR pulse sequence is compatible with any patient position and entry.
Patient Entry	**[Head First]**	

FSE-IR - What you select		Selection Notes
Coil	**[Head]**	**Coil:** Select the coil that produces the optimum coverage and SNR.
Series Description		**Series Description:** Enter a suitable series description. If you don not enter a description, the system enters one for you. The series description default is the selected scan mode, PSD, and imaging options.

IMAGING PARAMETERS area



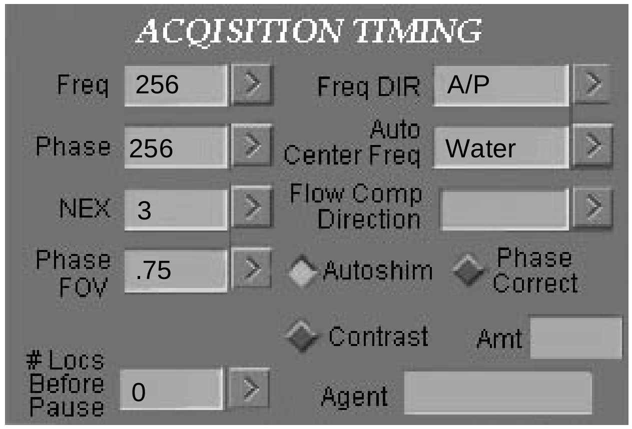
Plane	**[Axial]**	**Plane:** FSE-IR is compatible with any scan plane (except 3 plane); select the plane that best meets the clinical need.
Mode	**[2D]**	**Mode:** Select [2D]. FSE-XL is only compatible with 2D.
Pulse Seq	**[FSE-IR]**	**Pulse Seq:** Select [FSE-IR]. Click on the [Accept] button in the window to register the selection.
Imaging Options	**[FC, NPW, TRF, VBw]**	**Imaging Options:** Select imaging options that optimizes SNR, spatial resolution, # of slices and reduce motion artifacts. Click on the [Accept] button to register the selections.[Full Echo Train] is for a dual echo FSE scan only. The [Full Echo Train] option completes all echo trains for Effective TE1 before Effective TE2 is initiated. If you are acquiring a dual echo acquisition and do NOT select [Full Echo Train], the system uses a split echo train method.
PSD Name	**N/A**	**PSD Name:** Not applicable for FSE-IR.
Protocol	**N/A**	

SCAN TIMING area

# of echoes	**[1]**	**# of echoes:** Select 1 echo.
TE	**[40]**	**TE:** Short TEs produce: increased T1 and increased SNR. Minimum TE changes as RBw changes.

FSE-IR - What you select		Selection Notes
TE2	**N/A**	**TE2:** The maximum allowed value for TE2 in a FSE-IR sequence may not match the maximum shown adjacent to the TE text field in the Scan Timing area. This is due to the fact that the system cannot allow for all possible parameter selections which affect the maximum TE for FSE-IR. Therefore, you may find that the actual TE2 exceeds the posted maximum.
TR	**[3150]**	**TR:** Long TRs produce: increased SNR, increased # of slices, and increased scan time. TR is not selectable with gated scans. The TR is determined by the RR intervals on the Gating Additional Parameters screen.
TI	**[170]**	**Inv. Time:** Select a TI to suppress the signal from fat: ~145ms on a 1.0T system and ~170ms on a 1.5T system.
Flip Angle	**N/A**	
Echo Train Length	**[16]**	**Echo Train Length:** Long ETLs produce decreased scan time, increased edge blurring, increased signal from fat and decreased # of slices.
Bandwidth	**[16]**	**Bandwidth:** RBw can only be changed if it was selected from the Imaging Options window. As the RBw decreases, the following occurs: increased SNR, increased chemical shift artifact, increased minimum TE which can potentially decreases # of slices and increased motion artifact.
Bandwidth 2	**N/A**	**Bandwidth2:** RBW2 is only selectable with a 2 echo Spin Echo acquisition.
SCANNING RANGE area		
FOV	**[23]**	**FOV:** Select a FOV that covers the anatomy of interest. Anatomy outside the FOV in the phase direction results in aliasing. Small FOVs produce: increased resolution, decreased SNR, and can increase the minimum TE value.
Slice Thickness	**[5]**	**Slice Thickness:** Thin slices produce: increased resolution and decreased SNR.
Spacing	**[2.0]**	**Spacing:** Select a spacing that reduces cross-talk between slices (typically 20% of the slice thickness) If your scan is a dual acquisition with no concantenated SAT pulse, 0 spacing is allowed.
Start, End Locations		**Start, End Locations:** Typically the start and end locations are programmed from the Graphic Rx program.
# Slices	**[7]**	**# Slices:** The maximum number of slices available is determined by the TR, TE, TI, SAR, and gradient stress.

FSE-IR - What you select		Selection Notes
ACQUISITION TIMING area		

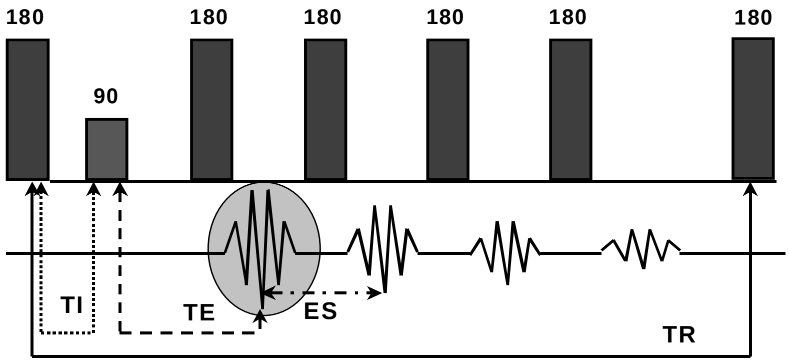


Freq	**[256]**	**Freq:** Increasing the frequency matrix produces: increased echo space, increased resolution, decreased SNR, and decreased # of slices.
Phase	**[256]**	**Phase:** Phase controls scan time and may control resolution. Increasing phase steps may decrease edge blurring.
NEX	**[3]**	**NEX:** Select a NEX value that produces sufficient SNR.
Phase FOV	**[.75]**	**Phase FOV:** Select 0.75 or 0.5 to reduce phase steps and thus decrease scan time, decreasing FOV in the phase direction, and decreasing SNR slightly. The phase FOV dimension is displayed next to the phase FOV factor.
Freq DIR	**[A/P]**	**Freq DIR:** The direction displayed is the default frequency direction which is typically the long axis of the image. To swap phase and frequency, select the other direction.
Auto Center Freq	**[Water]**	**Auto Center Freq:** Select the CF peak that is set during prescan.
Flow Comp DIR	**[Slice]**	**Flow Comp DIR:** Flow Comp direction can only be selected when Flow Comp is active. The default direction is based on the selected scan plane except with oblique which has no default.
Autoshim	**[On]**	**Autoshim:** Select Autoshim when using fat SAT or an FOV off center, and on the first series of each exam.
Phase Correct	**[On]**	**Phase Correct:** By turning phase correct on this helps to correct any artifact occurring in the phase direction.
# of Acqs/Locs Before Pause	**N/A**	
Additional Parameters SAT Screen		

FSE-IR - What you select		Selection Notes
I	**[80]**	SAT pulses may decrease the # of slices/acquisition. Fat SAT is frequently used with T2 weighted scans acquired with long ETLs.
S	**[80]**	
Additional Parameters		To prescribe oblique slices you must select **[Oblique]** in the Plane pull-down menu.
GRAPHIC RX Screen		
Click on the image to display the line cursor for Graphic Rx.		The SAT band function can be accessed from the GRAPHIC Rx window and vice versa. If you had graphically prescribed the previous axial series the same prescription can be copied using the **[Copy RX]** button. Consider using an offset to center the anatomy in the middle of the screen so that you can use a PFOV less than 1 and therefore reduce the scan time. View the Advisory panel to note the Max # of slices/Acq and the # of Acqs you are prescribing. The scan time increases as the # of Acquisitions increase.
SCAN OPERATIONS area		
	[Save Series] **[Prep to Scan]** **[Auto Prescan]** **[Scan]**	Enter data in all the fields and click on **[Save Series]**. The series is saved as RXD.

FLAIR and T1 FLAIR

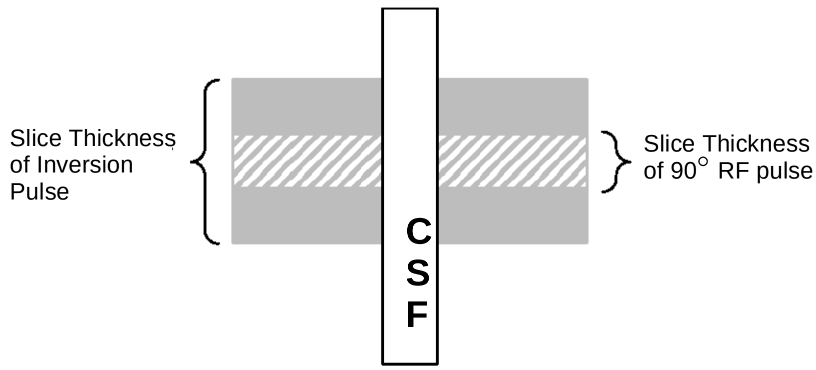
The FLAIR (Fluid Attenuated Inversion Recovery) pulse sequence is a Fast Inversion Recovery technique that nulls the CSF signal while maintaining T2 contrast. Just like FSE-IR it consists of an initial 180° inversion pulse prior to the 90° excitation pulse. A diagram of the sequence is as follows:



In comparison the FSE-IR and the FLAIR sequence is played out in the same manner the major difference is the duration of the TI time. Usually with the FLAIR sequence the twice as long, approximately 220ms, this allows sufficient time to null signal from CSF. Used in conjunction with a much longer TR (approximately 11,000ms), this results in a T2 weighted image with CSF nulled. With this TI and TR time FLAIR interleaves slice acquisitions thus improving imaging efficiency and more acceptable scan times.

The same principle can also be applied to the T1 FLAIR sequence. This sequence is played out in the same manner as both the FSE-IR and the FLAIR sequences. Again the TI and TR times are the differences between the pulse sequences. TI times are approximately 750ms with TR times approximately 2000ms, to obtain T1 weighted contrast. Slices are obtained by the interleaving method.

CSF artifacts arises when non-inverted CSF is able to flow into the imaging slice. CSF artifacts appear either as non-nulled (bright) CSF and/or CSF ghosts replicated along the phase encode direction. In order to minimize these affects, the width of the inversion slice is made wider than the width of the imaging slice whenever possible. This widening of the inversion pulse attempts to invert CSF that flows into the imaging slice during the TI interval.



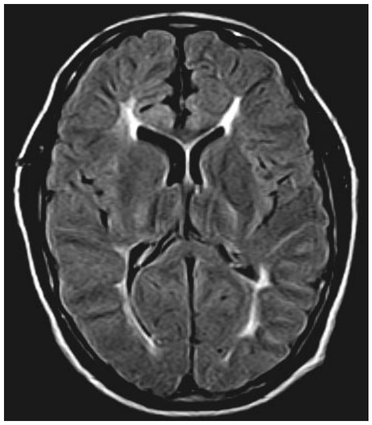
If, for example, a slice gap is chosen, the inversion slice thickness is automatically widened to include the imaging slice thickness plus the slice gap.

Another way to cause an increase in the thickness of the inversion pulse is to prescribe multiple acquisitions. Usually the scan software uses multiple acquisitions only if the number of slice locations requested is larger than the number of locations that can fit into one acquisition. With the FLAIR PSD, however, you can force the scan software to use multiple acquisitions no matter what the number is of requested slice locations. This is done by choosing the "minimum number of acquisitions" on the page of the Additional Parameters User CV screen. By selecting 3 acquisitions, for example, the scan software divides the total set of prescribed slices into 3 different acquisitions. The inversion slice thickness for each acquisition increases by a factor of 3. Whenever multiple acquisitions are used, the inversion thickness is again widened, reducing the CSF artifacts. For two-acquisition exams, the inversion thickness is approximately three times as thick as the imaging slice. For maximum suppression of CSF ghosting artifacts, you are encouraged to use two- or three-acquisition protocols.

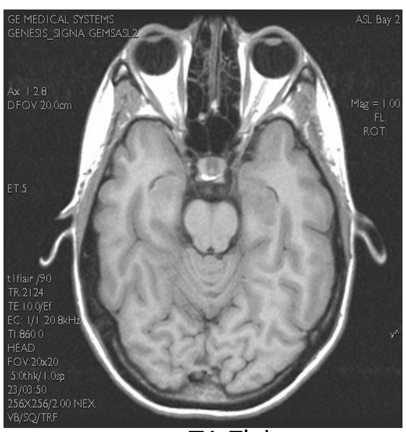
FLAIR and T1 FLAIR Image Characteristics

FLAIR as well as T1 FLAIR weighted images have a improved image contrast and more SNR than FSE images. Both are less sensitive to magnetic field inhomogeneities and off-center FOV effects. With FLAIR acquisition bright signal is suppressed from

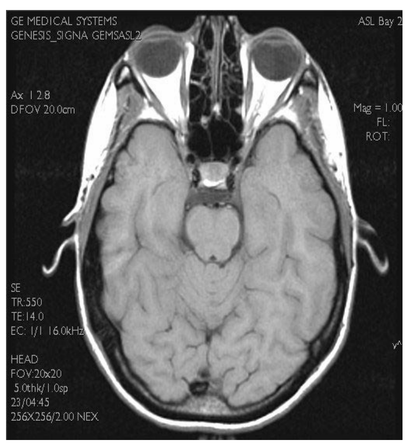
CSF on T2 weighted images. Structures adjacent to fluid filled structures become more apparent.



T1 Flair images are displayed with improved contrast to noise and signal to signal to noise ratios compared to T1 weighted spin echo sequences.



T1 Flair



Spin Echo

Something to Think About...

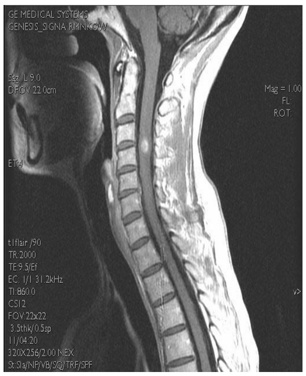
- The FLAIR sequence is not compatible with the Sequential imaging option.
- A result of FLAIR's phase encode ordering scheme (which is similar to No Phase Wrap), is that the effective TE of the acquisition must be in the middle of the echo train. Therefore, for a given echo spacing (ESP), once an effective TE is selected the ETL is completely determined. For example, using a 24cm FOV with a 32 kHz receive bandwidth (RBw) and a 256x -resolution, the ESP is about 13msec. With a chosen TE of

145msec, the ETL is approximately 22. (ETL = 2 TE ÷ ESP).

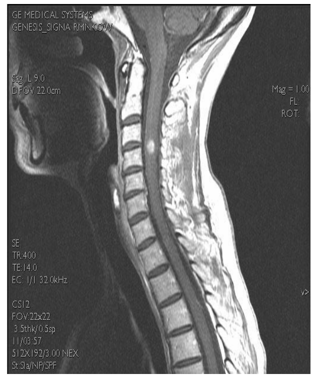
So, as one prescribes longer effective TEs, the calculated ETL increases accordingly. Based on your selection of TE, FOV, x-resolution, and RBw (which determines the ESP), the FLAIR pulse sequence chooses the appropriate ETL. Therefore, the ETL selection has been removed from the scan prescription process.

- Since the ETL is tied to the TE, as you select shorter TEs the scan time increases. In order to compensate for the scan time increase, you may choose to reduce the TR. Keep in mind, however, that in order to maintain CSF nulling, the TR must be at lease 3 to 4 times the value of the TI. If you choose a TR that is significantly lower than 3 x TI, the quality of the CSF nulling degrades. Reducing the TI and TR together allows reduced scan time and CSF nulling, but also reduces the gray/white matter contrast in the image.
- The FLAIR pulse sequence uses a modified phase encode ordering scheme that can be described as a high-sort, no phase wrap acquisition. This phase encoding scheme reduces flow artifacts in the FSE acquisition. One result of using this phase encoding scheme is that no phase wrap is always on in the FLAIR acquisition. Therefore, the No Phase Wrap option does not need to be selected, nor can it be turned off.
- T1 Flair sequences can only be used in Picture This mode. Parameters can not be modified.
- When performing a T1 Flair with contrast, if the T1 shortening of contrast corresponds to the null point of the enhancing lesion, contrast enhancement could be

suppressed. Note the differences in lesion enhancement on the Sagittal T1 cervical spine images shown below.



T1 Flair



SE

- RBw's lower than +/-7.81kHz is not supported with T1 Flair sequences.

Associated Imaging Options

In the following table the X's indicate the options available for use with the FLAIR and T1 Flair pulse sequences.

Imaging Options			
X	None	X	Variable Bandwidth
X	Flow Compensation	X	No Phase Wrap
	POMP	X	Extended Dynamic Range
	Square Pixel	X	Surface Coil Intensity Correction
	Respiratory Compensation		Classic
	Magnetization Transfer		Sequential
	Cardiac Gating/Triggering		Respiratory Gating/Triggering
X	Tailored RF		IR Prepared
	DE Prepared		Multi-Phase
X	Full Echo Train		CCOMP
X	ZIP 1024	X	ZIP 512
	Zip x 2		ZIP x 4
	SmartPrep		Blood Suppression
	Multi Station		Real Time

Applications

FLAIR sequences are most commonly used for T2 neuro applications where nullification of the CSF signal.

T1 Flair pulse sequences are designed to scan the same number of slices as the T1 weighted spin echo sequence in the same or shorter scan time and to achieve better tissue contrast-to-noise as well as signal-to-noise ratios.

CAUTION: **Provide all patients with ear protection prior to any scan to help avoid possible hearing impairment.** Acoustic noise levels can exceed 99 dBA in the magnet bore.

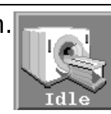
Setting up a FLAIR or T1 Flair pulse sequence

The decision matrix is only for prescribing a FLAIR or T1 Flair sequence. The purpose of the decision matrix to help you understand the trade-offs that occur when you change the values for a particular parameter and to provide a framework with which you may build you own unique protocol.

The selected values are only an example of what could be used for a FLAIR or T1 Flair sequence and are not to be considered recommendations by GE Medical Systems. For specific protocols, refer to the protocols on your system.

.

<table>
<tr><th>FLAIR or T1 Flair - What you select</th><th>Selection Notes</th></tr>
<tr><td colspan="2">SCAN DESKTOP screen</td></tr>
<tr><td></td><td>

Select **Scan Desktop** icon. 

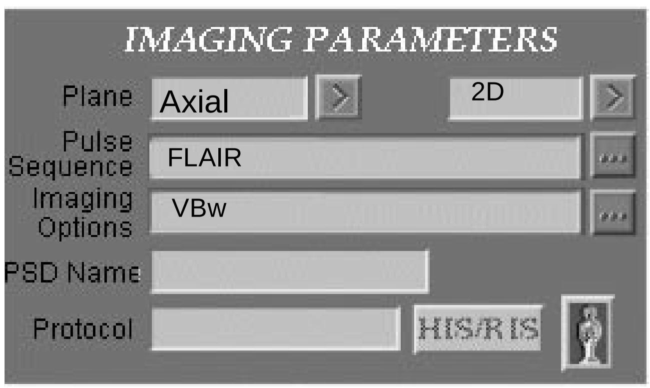
Click on **[New Patient]** and fill in the patient information.

NOTE: In order to prescribe a T1 Flair sequence you must choose a predefined protocol for the Picture This protocol list.

</td></tr>
<tr><td colspan="2">PATIENT POSITION area</td></tr>
</table>

FLAIR or T1 Flair - What you select		Selection Notes
Patient Position	**[Supine]**	**Position and Entry:** An FSE-IR pulse sequence is compatible with any patient position and entry.
Patient Entry	**[Head First]**	
Coil	**[Head]**	**Coil:** Select the coil that produces the optimum coverage and SNR.
Series Description		**Series Description:** Enter a suitable series description. If you don not enter a description, the system enters one for you. The series description default is the selected scan mode, PSD, and imaging options.

IMAGING PARAMETERS area



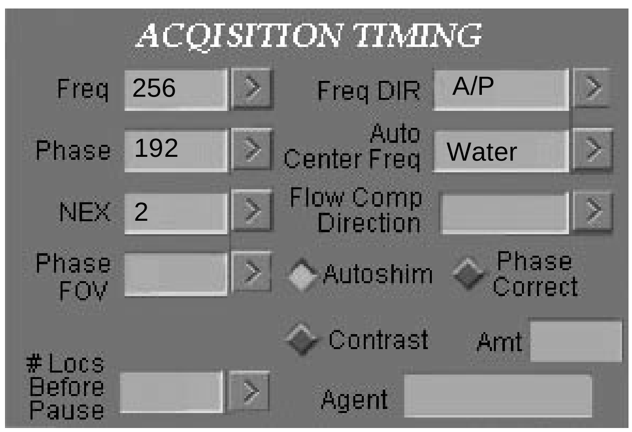
Plane	**[Axial]**	**Plane:** FLAIR is compatible with any scan plane (except 3 plane); select the plane that best meets the clinical need.
Mode	**[2D]**	**Mode:** Select [2D]. FLAIR is only compatible with 2D.
Pulse Seq	**[FLAIR]**	**Pulse Seq:** Select [FLAIR]. Click on the [Accept] button in the window to register the selection.
Imaging Options	**[VBw]**	**Imaging Options:** Select imaging options that optimizes SNR, spatial resolution, # of slices and reduce motion artifacts. Click on the [Accept] button to register the selections.[No Phase Wrap] is always on due to the PSD design. Therefore, if you have anatomy outside the FOV you don't need to turn on [No Phase Wrap].
PSD Name	**N/A**	**PSD Name:** Not applicable for FLAIR.
Protocol	**N/A**	

FLAIR USER CV Screen

FLAIR or T1 Flair - What you select		Selection Notes
Minimum Acquisitions	**[2]**	**Minimum Acquisitions:** Selection on the FLAIR User CV screen has a different meaning in comparison to other PSDs. Although the # of acquisitions still controls the scan time, by programming more acquisition, it changes the shape of the 180 inversion pulse in addition to increasing scan time. In FLAIR, the [Minimum Acquisitions] is also used as a factor to multiply the slice thickness of the Inversion Pulse. The thickness of the Inversion pulse = slice thickness x # of acquisitions. The thickness of the Excitation pulse = the value selected in the Scan Range area. A thicker Inversion pulse reduces motion artifact for CSF.
		SCAN TIMING area
# of echoes	**N/A**	**# of echoes:** Number of echoes is not a selectable parameter.
TE	**[220]**	**TE:** The effective TE changes are as the field strength changes. Increasing the TE and the scan time decreases because the ETL increases. 1.5T = 220msec; 1.0T = 220msec.
TE2	**N/A**	
TR	**[11000]**	**TR:** Keep the TR 3 to 4 times longer than the TI time of CSF, for optimum CSF suppression. Reducing the TI and TR together, allows reduced scan time and CSF nulling, but it also reduces the gray/white matter contrast. TR changes by field strength. 1.5T = 11000msec; 1.0T = 2000msec
TI	**[2200]**	**Inv. Time:** Inversion time is the time from the inversion pulse to the excitation pulse. It is critical that this be properly programmed for CSF suppression. The TI changes by field strength. 1.5T = 2200msec; 1.0T = 2000msec
Flip Angle	**N/A**	
Echo Train Length	**N/A**	**Echo Train Length:** FLAIR automatically selects and calculates the ETL. ETL = 2 x (TE ÷ ESP) ESP is the echo spacing and is automatically calculated. It is not the minimum TE value displayed next to the TE type-in field.
Bandwidth	**[16]**	**Bandwidth:** The Receiver Bandwidth changes as the field strength changes. As Receive Bandwidth increases, the minimum TE decreases, which means the ESP decreases (which is desirable—as ESP decreases, ETL increases, and scan time decreases). 1.5T = 32 kHz; 1.0T = 12.8 kHz
Bandwidth 2	**N/A**	
		SCANNING RANGE area

FLAIR or T1 Flair - What you select		Selection Notes
FOV	**[24]**	**FOV:** Select a FOV that covers the anatomy of interest. Anatomy outside the FOV in the phase direction results in aliasing. Small FOVs produce: increased resolution, decreased SNR, and can increase the minimum TE value.
Slice Thickness	**[5]**	**Slice Thickness:** Thin slices produce: increased resolution and decreased SNR.
Spacing	**[2.5]**	**Spacing:** Select a spacing that reduces cross-talk between slices (typically 20% of the slice thickness).
Start, End Locations		**Start, End Locations:** Typically the start and end locations are programmed from the Graphic Rx program.
# Slices	**[8]**	**# Slices:** The maximum number of slices available is determined by the TR, TE, TI, SAR, and gradient stress.

ACQUISITION TIMING area



Freq	**[256]**	**Freq:** Increasing the frequency matrix produces: increased echo space, increased resolution, decreased SNR, and decreased # of slices.
Phase	**[192]**	**Phase:** Phase controls scan time and may control resolution.
NEX	**[2]**	**NEX:** Select a NEX value that produces sufficient SNR.
Phase FOV	**N/A**	**Phase FOV:** [No Phase Wrap] which is always on, is not compatible with Phase FOV less than 1.
Freq DIR	**[A/P]**	**Freq DIR:** The direction displayed is the default frequency direction which is typically the long axis of the image. To swap phase and frequency, select the other direction.
Auto Center Freq	**[Water]**	**Auto Center Freq:** Select the CF peak that is set during prescan.
Flow Comp DIR	**[S/I]**	**Flow Comp DIR:** Flow Comp direction should match the direction of the flowing protons.

FLAIR or T1 Flair - What you select		Selection Notes
Autoshim	**[On]**	**Autoshim:** Select Autoshim when using fat SAT or an FOV off center, and in the first series of each exam.
Phase Correct	**[On]**	**Phase Correct:** By turning phase correct on this helps to improve image quality on a FLAIR.
# of Acqs/Locs Before Pause	**N/A**	
	Additional Parameters SAT Screen	
I	**[80]**	SAT pulses may decrease the # of slices/acquisition. Fat SAT is frequently used with T2 weighted scans acquired with long ETLs.
S	**[80]**	
Additional Parameters		To prescribe oblique slices you must select **[Oblique]** in the Plane pull-down menu.
	GRAPHIC RX Screen	
Click on the image to display the line cursor for Graphic Rx.		The SAT band function can be accessed from the GRAPHIC Rx window and vice versa. If you had graphically prescribed the previous axial series the same prescription can be copied using the **[Copy RX]** button. Consider using an offset to center the anatomy in the middle of the screen so that you can use a PFOV less than 1 and therefore reduce the scan time. View the Advisory panel to note the Max # of slices/Acq and the # of Acqs you are prescribing. The scan time increases as the # of Acquisitions increase.
	SCAN OPERATIONS area	
	[Save Series] [Prep to Scan] [Auto Prescan] [Scan]	Enter data in all the fields and click on **[Save Series]**. The series is saved as RXD.

Single Shot Fast Spin Echo (SSFSE) and Inversion Recovery (SSFSE-IR)

Single Shot Fast Spin Echo, (SSFSE) and Single Shot Fast Spin Echo-IR, (SSFSE-IR) are an ultrafast scanning techniques that acquires a data set within a single RF excitation period. Both PSDs are played out like their conventional counterparts; FSE and FSEIR with a few differences, all lines of K-space is filled within one TR period. Thus allowing for faster acquisition timing. Scan timing for each are figured as shown below:

FSE: TR x (phase matrix/ETL) x NEX

SSFSE and SSFSE-IR: (Acq rate + SAR delay) x # of slices

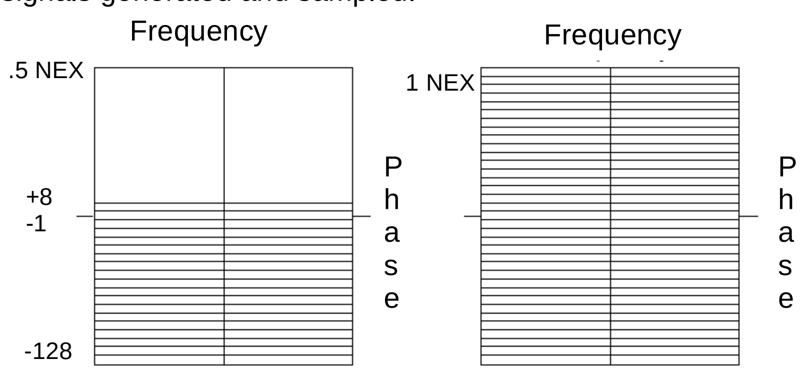
- The phase matrix, phase FOV, and the selected TE are used by the system to calculate the ETL.
- Single shot means that all phase encodings are acquired within one TR period, therefore TR is not a selectable parameter.
- The Acquisition Rate is the product of the ETL times the echo spacing.

Some other differences between the conventional FSE and the Single shots are:

FSE	SSFSE and SSFSE-IR
FSE allows selectable NEX values in the Acquisition Timing area.	SSFSE is a 0.5 NEX acquisition. NEX is not a selectable parameter.
FSE RF pulse design results in a longer ESP than SSFSE.	SSFSE uses a new RF pulse design that allows for significantly shorter echo spaces (ESP). The minimum TE no longer equates to the ESP. The shortened ESP allows acquisition of all phase encodings within a single RF excitation period with a minimum of edge blurring artifacts.
The number of slices allowed in an FSE acquisition may be limited by the SAR.	An SAR delay time is added to the acquisition time for each slice. For example, if the SAR delay time is 200ms and the acquisition time is 500ms, the total acquisition time (the only time you will see) is 700ms. Since the SAR delay may vary because of patient weight, the acquisition time may vary from one patient to the next even though the scan parameters are identical.

In SSFSE and SSFSE-IR, the minimum TE is determined by the echo spacing allowed for the scan prescription. A smaller echo spacing allowed for the scan prescription. A smaller echo spacing is allowed with large receive bandwidths: e.g. a +/-62.5 kHz RBw can produce a 4.5ms echo spacing. The trade-off for large receive bandwidths is lower SNR.

Partial Fourier phase encoding or Fractional NEX (0.5 NEX) is a technique in which only a fraction of the phase encodings is performed; the remaining encodings and the resulting data needed to complete K-space are computed for via a mathematical process. If more than half of the phase encodings gradient amplitudes are used (phase encoding step -128 to +8), as is the case with SSFSE, the data calculated to complete K-space are the complex conjugate (mirror image) of the actual signals generated and sampled.



The figure on the left is representative of the applied phase encoding steps and accompanying transversal of K-space when 0.5 NEX is used. The figure on the right is representative of 1 NEX.

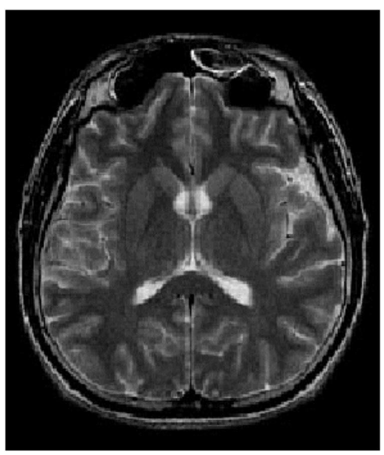
When minor phase variations in the compensated data are corrected, the image resolution remains constant, however, the SNR is decreased because there are fewer phase encodings to average together.

Fractional NEX or 0.5 NEX has been combined with SSFSE and SSFSE-IR to produce faster data acquisition — the fewer actual phase steps acquired, the faster the scan time. The acquisition method in SSFSE and SSFSE-IR contributes to edge blurring which can be lessened by decreasing your Phase FOV, increasing you matrix, or increasing your RBw. All of these parameters contribute to decreased SNR.

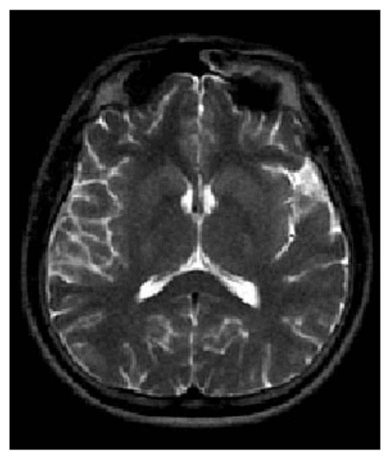
Single Shot FSE and Single Shot FSE-IR Image Characteristics

SSFSE creates T2 weighted images. TR controls the saturation or T1 effects in image contrast. The longer the TR, the less the T1 effects (note that for complete T1 relaxation from all structures, the TR would need to be approximately 20 seconds long). A standard FSE pulse sequence uses long TRs in the range 2000 ms - 6000 ms. Even though these repetitive TR periods are long, they still result in some saturation effects for tissues with very long TI relaxation rates.

SSFSE collects all phase encodings per slice after a single RF excitation pulse and therefore, in effect, has an infinite TR. The excitation pulse tips the unsaturated longitudinal magnetization to the transverse plane and acquires all the signal information. Since there is no wait period or TR for longitudinal regrowth to occur, there is no T1 effect in the image contrast. This means that an SSFSE image can be more heavily T2 weighted in comparison to an FSE image. AS the TE increase the image becomes more T2 weighted.

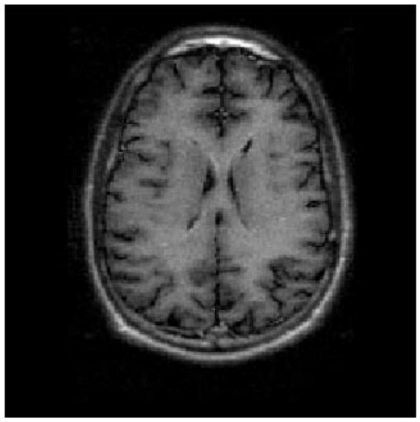


FSE T2 weighted



SSFSE T2 weighted

In a SSFSE-IR sequence, the TI value controls the contrast and produces either T1 weighted fat, or fluid suppressed images.



SSFSE-IR

Something to Think About...

- SSFSE and SSFSE-IR are a 2D acquisition mode only.
- Due to slice cross talk, SNR and contrast of a sequential acquisition is less than an interleaved acquisition. Select sequential to eliminate the image shift often observed in interleaved breath-hold abdominal scanning when those images are acquired for MIP post processing.
- To lessen the edge blurring that occurs with SSFSE or SSFSE-IR (except for maximum TE selection). increase the RBw and decrease the PFOV at the expense of reduced SNR.
- When selecting the maximum TE value, for very heavy T2 weighted images, consider using high phase and frequency matrix values, PFOV of 1, and the smallest allowed RBw value.
- For axial scans: if your goal is to reduce scan time and your patient does not fill the FOV in the phase direction, use a sagittal localizer to determine an offset for the FOV in the AP direction. Program the offset and then select a PFOV that reduces the FOV without resulting in phase wrap.
- When performing a SSFSE sequence, if the patient weight is 75 Kg (170 pounds) or higher, it is probable that Auto Prescan will fail and the following message will be posted: "Maximum power reached, check patient weight entered." If this occurs, select [Manual Prescan] and check the TG. Set the maximum value to 200. Exit Manual Prescan, then select [Scan].

- When performing an SSFSE or SSFSE-IR breath hold acquisition, the system divides the total number of prescribed slices into equal partitions based on the maximum number of slices which can be acquired within the selected time (the time resulting from entering a value for # of Locs Before Pause). The system divides the prescribed number of slice locations equally between the total number of breath holds needed to complete the prescribed number of slices.

Associated Imaging Options

In the following table the X's indicate the options available for use with the SSFSE and SSFSE-IR pulse sequences.

Imaging Options			
X	None	**X**	Variable Bandwidth
X	Flow Compensation		No Phase Wrap
	POMP	**X**	Extended Dynamic Range
	Square Pixel	**X**	Surface Coil Intensity Correction
	Respiratory Compensation		Classic
	Magnetization Transfer	**X**	Sequential
X	Cardiac Gating/Triggering	**X**	Respiratory Gating/Triggering
	Tailored RF		IR Prepared
	DE Prepared		Multi-Phase
	Full Echo Train		CCOMP
	ZIP 1024		ZIP 512
	Zip x 2		ZIP x 4
	SmartPrep		Blood Suppression
	Multi Station		Real Time

Applications

Single Shot sequences are most commonly used to reduce motion artifacts and imaging times. They are also helpful in imaging uncooperative patients in shorter scan times. With shorter scan times breath hold abdominal and cardiac imaging can be achieved. By using long TE scans images can be acquired of the gallbladder and billiary tree.

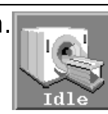
CAUTION: Provide all patients with ear protection prior to any scan to help avoid possible hearing impairment. Acoustic noise levels can exceed 99 dBA in the magnet bore.

Setting up a SSFSE or SSFSE-IR Pulse Sequence

The decision matrix is only for prescribing a SSFSE or SSFSE-IR sequence. The purpose of the decision matrix to help you understand the trade-offs that occur when you change the values for a particular parameter and to provide a framework with which you may build you own unique protocol.

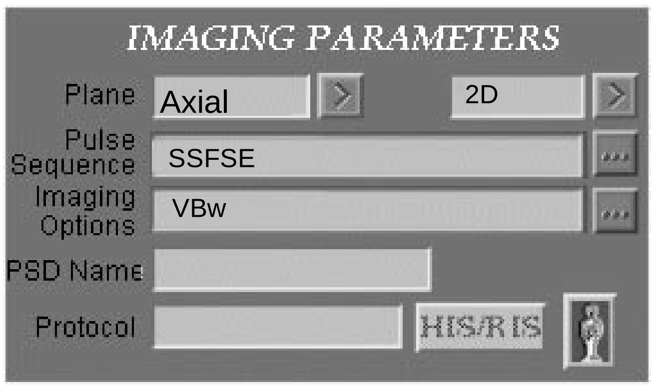
The selected values are only an example of what could be used for a SSFSE or SSFSE-IR sequence and are not to be considered recommendations by GE Medical Systems. For specific protocols, refer to the protocols on your system.

.

SSFSE or SSFSE-IR - What you select	Selection Notes
SCAN DESKTOP screen	
	Select **Scan Desktop** icon.  Click on **[New Patient]** and fill in the patient information. 
PATIENT POSITION area	
Patient Position **[Supine]**	**Position and Entry:** An SSFSE and SSFSE-IR are used in neuro and body scanning, so the patient position coil selections should reflect that. These values reflect a head scan.
Patient Entry **[Head First]**	

SSFSE or SSFSE-IR - What you select		Selection Notes
Coil	**[Head]**	**Coil:** Select the coil that produces the optimum coverage and SNR.
Series Description		**Series Description:** Enter a suitable series description. If you don not enter a description, the system enters one for you. The series description default is the selected scan mode, PSD, and imaging options.

IMAGING PARAMETERS area

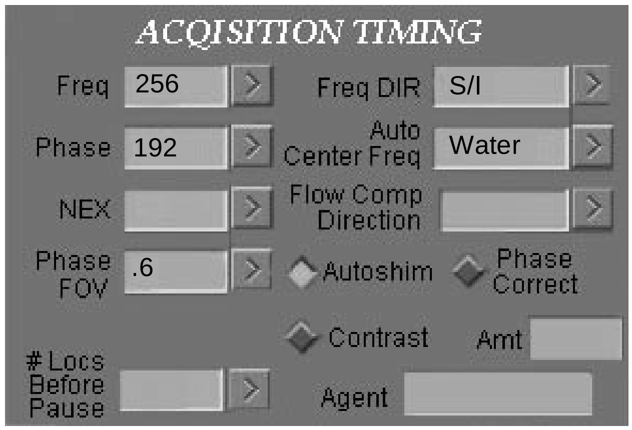


Plane	**[Axial]**	**Plane:** SSFSE and SSFSE-IR are compatible with any scan plane (except 3 plane); select the plane that best meets the clinical need.
Mode	**[2D]**	**Mode:** Select [2D]. SSFSE and SSFSE-IR only compatible with 2D.
Pulse Seq	**[SSFSE] or [SSFSE-IR]**	**Pulse Seq:** SSFSE is typically used for T2 weighted images and SSFSE-IR is used for either T1, short TI IR, or FLAIR weighted images.
Imaging Options	**[VBw]**	**Imaging Options:** Select imaging options that optimizes SNR, spatial resolution, # of slices and reduce motion artifacts. Click on the [Accept] button to register the selections. **Slice Acquisition Order:** Interleaved acquires first the odd slices and then the even slices. Sequential acquires the slices in numerical order. Neither affects scan time. By not selecting sequential, and interleaved technique is used. ° Select [Sequential] to eliminate the image shift often observed in interleaved breath hold abdominal scanning, when those images are acquired for MIP post processing. ° Sequential can result in a decrease in SNR and contrast in comparison to an interleaved acquisition.
PSD Name	**N/A**	**PSD Name:** Not applicable for SSFSE or SSFSE-IR.

SSFSE or SSFSE-IR - What you select		Selection Notes
Protocol	**N/A**	
	SCAN TIMING area	
# of echoes	**N/A**	**# of echoes, ETL, TR:** Number of echoes, ETL, and TR are not a selectable parameters. They are automatically calculated by the system.
TE	**[Maximum]**	**TE:** Select one of the TE options. ° Typically the long TE [Maximum] is used when doing MIP post processing exams, the medium TE (90) for T2 weighted exams, and the short (60) or [Minimum] TE for SSFSE-IR acquisitions. ° To get a long TE, select [Maximum], 512 frequency, 256 phase, PFOV = 1, and a low RBw.
TE2	**N/A**	
TR	**N/A**	**TR:** System automatically selects.
TI	**[2500] or [600] or [150]**	**Inv. Time:** Select a TI value only if SSFSE-IR was selected. Typically at 1.5T, use a TI of 2500 for FLAIR, 600 for T1 weighted, and 150 for Short TR IR. For a 1.0T system, use a TI of 2000 for FLAIR, 500 for T1 weighted, and 140 for a Short TI IR.
Flip Angle	**N/A**	
Echo Train Length	**N/A**	
Bandwidth	**[32]**	**Bandwidth:** There are only two choices for RBw: 31.3 kHz and 62 kHz. An additional choice of 20.8 kHz RBw is available for 1.0T. As Receive Bandwidth increases, the ESP decreases (which is desirable) and SNR decreases. Compensate for the loss in SNR that occurs with these wide RBws by increasing the slice thickness or FOV.
Bandwidth 2	**N/A**	
	SCANNING RANGE area	
FOV	**[28]**	**FOV:** Select a FOV that covers the anatomy of interest. Anatomy outside the FOV in the phase direction results in aliasing. Small FOVs produce: increased resolution, decreased SNR, and can increase the minimum TE value.
Slice Thickness	**[5]**	**Slice Thickness:** Thin slices produce: increased resolution and decreased SNR.
Spacing	**[2.5]**	**Spacing:** Select a spacing that reduces cross-talk between slices (typically 20% of the slice thickness).
Start, End Locations		**Start, End Locations:** Typically the start and end locations are programmed from the Graphic Rx program.

SSFSE or SSFSE-IR - What you select		Selection Notes
# Slices	**[10]**	**# Slices:** The (# of slices) x (Acq rate + SAR) determines the total scan time. Select the number of slices based on the anatomical coverage needed.

ACQUISITION TIMING area



Freq	**[256]**	**Freq:** Increasing the frequency matrix produces: increased echo space, increased resolution, decreased SNR, and decreased # of slices.
Phase	**[192]**	**Phase:** Phase controls scan time and may control resolution.
NEX	**N/A**	**NEX:** NEX is not selectable because all SSFSE scans are 0.5 NEX.
Phase FOV	**[.6]**	**Phase FOV:** A PFOV less than 1 (range from 0.5-1) can be selected if it does not result in anatomy outside the PFOV. The selected value is rounded to the nearest 1/16 FOV ° Increasing the PFOV results in increasing edge blurring and scan time, produces a minimal increase in SNR, and results in no change in spatial resolution.
Freq DIR	**[S/I]**	**Freq DIR:** Typically select the default frequency direction.
Auto Center Freq	**[Water]**	**Auto Center Freq:** Select the CF peak that is set during prescan.
Flow Comp DIR	**[Slice]**	**Flow Comp DIR:** Flow Comp direction can only be selected when Flow Comp is active. The default direction is based on the selected scan plane except with oblique, which has no default.
Autoshim	**[On]**	**Autoshim:** Select Autoshim when using fat SAT or an FOV off center, and in the first series of each exam.
Phase Correct	**[On]**	**Phase Correct:** Selecting [Phase Correct] improves image quality on an FSE pulse sequence.

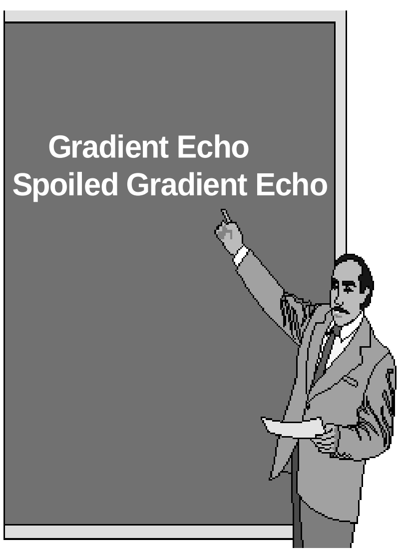
SSFSE or SSFSE-IR - What you select		Selection Notes
# of Acqs/Locs Before Pause	**[None]**	**# Acqs/Locs Before Pause:** This is typically selected for abdominal breath hold exams. If none is selected the images are acquired within one "block". If another value is selected, then the scan range is divided into multiple "blocks" where one block of images shall be scanned before the next block of scans in sequential order.
Additional Parameters SAT Screen		
I	**[80]**	SAT pulses may decrease the # of slices/acquisition. Fat SAT is frequently used with T2 weighted scans acquired with long ETLs.
S	**[80]**	
Additional Parameters		To prescribe oblique slices you must select **[Oblique]** in the Plane pull-down menu.
GRAPHIC RX Screen		
Click on the image to display the line cursor for Graphic Rx.		The SAT band function can be accessed from the GRAPHIC Rx window and vice versa. If you had graphically prescribed the previous axial series the same prescription can be copied using the **[Copy RX]** button. Consider using an offset to center the anatomy in the middle of the screen so that you can use a PFOV less than 1 and therefore reduce the scan time. View the Advisory panel to note the Max # of slices/Acq and the # of Acqs you are prescribing. The scan time increases as the # of Acquisitions increase.
SCAN OPERATIONS area		
	[Save Series] [Prep to Scan] [Auto Prescan] [Scan]	Enter data in all the fields and click on **[Save Series]**. The series is saved as RXD.

Volume 2

Chapter 4

Imaging with Gradient Echo Pulse Sequences

Where Am I?



Introduction

This chapter explains the pulsing components and timing factors directly related to the Gradient Echo (GRE) and Spoiled Gradient Echo (SPGR) pulse sequences. This chapter explains the concepts of each, and the step-by-step instructions to help you learn how to:

- Optimize Gradient Echo images
- Optimize Spoiled Gradient Echo images
- Set up a Gradient Echo pulse sequence
- Set up a Spoiled Gradient Echo pulse sequence

In addition, this chapter answers the following questions:

1. What are the pulsing components and timing factors for GRE, and SPGR sequences?
2. What is the correct TR, flip angle and the regulation of saturation effects?
3. What is the correct TE and the regulation of dephasing effects?
4. What are the imaging characteristics of a GRE and SPGR pulse sequences?
5. Which imaging options can be used with GRE and SPGR pulse sequences?
6. What are some applications for GRE and SPGR pulse sequences?

About... Gradient Echo Pulse Sequences

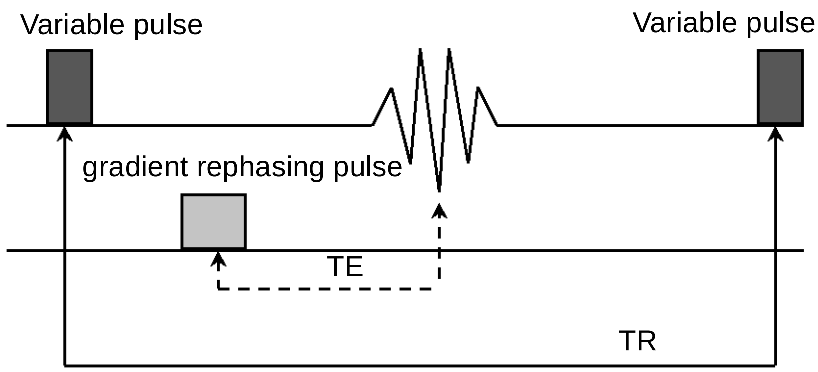
This section presents the concepts necessary to understand GRE and SPGR pulse sequences. Specifically you need to understand:

- Gradient Echo (GRE)
  - GRE image characteristics
  - 2D, 3D and 2D Multi-planar acquisitions
  - Associated imaging options
  - Applications for GRE
- Spoiled Gradient Echo (SPGR)
  - SPGR image characteristics
  - 2D and 3D acquisitions
  - Associated imaging options
  - Applications for SPGR

Gradient Echo (GRE)

Gradient Echo is a pulse sequence which reverses gradient polarity to rephase protons and form echoes. This is unlike the with conventional SE imaging where an RF is used to refocus the protons and generate and echo. Another difference when comparing conventional SE sequences to Gradient sequences, instead of using a 90° excitation pulse, a variable excitation pulse is used. This variable excitation pulse creates magnetization in the transverse plane; and is followed by a gradient pulse which rephrases the magnetization to produce gradient echo signals.

TE is now measured from the gradient rephasing pulse to echo. TR is now measured from the variable excitation pulse to the variable excitation pulse. A diagram of how GRE is played out is as follows:



Gradient Echo Diagram

Gradient Echo sequences are generally used to create images with T2* contrast. Scan times are figured by:

TR x NEX x # Phase Steps x # Slice Locations

In 3D imaging, a wide RF pulse is delivered to excite an entire scan volume or slab. Spatial encoding must then be done in the phase, frequency, and slice axes. Phase and frequency encoding occur just as they do in 2D pulse sequences. A third slice-select gradient is applied to create areas with slightly different phase relative to a point a gradient isocenter.

3D offers increased SNR and contiguous, thin slices without interference from crosstalk.

Isotropic voxels are important if the data set is to be used for reformatting into additional planes. To determine voxel size, first calculate pixel size:

FOV/matrix = pixel size

FOV = 24 cm, matrix = 256 x 256

(240 mm/256) x (240 mm/256) = 0.9 mm x 0.9 mm pixels

However, the pixel is 2 dimensions, a voxel is three dimensional. The slice thickness determines the third dimension of the voxel.

Gradient Echo Image Characteristics

Gradient Echo sequences can produce T1, T2 and PD weighted images in shorter scan times than SE and FSE. Unfortunately they are more sensitive to magnetic field inhomogeneties and paramagnetics than SE and FSE because of gradient rephasing. Gradient rephasing does not eliminate the effects of T2* dephasing. Air/tissue interfaces and bone/tissue interfaces, where the tissues are magnetized to different degrees, experience magnetic susceptibility artifacts.

In gradient echo sequences the TR and flip angle control the level of saturation and TE controls the level of dephasing and T2 contribution. There are several GRE sequences that can be acquired, they are: 2D GRE sequential, 2D GRE non-sequential (MPGR) and 3D GRE. For proper contrast weighting use the chart below to select your desired imaging parameters.

Weighting					
Seq		T1	T2/T2*	PD	T1/T2 Mixed
	TR	200 or less	200 or less	200 or less	20-50
	TE	min - 15	30-60	min - 15	min -15
	Flip	45-90	5-15	5-30	30-60
Non-Seq	TR	200-600	200-600	200-600	
	TE	min - 15	30-60	min - 15	
	Flip	45-90	5-15	5-30	

2D Non-sequential Gradient Echo is also called MPGR, Multi-Plane Gradient Recalled. It uses a Multi-Planar data acquisition mode with longer TR time (400 to 1000 ms) and small to moderate flip angles (10 to 35 degrees). The long TR times allow for multiple slice acquisitions and also through time, spoils the build up of residual transverse magnetization. Combine the above TR and flip angles with a short TE and the result are PD weighted images. Lengthen the TE and the result are T2 weighted images.

These images demonstrate the different types of contrast available with the MPGR pulse sequence. (A) shows the proton-density effect associated with low flip angle MPGR. Note the myelographic effect between the CSF and the spinal cord. Also note the T2 effect on the vertebral bodies. In image (B), the T1 weighting that can be obtained with large flip angle MPGR is shown. Again, note the darkening of the vertebral bodies (T2* effect). (C) shows the T2 effect associated with long TE MPGR. These images show improved T2* contrast between the CSF and spinal cord, as well as severe darkening of the vertebral bodies due to these effects.*

Something to Think About...

- As a general rule SNR within a GRE pulse sequence increases as:
  - TR increases;
  - Flip angle increases; and
  - TE decreases.

NOTE: TR and TE changes have a greater affect on SNR as compared to similar changes in Spin Echo sequences.

- Fractional Echo (TE) decreases SNR because only part of the echo is sampled. However, this is offset by an increase in SNR resulting from decreased T2 decay and the likelihood of decreased motion and susceptibility artifacts.
- Cross-talk affects SNR when the slice spacing is not large enough to eliminate RF excitation effects on adjacent slices. Sequential GRE acquisitions eliminate

cross-talk because all the data for one slice location is obtained before moving on to the next location.

- Possible signal voids occur at air/tissue interfaces, for example, bowel or sinuses (due to magnetic susceptibility), which increase as TE increases.
- Gradient echoes are more sensitive to any process which causes T2* dephasing, such as static field inhomogeneties, intravoxel dephasing cancellation due to chemical shift, and magnetic susceptibility artifacts.
- Depending on the TEs used, dark outlines separate fat from other tissues. Choose TE times carefully to place fat and water in or out of phase. The chart below displays the ms value when fat/water are in and out of phase. The cycle continues after the third illustrated out of phase column.

	Out of Phase	In Phase	Out of Phase...
1.0T	3.4	6.8	10.2
1.5T	2.1	4.2	6.3

- Gradient Echo Sequential is susceptible to zebra artifacts if the FOV is smaller than the anatomy and [No Phase Wrap] is off.
- Due to blood's brightness, caused by fresh flow of spins, flow motion artifacts may occur in 2D Sequential even if Flow Comp is used. These artifacts appear as bright circular areas across the image in the phase direction.

Associated Imaging Options

In the following table the X's indicate the option available for use with the Gradient Echo pulse sequence.

Imaging Options			
X	None	X	Variable Bandwidth
X	Flow Compensation	X	No Phase Wrap
	POMP	X	Extended Dynamic Range
X	Square Pixel	X	Surface Coil Intensity Correction
X	Respiratory Compensation		Classic
	Magnetization Transfer	X	Sequential

Imaging Options			
X	Cardiac Gating/Triggering		Respiratory Gating/Triggering
	Tailored RF		IR Prepared
	DE Prepared		Multi-Phase
	Full Echo Train	X	CCOMP
	ZIP 1024		ZIP 512
	Zip x 2		ZIP x 4
	SmartPrep		Blood Suppression
	Multi Station		Real Time

Applications

Gradient Echo sequences are used to acquire quick localizers. It is used for T1, T2 and PD contrast weighting. When wanting a pulse sequence with increased sensitivity to paramagnetics such as iron deposits that occur with stroke, this sequence is often used. Also 3D GRE is used throughout the body, in areas that are do not have a lot of motion, for thin contiguous imaging, with increased SNR.

When to use a particular pulse sequence varies with specific patient needs and constraints. The following table shows the most common applications for GRE sequences. **These are not to be considered recommendations by GE Medical Systems.**

2D Sequential GRE	2D Non-sequential GRE (MPGR)	3D GRE
PD or T2* breath-holds of chest, abdomen and pelvis	PD or T2* joints, cartilage and meniscus; extremities; spine	PD or T2 thin slice, high resolution spine images
PD or T2* musculo-skeletal images	Use to replace longer PD and T2 Spine Echo sequences	Thin slice, high resolution T2* joint/musculo-skeletal imaging
Quick localizers	Abdomen and chest imaging to obtain PD or T2* weighting with use of respiratory compensation and gating	Reformat into additional planes to eliminate the need for additional acquisitions
Imaging of cardiac phases when used with CINE mode		

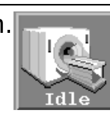
CAUTION: **Provide all patients with ear protection prior to any scan to help avoid possible hearing impairment.** Acoustic noise levels can exceed 99 dBA in the magnet bore.

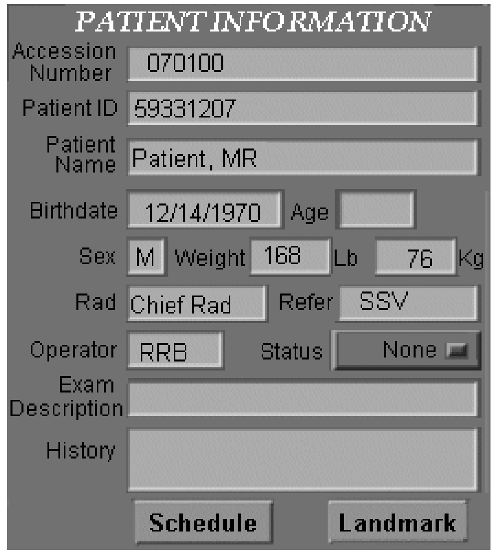
Setting up a Gradient Echo pulse sequence

The decision matrix is only for prescribing a 2D Sequential or 3D Gradient Echo scan. The purpose of the decision matrix to help you understand the trade-offs that occur when you change the values for a particular parameter and to provide a framework with which you may build you own unique protocol.

The selected values are only an example of what could be used for a T2* acquisition and are not to be considered recommendations by GE Medical Systems. For specific protocols, refer to the protocols on your system.

.

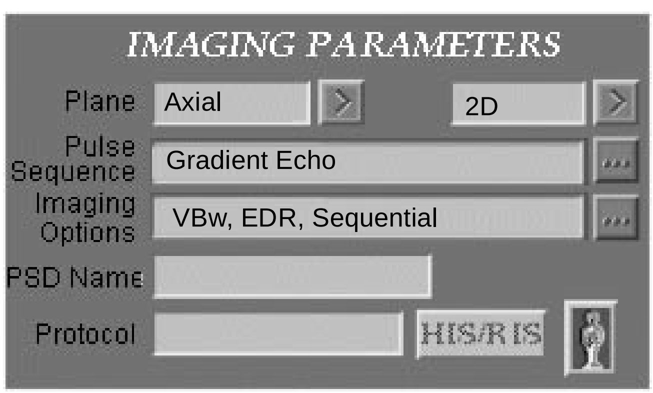
2D Seq/3D - What you select	Selection Notes
SCAN DESKTOP screen	
	Select **Scan Desktop** icon. 

2D Seq/3D - What you select		Selection Notes
		Click on **[New Patient]** and fill in the patient information. 

PATIENT POSITION area

Patient Position	**[Supine]**	**Position and Entry:** An Gradient Echo pulse sequence is compatible with any patient position and entry.
Patient Entry	**[Feet First]**	
Coil	**[Extremity]**	**Coil:** Select the coil that produces the optimum coverage and SNR.
Series Description		**Series Description:** Enter a suitable series description. If you don not enter a description, the system enters one for you. The series description default is the selected scan mode, PSD, and imaging options.

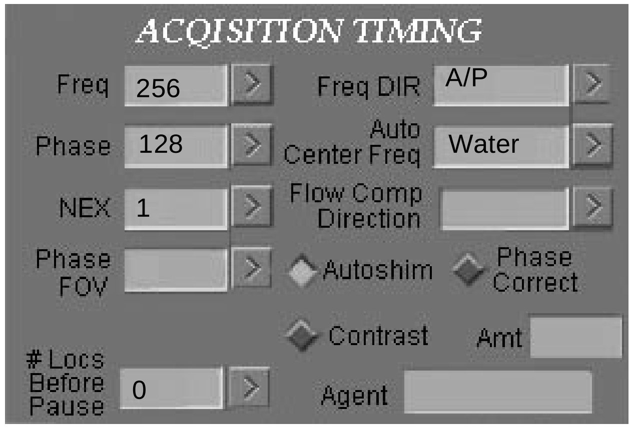
IMAGING PARAMETERS area



2D Seq/3D - What you select		Selection Notes
Plane	**[Axial]**	**Plane:** 2D Sequential GRE is compatible with any scan plane except 3 plane; select the plane that best meets the clinical need. 3D does not allow oblique, nor 3 plane.
Mode	**[2D]**	**Mode:** Select [2D] for a sequential gradient echo or [3D] for thin contiguous images.
Pulse Seq	**[Gradient Echo]**	**Pulse Seq:** Select [Gradient Echo]. Click on the [Accept] button in the window to register the selection.
Imaging Options	**[VBw, EDR, Sequential]**	**Imaging Options:** Select [Sequential] to acquire one slice at a time. Do not select [Sequential] for 3D. Select imaging options that optimizes SNR, Spatial resolution, and reduce motion artifacts. Click on the [Accept] button to register the selections.
PSD Name	**N/A**	**PSD Name:** Not applicable for 2D Sequential GRE.
Protocol	**N/A**	
SCAN TIMING area		
# of echoes	**[1]**	**# of echoes:** Only 1 echo is allowed for 2D Sequential and 3D GRE.
TE	**[Min Full]**	**TE:** Increase the TE to produce increased T2* contrast, decreased SNR, signal changes at fat/water interfaces, and increased magnetic susceptibility effects. TE values typically do not exceed 30 ms. Minimum is a fractional echo and may compromise SNR.
TR	**[200]**	**TR:** Long TRs produce: increased SNR, and increased scan time. 2D Sequential values vary based on the clinical application. Typical 3D values are 40-60 ms.
TI	**N/A**	
Flip Angle	**[30]**	**Flip Angle:** Typical 2D Flip Angle values: 20° to 30°. Typical 3D flip angles range from 5° to 8°. If you decrease the Flip Angle you increase T2* weighting and decrease SNR.
Echo Train Length	**N/A**	
Bandwidth	**[7.81]**	**Bandwidth:** RBw can only be changed if it was selected from the Imaging Options window. As the RBw decreases, the following occurs: increased SNR, increased chemical shift artifact, increased minimum TE which can potentially decreases # of slices and increased motion artifact.
Bandwidth 2	**N/A**	**Bandwidth2:** RBw2 is only selectable with a 2 echo Spin Echo acquisition. The value for RBw2 is for the second echo and typically lower than RBw1.
SCANNING RANGE area (for 2D Sequential acquisition)		

2D Seq/3D - What you select		Selection Notes
FOV	**[22]**	**FOV:** Select a FOV that covers the anatomy of interest. Anatomy outside the FOV in the phase direction results in aliasing. Small FOVs produce: increased resolution, decreased SNR, and can increase the minimum TE value.
Slice Thickness	**[5]**	**Slice Thickness:** Thin slices produce: increased resolution and decreased SNR.
Spacing	**[2.0]**	**Spacing:** Interslice cross-talk is eliminated on sequential gradient echoes. Typical spacing is 0-20% of the slice thickness.
Start, End Locations		**Start, End Locations:** Typically the start and end locations are programmed from the Graphic Rx program.
# Slices	**[9]**	**# Slices:** 2D GRE Sequential scans one slice per acquisition. The number of slices actually indicates the number of locations prescribed and the number of acquisitions.
SCANNING RANGE area (for 3D acquisition)		
FOV	**[16]**	**FOV:** Select a FOV that covers the anatomy of interest. Anatomy outside the FOV in the phase direction results in aliasing. Small FOVs produce: increased resolution, decreased SNR, and can increase the minimum TE value.
Slice Thickness	**[2]**	**Slice Thickness:** Thin slices produce: increased resolution and decreased SNR.
# of Scan Locs	**[60]**	**# of Scan Locs:** Choose the number of locations, 16 to 128, desired within each 3D Slab. Increasing Locs per slab in the volume increases SNR, scan time and range of coverage. No interscan spacing is required with 3D.
Start, End Locations		**Start, End Locations:** Start and end locations are programmed from the Graphic Rx program when the 3D box is deposited. 3D explicit Rx can be done in either L-I-P or R-S-A direction. 3D graphic Rx can only be done in L-I-P direction for orthogonal planes (note that oblique scan planes are not allowed with 3D GRE).
# Slabs	**[1]**	**# Slabs:** Determined by the # of Scan Locs and the desired range of anatomy to be covered.

2D Seq/3D - What you select		Selection Notes
ACQUISITION TIMING area		

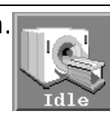


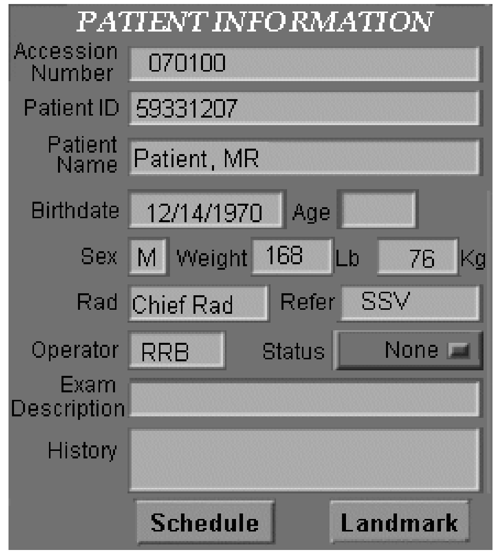
Freq	**[256]**	**Freq:** Increasing the frequency matrix produces: increased resolution, decreased SNR, and decreased # of slices.
Phase	**[128]**	**Phase:** Phase controls scan time and may control resolution.
NEX	**[1]**	**NEX:** Select a NEX value that produces sufficient SNR. low NEX are needed for breath-hold 2D acquisitions.
Phase FOV	**[1]**	**Phase FOV:** Select .75 or .5 to reduce phase steps and thus decrease scan time, decreasing FOV in the phase direction, and decreasing SNR slightly. The phase FOV dimension is displayed next to the phase FOV factor.
Freq DIR	**[A/P]**	**Freq DIR:** The direction displayed is the default frequency direction which is typically the long axis of the image. To swap phase and frequency, select the other direction.
Auto Center Freq	**[Water]**	**Auto Center Freq:** Select the CF peak that is set during prescan.
Flow Comp DIR	**N/A**	
Autoshim	**[On]**	**Autoshim:** Select Autoshim when using fat SAT or an FOV off center, and on the first series of each exam.
Phase Correct	**N/A**	
# of Acqs/Locs Before Pause	**[None]**	**# of Acqs/Locs Before Pause:** Prescribe an automatic pause in the scan for multiple location 2D sequential. Pause scanning at predetermined points for breath-hold, joint motion, or contrast perfusion studies.

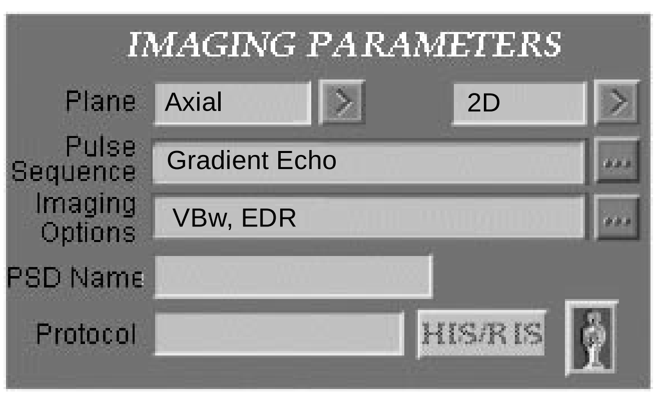
Additional Parameters
SAT Screen

I	**[80]**	SAT pulses may increase the minimum TR and TE.
S	**[80]**	

2D Seq/3D - What you select	Selection Notes
Additional Parameters	To prescribe oblique slices you must select **[Oblique]** in the Plane pull-down menu.
GRAPHIC RX Screen	
Click on the image to display the line cursor for Graphic Rx.	The SAT band function can be accessed from the GRAPHIC Rx window and vice versa. If you had graphically prescribed the previous axial series the same prescription can be copied using the **[Copy RX]** button. Consider using an offset to center the anatomy in the middle of the screen so that you can use a PFOV less than 1 and therefore reduce the scan time. In 2D Sequential, view the Advisory panel to note the # of Acqs you are prescribing. The scan time increases as the # of Acquisitions increase. 3D explicit Rx can be done in either L-I-P or R-S-A direction. 3D graphic Rx can only be done in L-I-P direction for orthogonal planes (note that oblique scan planes are not allowed with 3D GRE).
SCAN OPERATIONS area	
[Save Series] **[Prep to Scan]** **[Auto Prescan]** **[Scan]**	Enter data in all the fields and click on **[Save Series]**. The series is saved as RXD.

2D Non-Sequential - What you select	Selection Notes
SCAN DESKTOP screen	
	Select **Scan Desktop** icon. 

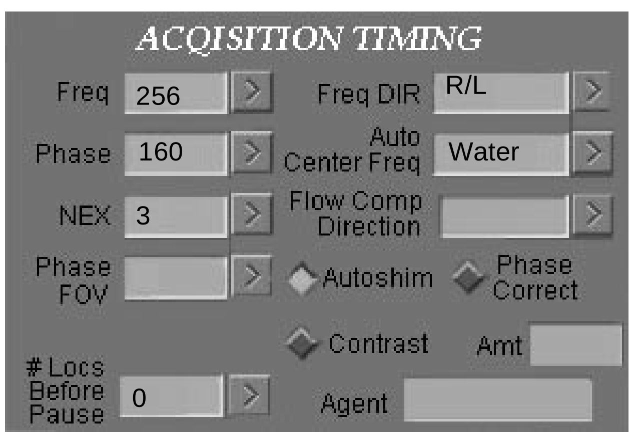
2D Non-Sequential - What you select		Selection Notes
		Click on **[New Patient]** and fill in the patient information. 
PATIENT POSITION area		
Patient Position	**[Supine]**	**Position and Entry:** An Gradient Echo pulse sequence is compatible with any patient position and entry.
Patient Entry	**[Head First]**	
Coil	**[Shoulder]**	**Coil:** Select the coil that produces the optimum coverage and SNR.
Series Description		**Series Description:** Enter a suitable series description. If you don not enter a description, the system enters one for you. The series description default is the selected scan mode, PSD, and imaging options.
IMAGING PARAMETERS area		



2D Non-Sequential - What you select		Selection Notes
Plane	**[Axial]**	**Plane:** 2D Sequential GRE is compatible with any scan plane except 3 plane; select the plane that best meets the clinical need. 3D does not allow oblique, nor 3 plane.
Mode	**[2D]**	**Mode:** Select [2D].
Pulse Seq	**[Gradient Echo]**	**Pulse Seq:** Select [Gradient Echo]. Click on the [Accept] button in the window to register the selection.
Imaging Options	**[VBw, EDR]**	**Imaging Options:** Select imaging options that optimizes SNR, Spatial resolution, and reduce motion artifacts. Do not select Sequential. Non-sequential can be used with gating and respiratory comp. Click on the [Accept] button to register the selections.
PSD Name	**N/A**	**PSD Name:** Not applicable for 2D Non-Sequential GRE.
Protocol	**N/A**	
SCAN TIMING area		
# of echoes	**[1]**	**# of echoes:** Select [1] for a single echo or [2] for a multiple echo. The early echo is PD weighted and the second, later echo is T2* weighted.
TE	**[25]**	**TE:** Short TEs produce: increased T1 and PD contrast, increased SNR, and increased # of slices. Minimum TE changes as RBw changes. Increase the TE to produce increased T2* contrast, decreased SNR, signal changes at fat/water interfaces, and increased magnetic susceptibility effects. TE values typically do not exceed 30 ms. Minimum is a fractional echo and may compromise SNR.
TE2	**N/A**	**TE2:** Long TEs produce: decreased # of slices, increased T2 contrast, and decreased SNR.
TR	**[600]**	**TR:** Short TRs produce: decreased SNR, and decreased # of slices, increased T1 contrast, and decreased scan time. Longer TRs (400 to 700 ms) produce: increased signal from fluids, increased SNR, increased scan time, and increased # of slices. TR is not selectable with gated scans. The TR is determined by the RR intervals on the Gating Additional Parameters screen.
TI	**N/A**	
Flip Angle	**[30]**	**Flip Angle:** Given a constant TR, if you increase Flip Angle, you increase T1 weighting. Typical T2* and PD Flip Angle values: 20° to 30°. TI values range from 60° to 100°.If you decrease the Flip Angle you increase T2* weighting and decrease SNR.
Echo Train Length	**N/A**	

2D Non-Sequential - What you select		Selection Notes
Bandwidth	**[9.21]**	**Bandwidth:** RBw can only be changed if it was selected from the Imaging Options window. As the RBw decreases, the following occurs: increased SNR, increased chemical shift artifact, increased minimum TE which can potentially decreases # of slices and increased motion artifact.
Bandwidth 2	**N/A**	**Bandwidth2:** RBw2 is only selectable with a 2 echo acquisition. The value for RBw2 is for the second echo and typically lower than RBw1.
	SCANNING RANGE area	
FOV	**[16]**	**FOV:** Select a FOV that covers the anatomy of interest. Anatomy outside the FOV in the phase direction results in aliasing. Small FOVs produce: increased resolution, decreased SNR, and can increase the minimum TE value.
Slice Thickness	**4]**	**Slice Thickness:** Thin slices produce: increased resolution and decreased SNR.
Spacing	**[1.0]**	**Spacing:** Select a spacing that reduces interslice cross-talk (typically 20% of the slice thickness). If your scan is a dual acquisition with no concantenated SAT pulse, 0 spacing is allowed.
Start, End Locations		**Start, End Locations:** Typically the start and end locations are programmed from the Graphic Rx program.
# Slices	**[14]**	**# Slices:** The maximum number of slices available is determined by the TR, TE, flip angle, SAR, and gradient stress.

ACQUISITION TIMING area



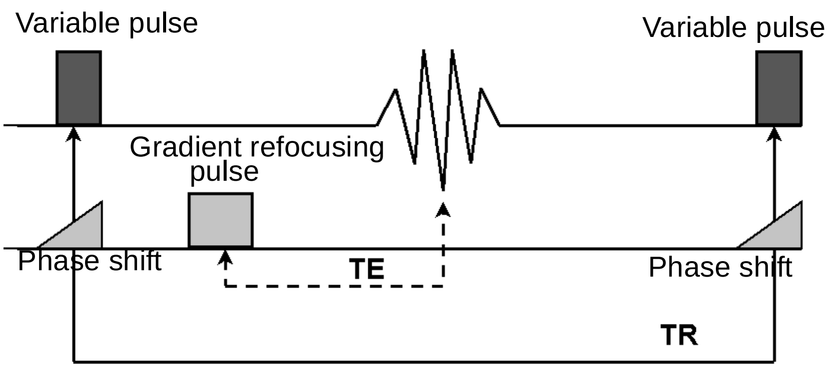
Freq	**[256]**	**Freq:** Increasing the frequency matrix produces: increased resolution, decreased SNR, and decreased # of slices.
Phase	**[160]**	**Phase:** Phase controls scan time and may control resolution.

2D Non-Sequential - What you select		Selection Notes
NEX	**[3]**	**NEX:** Select a NEX value that produces sufficient SNR.
Phase FOV	**[1]**	**Phase FOV:** Select .75 or .5 to reduce phase steps and thus decrease scan time, decreasing FOV in the phase direction, and decreasing SNR slightly. The phase FOV dimension is displayed next to the phase FOV factor.
Freq DIR	**[A/P]**	**Freq DIR:** The direction displayed is the default frequency direction which is typically the long axis of the image. To swap phase and frequency, select the other direction.
Auto Center Freq	**[Water]**	**Auto Center Freq:** Select the CF peak that is set during prescan.
Flow Comp DIR	**N/A**	
Autoshim	**[On]**	**Autoshim:** Select Autoshim when using fat SAT or an FOV off center, and on the first series of each exam.
Phase Correct	**N/A**	
# of Acqs/Locs Before Pause	**N/A**	
Additional Parameters SAT Screen		
I	**[80]**	SAT pulses may increase the minimum TR and TE.
S	**[80]**	
Additional Parameters		To prescribe oblique slices you must select **[Oblique]** in the Plane pull-down menu.
GRAPHIC RX Screen		
Click on the image to display the line cursor for Graphic Rx.		The SAT band function can be accessed from the GRAPHIC Rx window and vice versa. If you had graphically prescribed the previous axial series the same prescription can be copied using the **[Copy RX]** button. Consider using an offset to center the anatomy in the middle of the screen so that you can use a PFOV less than 1 and therefore reduce the scan time. In 2D Sequential, view the Advisory panel to note the # of Acqs you are prescribing. The scan time increases as the # of Acquisitions increase.
SCAN OPERATIONS area		

2D Non-Sequential - What you select	Selection Notes
[Save Series] **[Prep to Scan]** **[Auto Prescan]** **[Scan]**	Enter data in all the fields and click on **[Save Series]**. The series is saved as RXD.

Spoiled Gradient Echo (SPGR)

Spoiled Gradient Echo is a pulse sequence which employs an initial RF spoiler gradient to destroy any residual transverse magnetization before each RF excitation. With SPGR, T2 dependence is almost completely eliminated (although the T2* dependence introduced between excitation and echo readout is still present). SPGR's spoiling is accomplished by adding a phase shift to each successive RF excitation pulse. This results in shifting the residual transverse components out of phase with each other to prevent build-up of a steady state component, thus reducing T2* contribution. The result is excellent uniformity of contrast and less gradient stress as compared to GRE. There are two sequences included in the SPGR family, both produce T1 contrasted images, they are 2D SPGR sequential and 3D SPGR. A diagram of the sequence is as follows:



SPGR diagram

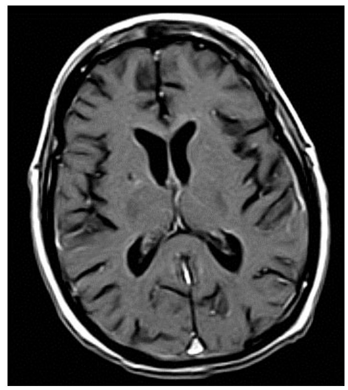
With 2D SPGR pulse sequences slice data is acquired sequentially, one location at a time. Scan time represents the time it takes to gather the data for one location. If multiple locations are prescribed, the result is a multiple acquisition. The scan time formula is as follows:

TR x NEX x # of Phase Steps x # of Slice Locations

For a 3D SPGR acquisition the formula would be the same. Fast sequences allow prescription of multiple slabs. If more than one slab is applied, multiply the formula by the number of slabs also. 3D SPGRs are acquired using the same method that is used when acquiring a 3D GRE sequence. The entire volume is excited and thin contiguous slices can be produced from this. The same drawbacks also apply.

Spoiled Gradient Echo Image Characteristics

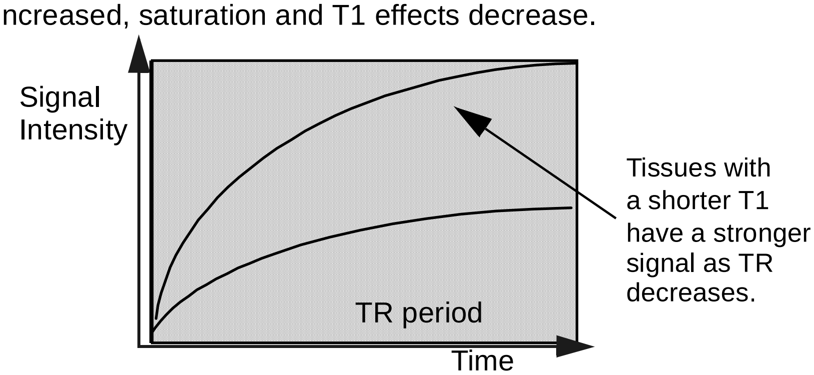
Spoiled Gradient Echo (SPGR) produces T1-weighted images with shorter scan times than SE T1-weighted images, but the the drawback is that the SPGR is subject to air/tissue and bone/tissue interfacing artifacts.



The image on the left is an SPGR image. The image on the right is a spin echo image. Notice the brighter signal of the brain white matter in the SPGR image.

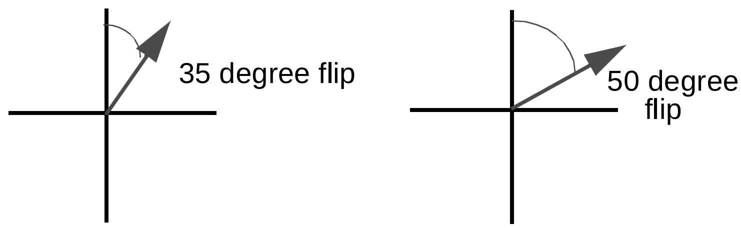
SPGRs are subject to the same magnetic susceptibility artifacts as any other gradient echo sequence but is excellent for demonstrating images with increased sensitivity to paramagnetics such as iron deposits that occur with strokes.

The TR and flip angles play a big part in demonstrating image contrast. TR represents the rate of the excitation pulse and the T1 relaxation time of tissue allowed to recovery. As TR decreases, saturation and T1 effects increases. When TR is increased, saturation and T1 effects decrease.



Flip angles affects the amount of recovery that occurs between each excitation pulse. As a rule: the higher the flip angle the more saturation and T1 effects are seen in the image. The lower the flip angle the less saturation and T1 effects are seen in the image. The chart below helps to illustrate the flip angle concept.

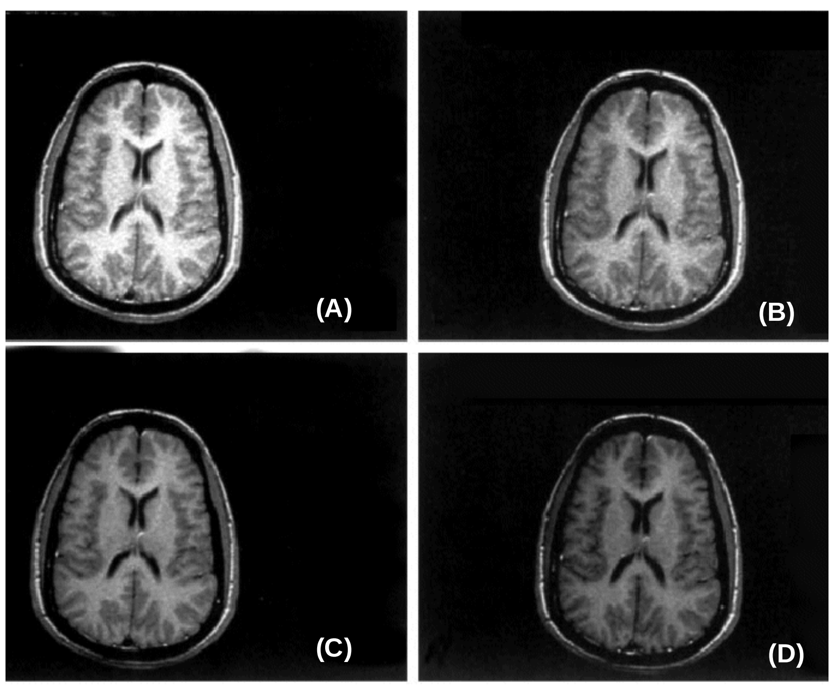
As the flip angle increases, the nuclei have farther to recover, and saturation effects result.



Flip Angle diagram

NOTE: Use the weighting chart presented in the GRE section of this chapter for parameters for T1 sequential SPGR images.

To further show how flip angles contribute to SPGR images look at the differences in the images below.



These axial SPGR head images demonstrate that, at different TR times, different flip angles results in optimal images. (A) uses a 24 TR and a 30 degree flip. (B) uses a 24 TR and a 45 degree flip. (C) uses a 50 TR and a 30 degree flip. (D) uses a 50 TR and 60 degree flip. Note that *at the 24 TR time, the 30 degree flip is better than the same flip angle at 50 TR.*

Something to Think About...

- Keeping the TR and flip angle within 10 points of another produces the optimum SNR.
- 3D: Shorter flip angles can be used when paired with short TR and TE. Typical values range from 25° to 45°.

NOTE: The same GRE something to think about apply to SPGRs, please review that section displayed earlier in this chapter.

Associated Imaging Options

In the following table the X's indicate the option available for use with the SPGR pulse sequence.

Imaging Options			
X	None	X	Variable Bandwidth
X	Flow Compensation	X	No Phase Wrap
	POMP	X	Extended Dynamic Range
X	Square Pixel	X	Surface Coil Intensity Correction
	Respiratory Compensation		Classic
	Magnetization Transfer	X	Sequential
	Cardiac Gating/Triggering		Respiratory Gating/Triggering
	Tailored RF		IR Prepared
	DE Prepared		Multi-Phase
	Full Echo Train	X	CCOMP
	ZIP 1024		ZIP 512
	Zip x 2		ZIP x 4
	SmartPrep		Blood Suppression
	Multi Station		Real Time

Applications

Like GRE sequences, SPGR sequences are good for quick localizers, as well as demonstrating iron deposits on images.

Use when wanting to achieve a quick T1 weighted image throughout the body.

When to use a particular pulse sequence varies with specific patient needs and constraints. The following table shows the most common applications for SPGR sequences. **These are not to be considered recommendations by GE Medical Systems.**

2D Sequential SPGR	3D SPGR
Brain, to accentuate gray/white matter contrast.	High resolution T1 joint and musculo-skeletal images.
T1 breath-hold of abdomen and pelvis.	Thin slice, high resolution T1 Pituitary and IACs.
Use as a contrast enhanced T1 alternative.	Thin slice, high resolution T1 spine imaging.
To obtain dark CSF or bright fat.	Reformat into additional planes to eliminate the need for additional acquisitions.

CAUTION: **Provide all patients with ear protection prior to any scan to help avoid possible hearing impairment.** Acoustic noise levels can exceed 99dBA in the magnet bore.

Setting up an Spoiled Gradient Echo pulse sequence

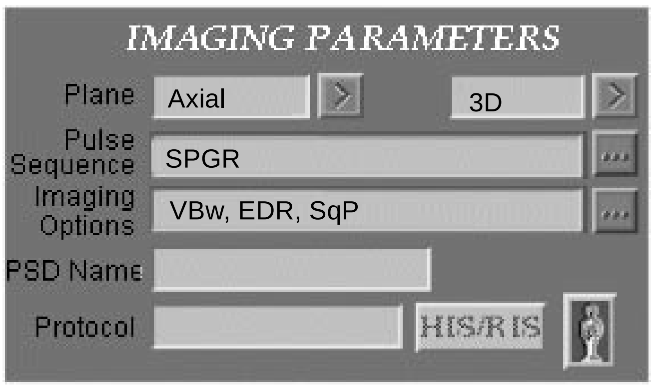
The decision matrix is only for prescribing a 2D or 3D SPGR scan. The purpose of the decision matrix to help you understand the trade-offs that occur when you change the values for a particular parameter and to provide a framework with which you may build you own unique protocol.

The selected values in the left hand column are only an example of what could be used for a T1 weighted 3D SPGR acquisition and are not to be considered recommendations by GE Medical Systems. For specific protocols, refer to the protocols on your system.

2D/3D SPGR- What you select	Selection Notes
SCAN DESKTOP screen	
	Select **Scan Desktop** icon.  Click on **[New Patient]** and fill in the patient information. 
PATIENT POSITION area	
Patient Position **[Supine]** Patient Entry **[Head First]**	**Position and Entry:** A SPGR pulse sequence is compatible with any patient position and entry.

2D/3D SPGR- What you select		Selection Notes
Coil	**[Head]**	**Coil:** Select the coil that produces the optimum coverage and SNR.
Series Description		**Series Description:** Enter a suitable series description. If you do not enter a description, the system enters one for you. The series description default is the selected scan mode, PSD, and imaging options.

IMAGING PARAMETERS area



Plane	**[Axial]**	**Plane:** 2D SPGR is compatible with any scan plane except 3 plane; select the plane that best meets the clinical need.
Mode	**[3D]**	**Mode:** Select [2D] for a sequential acquisition, or select [3D] for a volume scan.
Pulse Seq	**[SPGR]**	**Pulse Seq:** Select [SPGR]. Click on the [Accept] button in the window to register the selection.
Imaging Options		**Imaging Options:** Select [Sequential] for 2D SPGR. Select imaging options that optimizes SNR, spatial resolution, # of slices and reduce motion artifacts. Consider VBw and EDR for 3D. Click on the [Accept] button to register the selections.
PSD Name	**N/A**	**PSD Name:** Not applicable for 2D/3D SPGR.
Protocol	**N/A**	

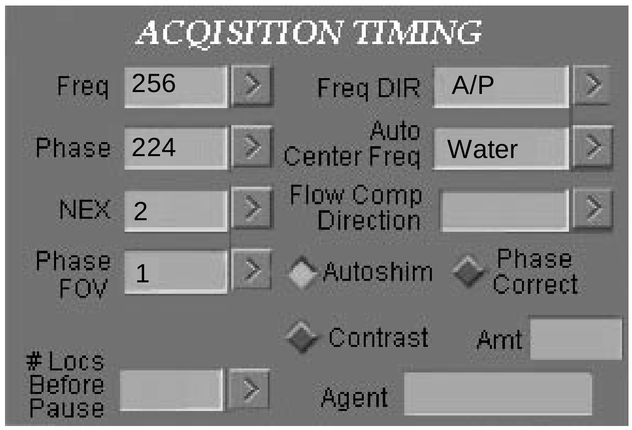
SCAN TIMING area

# of echoes	**[1]**	**# of echoes:** Only 1 echo is allowed for 2D and 3D SPGR.
TE	**[Min]**	**TE:** Short TEs produce: increased T1, increased SNR. Minimum TE changes as RBw changes. Minimum is a fractional echo and may compromise SNR.
TE2	**N/A**	Not selectable.
TR	**[33]**	**TR:** Short TRs produce: decreased SNR, increased T1 contrast, and decreased scan time. If the TR and flip angle are within 10 points of one another, the SNR is optimized.

2D/3D SPGR- What you select		Selection Notes
TI	**N/A**	
Flip Angle	**[45]**	**Flip Angle:** 2D: Given a constant TR, if you increase the Flip Angle you increase T1 weighting. Typical values range from 40° to 60°. 3D: Shorter flip angles can be used when paired with short TR and TE. Typical values range from 25° to 45°.
Echo Train Length	**N/A**	
Bandwidth	**[12.5]**	**Bandwidth:** RBw can only be changed if it was selected from the Imaging Options window. As the RBw decreases, the following occurs: increased SNR, increased chemical shift artifact, increased minimum TE which can potentially decreases # of slices and increased motion artifact.
Bandwidth 2	**N/A**	
SCANNING RANGE area (3D SPGR)		
FOV	**[20]**	**FOV:** Select a FOV that covers the anatomy of interest. Anatomy outside the FOV in the phase direction results in aliasing. Small FOVs produce: increased resolution, decreased SNR, and can increase the minimum TE value.
Slice Thickness	**[2]**	**Slice Thickness:** Thin slices produce: increased resolution and decreased SNR.
# of Scan Locs	**[28]**	**# of Scan Locs:** Choose the number of locations desired, 16 to 128, within each 3D Slab. Enter the number of scan locations that cover the anatomical area. As the number of scan locations increase, scan time and SNR increase.
Start, End Locations		**Start, End Locations:** Typically the start and end locations are programmed from the Graphic Rx program when the 3D box is deposited.3D explicit Rx can be done in either L-I-P or R-S-A direction. 3D graphic Rx can only be done in L-I-P direction for orthogonal planes (note that oblique scan planes are not allowed with 3D SPGR).
# Slabs	**[1]**	**# Slabs:** Determined by the # of Scan Locs and the desired range of anatomy to be covered.
SCANNING RANGE area (2D SPGR)		
FOV	**[38]**	**FOV:** Select a FOV that covers the anatomy of interest. Anatomy outside the FOV in the phase direction results in aliasing. Small FOVs produce: increased resolution, decreased SNR, and can increase the minimum TE value.
Slice Thickness	**[8]**	**Slice Thickness:** Thin slices produce: increased resolution and decreased SNR.
Spacing	**[2.0]**	**Spacing:** Interslice cross-talk is eliminated on sequential SPGR. Typically 20% of the slice thickness.

2D/3D SPGR- What you select		Selection Notes
Start, End Locations		**Start, End Locations:** Typically the start and end locations are programmed from the Graphic Rx program.
# Slices	**[2]**	**# Slices:** 2D SPGR scans sequentially. The number of slices actually indicates the number of locations prescribed and the number of acquisitions.

ACQUISITION TIMING area



Freq	**[256]**	**Freq:** Increasing the frequency matrix produces: increased resolution, decreased SNR, and decreased # of slices.
Phase	**[224]**	**Phase:** Phase controls scan time and may control resolution.
NEX	**[2]**	**NEX:** Select a NEX value that produces sufficient SNR.
Phase FOV	**[1]**	**Phase FOV:** Select .75 or .5 to reduce phase steps and thus decrease scan time, decreasing FOV in the phase direction, and decreasing SNR slightly. The phase FOV dimension is displayed next to the phase FOV factor.
Freq DIR	**[A/P]**	**Freq DIR:** The direction displayed is the default frequency direction which is typically the long axis of the image. To swap phase and frequency, select the other direction.
Auto Center Freq	**[Water]**	**Auto Center Freq:** Select the CF peak that is set during prescan.
Flow Comp DIR	**N/A**	
Autoshim	**[Off]**	**Autoshim:** Select Autoshim when using fat SAT or an FOV off center, and on the first series of each exam.
Phase Correct	**N/A**	

2D/3D SPGR- What you select		Selection Notes
# of Acqs/Locs Before Pause	**N/A**	**# of Acqs/Locs Before Pause:** Prescribe an automatic pause in the scan for multiple location 2D sequential. Pause scanning at predetermined points for breath-hold, joint motion, or contrast perfusion studies.
	Additional Parameters **SAT Screen**	
I	**[80]**	SAT pulses may decrease the # of slices/acquisition.
S	**[80]**	
Additional Parameters		To prescribe oblique slices you must select **[Oblique]** in the Plane pull-down menu.
	GRAPHIC RX Screen	
Click on the image to display the line cursor for Graphic Rx.		To prescribe oblique slices you must select **[Oblique]** in the Plane pull-down menu. The SAT band function can be accessed from the GRAPHIC Rx window and vice versa. If you had graphically prescribed the previous axial series the same prescription can be copied using the **[Copy RX]** button. Consider using an offset to center the anatomy in the middle of the screen so that you can use a PFOV less than 1 and therefore reduce the scan time. View the Advisory panel to note the Max # of slices/Acq and the # of Acqs you are prescribing. The scan time increases as the # of Acquisitions increase.
	SCAN OPERATIONS area	
	[Save Series] **[Prep to Scan]** **[Auto Prescan]** **[Scan]**	Enter data in all the text boxes and click on **[Save Series]**. The series is saved as RXD.

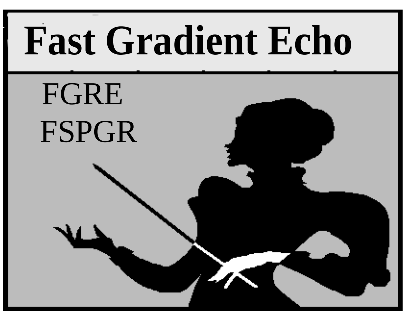
This page intentionally left blank.

Volume 2

Chapter 5

Imaging with Fast Gradient Echo Pulse Sequences

Where Am I?



Introduction

This chapter explains the pulsing components and timing factors directly related to the Fast Gradient Echo (FGRE) and Fast Spoiled Gradient Echo (FSPGR) pulse sequences. This chapter explains the concepts of each, and the step-by-step instructions to help you learn how to:

- Optimize Fast Gradient Echo images
- Optimize Fast Spoiled Gradient Echo images
- Set up a Fast Gradient Echo pulse sequence
- Set up a Fast Spoiled Gradient Echo pulse sequence

In addition, this chapter answers the following questions:

1. What are the pulsing components and timing factors for FGRE, and FSPGR sequences?

2. What is the correct TR, flip angle and the regulation of saturation effects?

3. What is the correct TE and the regulation of dephasing effects?

4. What are the imaging characteristics of a FGRE and FSPGR pulse sequences?

5. Which imaging options can be used with FGRE and FSPGR pulse sequences?

6. What are some applications for FGRE and FSPGR pulse sequences?

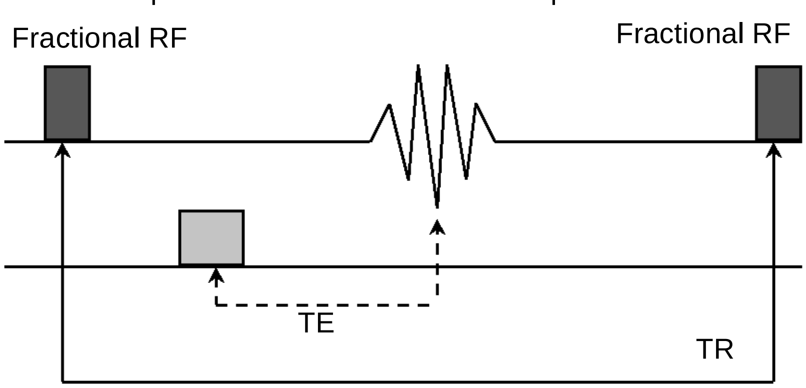
About... Fast Gradient Echo Pulse Sequences

This section presents the concepts necessary to understand FGRE and FSPGR pulse sequences. Specifically you need to understand:

- Fast Gradient Echo (FGRE) and Fast Spoiled Gradient Echo (FSPGR)
  - FGRE and FSPGR image characteristics
  - 2D, 3D and 2D Multi-planar acquisitions
  - Associated imaging options
  - Applications for FGRE and FSPGR

Fast Gradient Echo (FGRE) and Fast Spoiled Gradient Echo (FSPGR)

Fast Gradient Echo can be subdivided into two families, just like standard gradient echo; they are Fast GRE and Fast SPGR. Both sequences use variable flip angles to excite protons, then rephase them by means of gradients. Fast GRE is a combination of a gradient echo and a fast spin echo sequence. The pulse sequence plays out the same as a gradient echo sequences, with the exception of additional fractional RF excitation (Alpha) pulses within a single TR period. The use of a fractional RF shortens the duration of the excitation pulse as well as the readout time. A wider receive bandwidth is also used to obtain shorter TRs and TEs. Thus shortening the total scan time as compared to conventional GRE sequences.



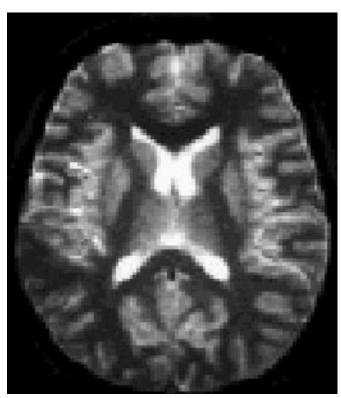
Fast Gradient Echo Diagram

The Fast Spoiled Gradient Echo sequence plays out just as a conventional SPGR sequence with the exception of additional RF excitation (Alpha) pulses within a single TR period.

Like GRE and SPGR fast GRE and fast SPGR can be acquired by using 2D sequential, 2D multi-planar and 3D sequences. 2D sequential is a technique which collects data one slice at a time. One phase encoding step is performed for one slice per TR. All phase encoding steps are completed for a slice before additional slices are initiated. Total scan time is directly related to the number of locations prescribed. Fast multi-plane SPGR acquires multiple slice locations within the same TR, using longer TRs to accommodate more locations. 3D fast SPGR and fast GRE provide the benefits of 3D acquisition which are increased SNR and contiguous slices without cross-talk, while still allowing faster scan times.

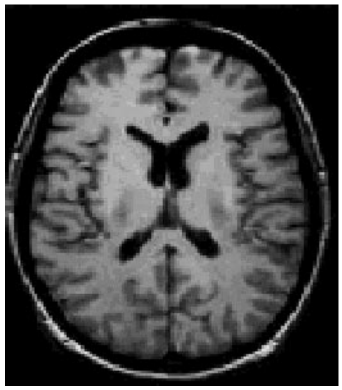
Fast Gradient Echo Image Characteristics

Fast gradient echo sequences produce the same image characteristics as standard gradient sequences. The use of rewinder pulses in FGRE sequences generally enhance T2 weighting within images. In T2 weighted FGRE images, tissues with short T2 are dark and tissues with long T2 are bright. In the brain CSF produces the brightest signal on moderate to late TE images. Just like standard GRE images air-tissue and bone-tissue interfaces may have signal voids due to magnetic susceptibility artifacts.



FGRE image

Spoiler pulses are used in FSPGR sequences, and they help to enhance T1 weighting in images tissues with short T1 are bright and tissues with long T1 are dark; in the brain white matter is brighter then gray matter and CSF is dark, in FGRE images.



FSPGR image

K-space

There are three different types of K-space filling, sequential, centric and elliptic centric. All are available with FSPGR and FGRE sequences.

Sequential ordering is the default setting when not using the Smartprep option. It acquires the contrast sensitive information along the Ky axis at the middle of the scan, filling contrast sensitive data equally along the Kz (slice) axis throughout the total scan time.

Centric ordering is the default setting when using the Smartprep feature. The sequence acquires the contrast sensitive data along the Ky axis at the beginning of the scan, the higher spatial resolution. Along the Kz (slice) axis data is recorded throughout the total scan.

Elliptic Centric ordering can be selected at anytime, within the User CV page, with or without the use of the Smartprep feature. The sequence acquires first the contrast sensitive information in both the Ky and the Kz (slice) axes simultaneously. This is only applicable in 3D sequences. This means that this data is collected in a much shorter time than in sequential or centric ordering.

Something to Think About...

- Due to the short TRs used with standard Fast SPGR/Fast GRE, saturation effects occur resulting in a reduction in SNR and CNR. Short TRs do not allow flip angle flexibility to manipulate image contrast because increasing the flip angle can produce greater saturation effects.

- Increasing NEX to improve SNR may not be an option because of the resulting increase in scan time. However, the multi-planar option can be used to improve SNR with Fast SPGR.
- Contrast may be manipulated with the use of MRI contrast agents or the tissue preparation sequences available with Fast GRE.
- Effects of chemical shift may become apparent in two ways:
  - With very short TEs, this occurs in an image when a voxel contains both fat and water. If the echo is collected with fat and water in phase, the fat and water signal combine and generate a larger signal as compared to an echo collected with fat and water out of phase. This should not be confused with the spatial mis-registration that occurs in spin echo images exhibiting chemical shift effects.
  - The images are often characterized by a low-intensity boundary between fat and tissues which contain mainly water. If voxels contain both fat and water, partial voluming can occur. This can cause an almost complete signal void in these voxels. This boundary effect can be advantageous in determining the division between adipose tissue and pathology but disadvantageous when evaluating the boundaries between organs. Because of this effect, the shortest TE available for the Fast SPGR/GRE sequences may not produce the desired image contrast. Select the shortest echo time allowed by a a TE that guarantees that fat and water are in phase.
- FGRE 3D with Slice ZIP or ZIP 512 does not support multi-slab acquisitions.
- The maximum time most patients can hold their breath is 20-25 seconds. Keep this in mind when selecting parameters that affect scan time.
- When using Respiratory Triggering with Fast Spin Echo (FSE), the available imaging time is used to collect data from all of the slices (TR time). In FGRE 3D, the available imaging time is segmented by the Min TR (set by selected imaging parameters). It is used to acquire

as many phase and slice encodings as possible that will fit in the available imaging time for one respiratory interval. Because the 3D data set is acquired over multiple respiratory intervals, it is recommended that a larger trigger window (~60%) be used so as much data as possible is acquired between respiration. This is done to minimize respiratory motion.

- A PFOV less than 1 (range from 0.5-1.0) can be selected if it doesn't result in anatomy outside the PFOV. The selected values are rounded to the nearest 1/16 FOV.
- SPECIAL supports manual tuning for center frequency adjustment but DOES NOT support manual tuning for flip angle adjustment.
- There is a slight increase in scan time to account for the inversion pulse that is applied once every 64 slice encodings. This increase in scan time is much shorter than the increase that would occur if a fat SAT pulse was used.
- ZIP 512 produces a small decrease in SNR, typically much less than selecting a 512 acquisition.
- ZIP 512 images take longer to reconstruct and require more disk space than 256 images. The additional reconstruction time and required storage space are identical to an acquired 512 image.
- ZIP 512 enhances the apparent image resolution. It can make truncation (Gibbs) artifacts more noticeable. Increasing the phase matrix value up to 256, or decreasing the FOV can reduce this artifact.
- Slice ZIP has no effect on SNR.
- When decreasing slice thickness, the number of discarded end slices automatically are doubled or quadrupled if you select Slice ZIP.
- In the Scan Range area, the "Slice Location" text value multiplied times the Slice ZIP factor is your real number of reconstructed slices.
- In Graphic Rx, the width of the tick line represents the number of slices prescribed which includes the discard slices.
- Although Slice ZIP is a very useful 3D scan feature for improving exam resolution, it is possible to select slices that are too thick. Gibbs ringing artifacts can result when the slice thickness gets too large, typically 2 mm or

greater in the head, or 4 mm or greater in the body. This ringing artifact can occur in both the phase and slice direction. It is often most apparent on a reformatted image when the artifact occurs in the slice direction.

- A Slice ZIP x 4 only gives a marginal improvement in effective resolution over a Slice ZIP x 2. Slice ZIP x 4 images are overlapped by 75% of the slice thickness instead of 50% of the slice thickness. The marginal improvement in the effective resolution comes at the expense of an additional factor of 2 in reconstruction time.
- If excessive ghosting is present within a 3D Fast GRE/SPGR image, when using 1 NEX and No Phase Wrap (NPW), you may want to increase the NEX to 2 to help to eliminate.

Associated Imaging Options

In the following table the X's indicate the option available for use with the Fast GRE and Fast SPGR pulse sequences.

Imaging Options			
X	None	**X**	Variable Bandwidth
X	Flow Compensation	**X**	No Phase Wrap
	POMP	**X**	Extended Dynamic Range
X	Square Pixel	**X**	Surface Coil Intensity Correction
	Respiratory Compensation		Classic
	Magnetization Transfer	**X**	Sequential
X	Cardiac Gating/Triggering		Respiratory Gating/Triggering
	Tailored RF	**X**	IR Prepared
X	DE Prepared	**X**	Multi-Phase
	Full Echo Train	**X**	CCOMP
X	ZIP 1024	**X**	ZIP 512
X	Zip x 2	**X**	ZIP x 4
	SmartPrep		Blood Suppression
	Multi Station		Real Time

NOTE: Gating and IR Prep are not compatible with FSPGR.

Applications

Some suggested FGRE and FSPGR are quick localizers and anywhere in the body for producing quick T1, T2 and PD images. FGRE and FSPGR increases sensitivity to paramagnetics, such as iron deposits, this is helpful when imaging strokes. Use multiphase with FGRE and/or FSPGR for dynamic contrast imaging or kinematic studies. Use SPECIAL to suppress competing signal from fat in musculoskeletal studies or contrast enhanced studies.

These are not to be considered recommendations by GE Medical Systems.

Standard 2D Sequential FGRE/SPGR	Multi-Phase FSPGR	IR/DE Prepared FGR	2D Multi-Planar FMPFGR FMSPGR	3D FGRE/FSPGR
T1 and T2* Breath-hold abdomen and pelvis imaging.	Temporally resolved contrast perfusion studies.	IR - to suppress signal from a selective tissue or organ such as the liver or spleen (See prep time table below.)	To obtain multiple slice locations of the abdomen or pelvis in a single breath-hold.	High resolution T1 or T2* joint and musculo-skeletal images when faster scan times are desired.
Contrast enhanced T1 abdomen and pelvis.	Joint motion studies of the knee, TMJ and wrist.	DE - to produce greater T2* contrast.	Contrast enhanced T1 images of the abdomen and pelvis.	Reformat into multiple planes to eliminate need for additional acquisitions.
Ultra-fast localizers	Flexion/Extension studies of the cervical spine.		To improve SNR over sequential Fast sequences.	Breath-hold abdominal and breast imaging with or without SPECIAL. (See images below).
Breath-hold cardiac/aortic arch imaging when used with FGR/FSPGR and gating (Fast-Card).				Multi-Phase contrast enhanced volume imaging. Use Slice ZIP or ZIPx2 or ZIPx4 to increase spatial resolution without increasing scan time.

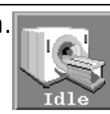
CAUTION: **Provide all patients with ear protection prior to any scan to help avoid possible hearing impairment.** Acoustic noise levels can exceed 99 dBA in the magnet bore.

Setting up a Fast Gradient Echo pulse sequence

The decision matrix is only for prescribing a Fast GRE/SPGR scan. The purpose of the decision matrix to help you understand the trade-offs that occur when you change the values for a particular parameter and to provide a framework with which you may build you own unique protocol.

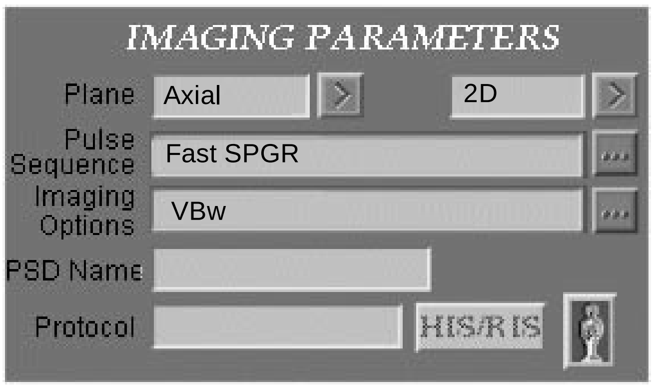
The selected values are only an example of what could be used for a T1 Multi-plane SPGR acquisition and is not to be considered a recommendation by GE Medical Systems. For specific protocols, refer to the protocols on your system.

.

FGRE/SPGR - What you select	Selection Notes
SCAN DESKTOP screen	
	Select **Scan Desktop** icon.  Click on **[New Patient]** and fill in the patient information. 
PATIENT POSITION area	

FGRE/SPGR - What you select		Selection Notes
Patient Position	**[Supine]**	**Position and Entry:** A FGRE/SPGR pulse sequence is compatible with any patient position and entry.
Patient Entry	**[Feet First]**	
Coil	**[Body]**	**Coil:** Select the coil that produces the optimum coverage and SNR.
Series Description		**Series Description:** Enter a suitable series description. If you don not enter a description, the system enters one for you. The series description default is the selected scan mode, PSD, and imaging options.

IMAGING PARAMETERS area



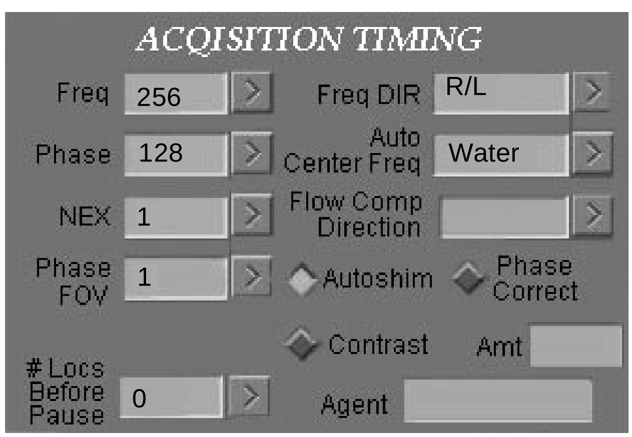
Plane	**[Axial]**	**Plane:** 2D FGR/FSPGR is compatible with any scan plane except 3 plane; select the plane that best meets the clinical need. 3D does not allow oblique, nor 3 plane.
Mode	**[2D]**	**Mode:** Select [2D] for a sequential gradient echo or [3D] for thin contiguous images.
Pulse Seq	**[Fast SPGR]**	**Pulse Seq:** Select [Fast SPGR] for T1 contrast, [Fast GRE] for T2*. Click on the [Accept] button in the window to register the selection.

FGRE/SPGR - What you select		Selection Notes
Imaging Options	**[VBw]**	**Imaging Options:** Select [Sequential] to acquire one slice at a time. Do not select [Sequential] for 3D. [Multi-Phase] can be selected to acquire multiple images at the same location for temporal resolution. [Sequential] must be selected for Multi-Phase acquisitions. Select a Prep pulse with a Fast GRE sequential pulse sequence to vary the contrast effects: [IR Prepared] to obtain T1 weighting, [DE Prepared] for increased T2 weighting. Select [ZIP512] to improve in-plane resolution with a minimal decrease in SNR, but with a trade-off in reconstruction time and disc storage (the image is stored as a 512x512 slice image data set). Select a Slice ZIP factor to increase the # of slices (by a factor of 2 or 4) without increasing the scan time. For example, with a ZIP x 2, the slices are overlapped by half the slice thickness. Select imaging options that optimizes SNR, Spatial resolution, and reduce motion artifacts. Click on the [Accept] button to register the selections.
PSD Name	**N/A**	**PSD Name:** Not applicable for 2D or FGRE/FSPGR.
Protocol	**N/A**	
SCAN TIMING area		
# of echoes	**[1]**	**# of echoes:** Only 1 echo is allowed.
TE	**[Min]**	**TE:** Short TEs produce: Increase T1 contrast, and increased SNR. Increase the TE to produce: increased T2* contrast, decreased SNR, signal changes at fat/water interfaces, and increased magnetic susceptibility effects. Longer TEs are compatible with narrower RBws. Wide RBw and fractional echo may decrease SNR.
TR	**[100]**	**TR:** Short TRs produce: decreased SNR, increased T1 contrast, and decreased scan time. Long TRs produce: increased SNR, and increased scan time. • TR is not selectable with Tissue Prepared, Multi-Phase, and 3D sequences. The minimum value is set by the system. • Fast Multi-Plane SPGR uses longer TRs (60-100 ms) and allows larger flip angles (40-60°) which can improve SNR. • If the TR and flip angle are within 10 points of one another, the SNR is optimized.
TI	**N/A**	

FGRE/SPGR - What you select		Selection Notes
Prep Time	**N/A**	**Prep Time:** Prep Time only appears if SPECIAL, DE Prep, or IR Prep is selected. For SPECIAL, select a T1 in the 30-60 ms range, and the system determines the optimum flip angle for the Inversion pulse. Selecting SPECIAL slightly increases the scan time which is significantly less than what occurs with a FAT SAT pulse. Prep time is also available when IR or DE Prep pulses are being used. This sets the time between the last prep pulse and the RF excitation pulse for IR. It sets the time between the first and third prep pulses of the DE sequence. Tissue contrast varies as Inversion Time varies.
Flip Angle	**[50]**	**Flip Angle:** T1 Contrast: 2D: Given a contrast TR, if you increase flip angle you, increase T1 weighting. Typical values range from 40° to 60°. 3D: shorter flip angles can be used when paired with short TR and TE. Typical values range from 25° to 45°. T2* Contrast: Typical 2D flip angle values: 20° to 30°. Typical 3D flip angles range from 5 to 8. If you decrease flip angle, you increase T2* weighting and decrease SNR.
Echo Train Length	**N/A**	
Bandwidth	**[15.63]**	**Bandwidth:** RBw can only be changed if it was selected from the Imaging Options window. As the RBw decreases, the following occurs: increased SNR, increased chemical shift artifact, increased minimum TE which can potentially decreases # of slices and increased motion artifact. Generally, wider bandwidths are used with Fast sequences to keep minimum TEs and TRs.
Bandwidth 2	**N/A**	
SCANNING RANGE area (for 2D acquisition)		
FOV	**[36]**	**FOV:** Select a FOV that covers the anatomy of interest. Anatomy outside the FOV in the phase direction results in aliasing. Small FOVs produce: increased resolution, decreased SNR, and can increase the minimum TE value.
Slice Thickness	**[10]**	**Slice Thickness:** Thin slices produce: increased resolution and decreased SNR.
Spacing	**[2.0]**	**Spacing:** Interslice cross-talk is eliminated on sequential gradient echoes. Typical spacing is 0-20% of the slice thickness.
Start, End Locations		**Start, End Locations:** Typically the start and end locations are programmed from the Graphic Rx program.

FGRE/SPGR - What you select		Selection Notes
# Slices	**[8]**	**# Slices:** Sequential scans one slice per acquisition. The number of slices actually indicates the number of locations prescribed and the number of acquisitions.
SCANNING RANGE area (for 3D acquisition)		
FOV	**[36]**	**FOV:** Select an FOV that covers the anatomy of interest. Anatomy outside the FOV in the phase direction results in aliasing. Small FOVs produce: increased resolution, decreased SNR, and can increase the minimum TE value.
Slice Thickness	**[1.5]**	**Slice Thickness:** Thin slices produce: increased resolution and decreased SNR.
# of Scan Locs	**[60]**	**# of Scan Locs:** Choose the number of locations, 8-24 in multiples of 2 (e.g. 8, 10, 12, 14...) desired within each 3D Slab. Increasing Locs per slab in the volume increases SNR, scan time and range of coverage. No interscan spacing is required with 3D.
Start, End Locations		**Start, End Locations:** Start and end locations are programmed from the Graphic Rx program when the 3D box is deposited. 3D explicit or graphic Rx can be done in either L-I-P or R-S-A direction.
# Slabs	**[1]**	**# Slabs:** Determined by the # of Scan Locs and the desired range of anatomy to be covered. If Slice ZIP is turned on, multi-slab is not compatible.

ACQUISITION TIMING area



Freq	**[256]**	**Freq:** As the Frequency matrix increases, resolution increases, SNR decreases, and minimum TR and TE values increases. A frequency matrix from 128 to 512 can be selected in increments of 32.
Phase	**[128]**	**Phase:** Phase controls scan time and may control resolution.

FGRE/SPGR - What you select		Selection Notes
NEX	**[1]**	**NEX:** Select a NEX value that produces sufficient SNR. Breath-hold acquisitions may require lower NEX values to decrease scan time. SNR also decreases.
Phase FOV	**[1]**	**Phase FOV:** A PFOV less than 1 (range from 0.5-1.0) can be selected if it doesn't result in anatomy outside the PFOV. The selected value is rounded to the nearest 1/16 FOV.
Freq DIR	**[R/L]**	**Freq DIR:** The direction displayed is the default frequency direction which is typically the long axis of the image. To swap phase and frequency, select the other direction.
Auto Center Freq	**[Water]**	**Auto Center Freq:** Select the CF peak that is set during prescan.
Flow Comp DIR	**N/A**	
Autoshim	**[On]**	**Autoshim:** Select Autoshim when using fat SAT or an FOV off center, and on the first series of each exam.
Phase Correct	**N/A**	
# of Acqs/Locs Before Pause	**[None]**	**# of Acqs/Locs Before Pause:** If the slice number you prescribe results in multiple acquisitions, you can program a pause time to allow the patient to breathe. This is not available if a value other than [Minimum] is selected at the Multi-Phase screen. Pause scanning at predetermined points for breath-hold, joint motion, or contrast perfusion studies.
Additional Parameters SAT Screen		
FAT	**[On]**	**FAT:** Select FAT SAT if SPECIAL was selected.
Additional Parameters Multi-Phase screen		
Phases per Location	**[5]**	**Phases per Location:** Enter the number of images/phases desired at each prescribed location at the Phases per Location text box. (Slices/Location) x (Number of Slices) cannot exceed 512.
Phases Acquisition Order	**[Interleave]**	**Phases Acquisition Order:** Select [Interleave] to obtain the first "phase" at each location, followed by the second phase at each location and so on. Select [Sequential] to obtain all images fro the first location before moving on to the next location(s).
Additional Parameters USER CV screen This screen is only available with the 3D mode.		
SPECIAL	**[1]**	**Special:** Select 1 to turn SPECIAL on for a fat suppressed acquisition and 0 to turn it off.

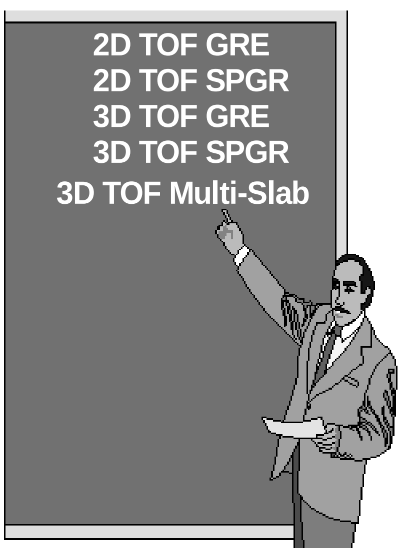
FGRE/SPGR - What you select		Selection Notes
Burst Scan Time	**[0]**	**Burst Scan Time:** Select 0 to turn Burst Scan Time off, or select a Burst Scan Time that is equal to or longer than the acquisition time (maximum value = 60 sec.). Typically, select the Burst Scan Time as the last programmed parameter, since scan time is a function of so may other parameters.
Delay After Acq	**[Min]**	**Delay After Acq:** Enter a time, from 50 ms to 20 secs, to let the system automatically start scanning when performing a time delay study. If you wish to start the delay acquisitions yourself, enter 50 ms here, and enter a value in the "Locs Before Pause" text box in the Acquisition Time area.
GRAPHIC RX Screen		
Click on the image to display the line cursor for Graphic Rx.		The SAT band function can be accessed from the GRAPHIC Rx window and vice versa. If you had graphically prescribed the previous axial series the same prescription can be copied using the **[Copy RX]** button. Consider using an offset to center the anatomy in the middle of the screen so that you can use a PFOV less than 1 and therefore reduce the scan time. View the Advisory panel to note the # of Acqs you are prescribing. The scan time increases as the # of Acquisitions increase. 3D explicit Rx can be done in either L-I-P or R-S-A direction. 3D graphic Rx can be done in either L-I-P or R-S-A direction.
SCAN OPERATIONS area		
	[Save Series] **[Prep to Scan]** **[Auto Prescan]** **[Scan]**	Enter data in all the text boxes and click on **[Save Series]**. The series is saved as RXD.

Volume 2

Chapter 6

Imaging with Time of Flight Pulse Sequences

Where Am I?



Introduction

This chapter explains the pulsing components and timing factors directly related to the Time of Flight pulse sequences. This chapter explains the concepts of each, and the step-by-step instructions to help you learn how to:

- Optimize Time of Flight GRE images
- Optimize Time of Flight SPGR images
- Optimize Time of Flight Multi-slab images
- Set up a Time of Flight GRE sequence
- Set up a Time of Flight SPGR sequence

In addition, this chapter answers the following questions:

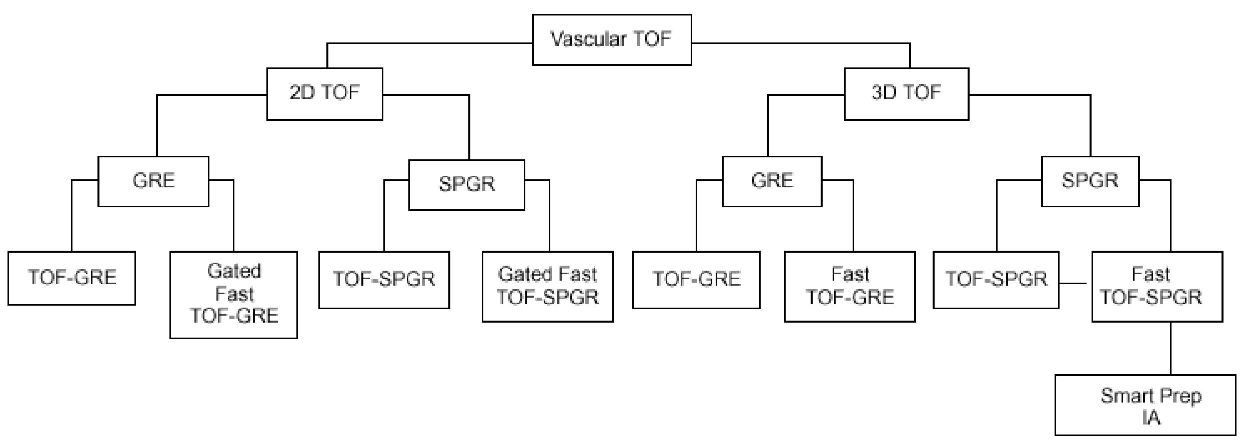
1. What is the contrast mechanism in TOF?
2. What is the RF pulsing pattern?
3. How do the timing factors control the RF pulsing?
4. How do TR and flip angle regulate saturation effects?
5. How does TE regulate dephasing effects?
6. How does 3D collect data?
7. What special imaging options are enabled by TOF and how do they work?
8. How are the TOF sequences classified?
9. What are the image characteristics?
10. What are the applications?

About... Time of Flight Pulse Sequences

This section presents the concepts necessary to understand Time of Flight pulse sequences. Specifically you need to understand:

- 2D Time of Flight GRE and SPGR
  - Image characteristics
  - Associated imaging options
  - Applications for TOF GRE/SPGR
- 3D Time of Flight GRE/SPGR and Multi-slab
  - Image characteristics
  - Associated imaging options
  - Applications for TOF Multi-slab

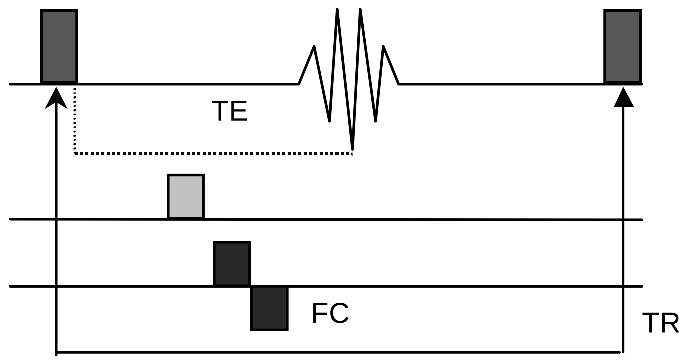
There are several different pulse sequences within the vascular TOF family they are all related to the gradient echo family of pulse sequences.



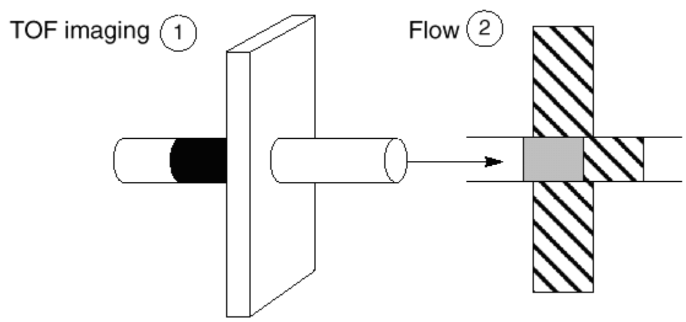
2D Time of Flight GRE and SPGR

Time of Flight (TOF) imaging is based on conventional gradient echo scanning with Flow Compensation. This imaging technique relies primarily on flow-related enhancements to distinguish moving from stationary spins in creating MRI angiograms.

Time of Flight acquires 1 phase encoding value per TR period in a 2D or 3D mode. A variable angle RF excitation pulse, gradient rephasing and flow compensation is used.



MRI angiogram images are created by repeatedly exciting a predefined volume of anatomy until the stationary tissue is partially saturated and the signal from the tissue is suppressed. Blood flowing into the predefined volume of anatomy is not saturated but fully magnetized by the main magnetic field and yields a stronger signal. In the resulting image, the blood appears bright and the stationary tissue is suppressed. This phenomena is called a flow-related enhancement.



TOF-SPGR uses RF spoiling to minimize residual transverse magnetization to optimize T1 weighting. TOF-GRE uses a non RF Spoiled gradient echo technique and increased T2* effects may be noted.

Both PSDs can produce Reconstruction and MIP images:

- Magnitude, collapsed, and projection images can be generated.
- Reconstruction is done concurrent with the acquisition.

2D TOF completes data acquisition for one slice before moving on to subsequent slice locations. Images can be acquired using a TOF-SPGR or TOF-GRE sequence.

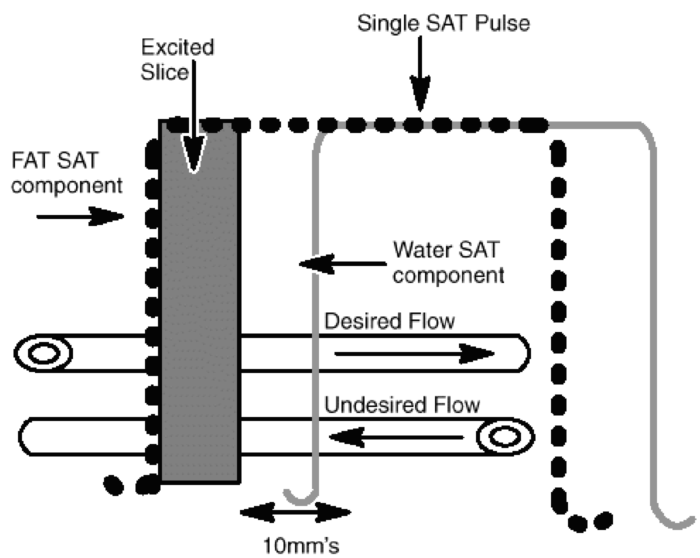
The advantages of 2D TOF include:

- Sensitivity to slow flow or moderate flow
- Minimal saturation effects at normal flow velocities
- Speed

This is a fast technique, usually completed in 5 – 7 minutes. Spatial SAT pulses are generally used to decrease signal from unwanted flow. When prescribing SAT bands in the slice direction, select only the SAT direction. The system sets the spacing and slab thickness. The SAT band starts 20 mm from the slice being acquired.

Slice direction SAT bands concatenates, that is they move along with the slices, unless a change is made to the SAT band thickness and/or spacing.

2D TOFX is a type-in Time of Flight pulse sequence with optimized SAT thickness and gap to improve background suppression. The optimized thickness is 80 mm and the gap is 10 mm. Even though stationary tissue is suppressed, fat, because of its short T1 characteristics, regrows quickly. By taking advantage of the chemical shift properties inherent to the SAT pulse and its relative position, the fat is suppressed.



The very narrow bandwidth and chemical shift of 220Hz between fat/water (at 1.5T) causes a spatial shift of the FAT SAT portion of the SAT pulse to "cover" the excited slice.

2DTOFX spatial saturation pulses are designed to produce fat suppression. The effectiveness of the fat saturation is maximized at a 10 mm SAT gap. As the SAT gap increases, the fat suppression becomes less effective. In regions of highly pulsatile flow (e.g., popliteal, iliac) a narrow SAT gap can result in pulsatile artifacts due to saturation of retrograde flow.

Time-of-Flight images are annotated `TOF/SPGR/Flip Angle`, `TOF/GR/Flip Angle`, `2dtofx/Flip Angle`.

The type-in option is **`TOF`** or **`TOFS`** and is not case sensitive.

Something to Think About...

- 2D TOF is relatively insensitive to in-plane blood flow, which can simulate a vascular lesion.

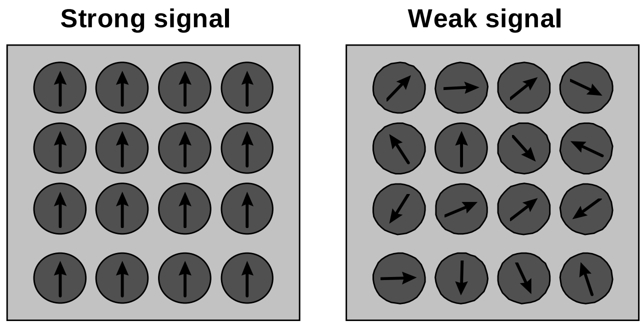
- A long minimum TE makes the acquisition insensitive to very fast in-plane and turbulent blood flow.
- 2D TOF acquisitions have the potential for overestimating stenosis because the minimum TE is relatively long in comparison to 3D TOF.
- Patient motion can result in misregistration of the acquired slices when viewed in projection.
- Simulated flow-related enhancements can result from short T1 substances like methemoglobin in subacute hematomas.
- Programming a thin slice combined with FC increases the minimum TE value.

Imaging Considerations

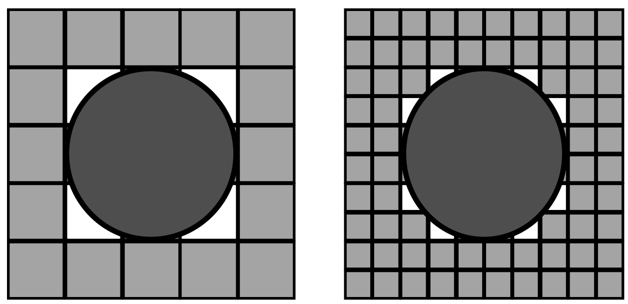
Scan Parameter	Effect of Scan Parameter
Short TE (fractional/partial)	Decreases signal loss and artifacts. Short TR Suppresses the signal from stationary tissue. Maximizes the vessel contrast due to flow-related enhancements.
Thin slices	Maximizes in-flow enhancement. Reduces the effects of in-plane flow.
Flip angle approximately 60°	Saturates stationary tissues without compromising intravascular signal intensity.
Image plane perpendicular to flow	Prevents saturation of flowing spins due to multiple RF pulses.
Sat Pulse	Eliminates signal from overlapping vascular structures. For example, apply: • The SAT pulse superior to the scanning range to minimize signal from the jugular vein. • The SAT pulse inferior to emphasize the jugular vein. • A superior SAT pulse to selectively image the pelvic vein. Do not modify the defaulted SAT thickness or gap.
Flow Comp	Reduces phase dispersion increasing vascular signal when used with minimum TE.
MRI contrast agents	Shortens the T1 of blood.

Time of Flight Image Characteristics

MRA images are inherently low in SNR. Intra-voxal phase dispersion decreases SNR and is affected by voxel size, sequence timing and flow dynamics.



Voxel size also affects spatial resolution and the ability to visualize small vessels.



Images with flowing nuclei are bright while stationary nuclei are dark. Stagnant, slow flow or in-plane flow produces decreased signal as it becomes saturated.

3D TOF Intra-cranial vessels

Associated Imaging Options

In the following table the X's indicate the option available for use with the Time of Flight pulse sequence.

Imaging Options			
X	None	**X**	Variable Bandwidth
X	Flow Compensation	**X**	No Phase Wrap
	POMP	**X**	Extended Dynamic Range
X	Square Pixel	**X**	Surface Coil Intensity Correction
	Respiratory Compensation		Classic
X	Magnetization Transfer	**X**	Sequential
	Cardiac Gating/Triggering		Respiratory Gating/Triggering
	Tailored RF		IR Prepared
	DE Prepared		Multi-Phase
	Full Echo Train		CCOMP
X	ZIP 1024	**X**	ZIP 512
X	Zip x 2	**X**	ZIP x 4
	SmartPrep		Blood Suppression
	Multi Station		Real Time

NOTE: Magnetization Transfer, ZIP 512, 1024, ZIPx2, and ZIPx4 are not compatible with 2D TOF pulse sequences.

Applications

2D TOF GRE or SPGR is used for:

- Demonstrating the carotid bifurcation or venous anatomy
- Evaluating suspected basilar artery occlusive disease
- Imaging pelvic and lower extremity vasculature
- Mapping cortical veins
- Evaluating suspected intra-cranial venous thrombosis

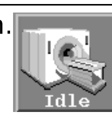
CAUTION: **Provide all patients with ear protection prior to any scan to help avoid possible hearing impairment.** Acoustic noise levels can exceed 99 dBA in the magnet bore.

Setting up a 2D TOF pulse sequence

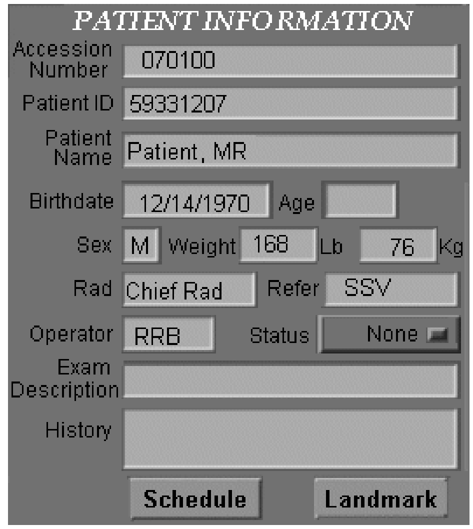
The decision matrix is only for prescribing a 2D Time of Flight scan. The purpose of the decision matrix to help you understand the trade-offs that occur when you change the values for a particular parameter and to provide a framework with which you may build you own unique protocol.

The selected values are only an example of what could be used for a TOF SPGR acquisition and are not to be considered recommendations by GE Medical Systems. For specific protocols, refer to the protocols on your system.

.

2D TOF - What you select	Selection Notes
SCAN DESKTOP screen	
	Select **Scan Desktop** icon. 

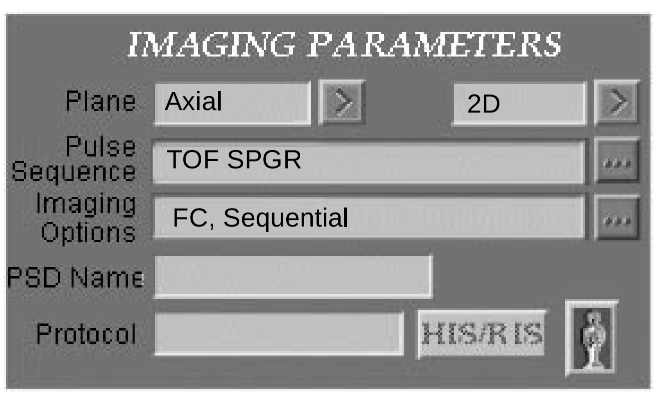
2D TOF - What you select		Selection Notes
		Click on **[New Patient]** and fill in the patient information.



PATIENT POSITION area

Patient Position	**[Supine]**	**Position and Entry:** An 2D TOF pulse sequence is compatible with any patient position and entry.
Patient Entry	**[Head First]**	
Coil	**[Anterior Neck]**	**Coil:** Select the coil that produces the optimum coverage and SNR.
Series Description		**Series Description:** Enter a suitable series description. If you don not enter a description, the system enters one for you. The series description default is the selected scan mode, PSD, and imaging options.

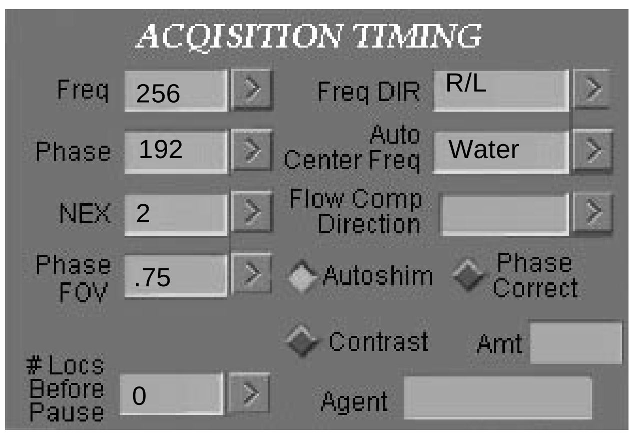
IMAGING PARAMETERS area



2D TOF - What you select		Selection Notes
Plane	**[Axial]**	**Plane:** 2D TOF is compatible with any scan plane except 3-Plane. Select the plane that best meets the clinical need. Maximum flow-related enhancement occurs when blood flow is perpendicular to the imaging plane.
Mode	**[2D]**	**Mode:** Select [2D].
Pulse Seq	**[TOF SPGR]**	**Pulse Seq:** Select [TOF-SPGR] or [TOF-GRE]. SPGR typically reduces the signal from fat more than TOF-GRE. Click **[Accept]** to register the selection.
Imaging Options	**[FC, Sequential]**	**Imaging Options:** Select Sequential. Use of Flow Comp may increase the signal from blood by rephasing the moving spins, but Flow Comp increases the minimum TE. Select other imaging options that optimizes SNR and spatial resolution. Click **[Accept]** to register the selections.
PSD Name	**N/A**	**PSD Name:** To use 2DTOFX type **`2dtofx`** at PSD Name, otherwise a type-in PSD is not necessary.
Protocol	**N/A**	
SCAN TIMING area		
# of echoes	**[1]**	**# of echoes:** Only 1 echo is allowed for vascular sequences.
TE	**[Min]**	**TE:** Use the minimum TE for minimal dephasing effects. Minimum TE changes as RBw changes.
TR	**[40]**	**TR:** TRs in the range of 40 – 50 ms are generally used to adequately decrease signal from stationary tissue.
TI	**N/A**	
Flip Angle	**[60]**	**Flip Angle:** Choose a flip angle that suppresses stationary tissue without decreasing signal from blood, usually 45 – 60° for SPGR, 20 – 40° for GRE. As the flow gets faster, the flip angle may be increased.
Echo Train Length	**N/A**	
Bandwidth	**[16]**	**Bandwidth:** RBw can only be changed if it was selected from the Imaging Options window. As the RBw decreases, the following occurs: increased SNR, increased chemical shift artifact, increased minimum TE which can potentially decreases # of slices and increased motion artifact.
Bandwidth 2	**N/A**	
SCANNING RANGE area (for 2D Sequential acquisition)		
FOV	**[20]**	**FOV:** Select a FOV that covers the anatomy of interest. Anatomy outside the FOV in the phase direction results in aliasing. Small FOVs produce: increased resolution, decreased SNR, and can increase the minimum TE value.

2D TOF - What you select		Selection Notes
Slice Thickness	**[2.0]**	**Slice Thickness:** Thin slices produce increased flow-related enhancement, reduce effects of in-plane flow, increased resolution and decreased SNR.
Spacing	**N/A**	
Start, End Locations		**Start, End Locations:** Typically the start and end locations are programmed from the Graphic Rx program. As many slices as needed to cover the desired anatomy may be prescribed. As # of locations increases, total scan time increases.
# Slices	**[76]**	**# Slices:** The number of slices is one per acquisition. This area indicates the number of locations prescribed.

ACQUISITION TIMING area



Freq	**[256]**	**Freq:** Increasing the frequency matrix produces: increased resolution and decreased SNR.
Phase	**[192]**	**Phase:** Phase controls scan time and may control resolution.
NEX	**[2]**	**NEX:** Select a NEX value that produces sufficient SNR.
Phase FOV	**[.75]**	**Phase FOV:** Select .75 or .5 to reduce phase steps and thus decrease scan time, decreasing FOV in the phase direction, and decreasing SNR slightly. The phase FOV dimension is displayed next to the phase FOV factor.
Freq DIR	**[R/L]**	**Freq DIR:** The direction displayed is the default frequency direction which is typically the long axis of the image. To swap phase and frequency, select the other direction.
Auto Center Freq	**[Water]**	**Auto Center Freq:** Select the CF peak that is set during prescan.
Flow Comp DIR	**N/A**	

2D TOF - What you select		Selection Notes
Autoshim	**[On]**	**Autoshim:** Select Autoshim when using a FOV off center, and on the first series of each exam.
Phase Correct	**N/A**	
# of Acqs/Locs Before Pause	**[None]**	**# of Acqs/Locs Before Pause:** Although this text box is available, pauses are generally not used with TOF scans. Breath-hold exams are usually not done due to differences in anatomical location from slice.
Additional Parameters SAT Screen		
S	**[80]**	**SAT:** Select spatial SAT pulses perpendicular to the flow and in a direction that reduces unwanted flow. To suppress arterial flow above the heart use a superior SAT pulse, and to suppress arterial flow below the heart use an inferior SAT pulse.
Additional Parameters Vascular Options Screen		
Projection Images	**[19]**	**Projection Images:** Select `19` or `37` to automatically create projection images.
Collapse	**[On]**	**Collapse:** Select `On` to get a collapsed view in the plane of acquisition.
GRAPHIC RX Screen		
Click on the image to display the line cursor for Graphic Rx.		The SAT band function can be accessed from the GRAPHIC Rx window and vice versa. If you had graphically prescribed the previous axial series the same prescription can be copied using the **[Copy RX]** button. Consider using an offset to center the anatomy in the middle of the screen so that you can use a PFOV less than 1 and therefore reduce the scan time. In 2D Sequential, view the Advisory panel to note the # of Acqs you are prescribing. The scan time increases as the # of Acquisitions increase. 3D explicit Rx can be done in either L-I-P or R-S-A direction. 3D graphic Rx can only be done in L-I-P direction for orthogonal planes (note that oblique scan planes are not allowed with 3D GRE).
SCAN OPERATIONS area		

2D TOF - What you select	Selection Notes
[Save Series] **[Prep to Scan]** **[Auto Prescan]** **[Scan]**	Enter data in all the text boxes and click on **[Save Series]**. The series is saved as RXD.

3D TOF GRE/SPGR

3D TOF uses a volume acquisition to obtain image data. Either TOF-SPGR or TOF-GRE can be used in 3D mode.

Advantages of 3D TOF include:

- Improved SNR, contrast to noise, and high spatial resolution
- Relatively short scan times
- Sensitivity to fast and intermediate flow
- Very short TEs, which reduce the amount of spin dephasing
- Generation of magnitude, collapsed, and projection images
- Less overestimation of stenosis than with 2D TOF, because of low dephasing
- The use of MultiSlab acquisitions to decrease saturation effects of slow moving and in-plane blood
- Flexible frequency matrix selections
- Flexible Phase FOV
- Shorter TRs especially with MT
- Improved flow comp
- ZIP -Slice and 512

3D TOF SPGR images are annotated `3D TOF/SPGR/Flip Angle`.

3D TOF GRE images are annotated `3D/TOF/GR/Flip Angle`.

3D TOF provides several imaging options that are not available with 2D TOF:

- Mag Transfer
- Ramp Pulses (located on the Vascular Additional Parameters screen)
- ZIP 512

- Slice ZIP x 2 and ZIP x 4
- More frequency matrix and Phase FOV selections (located in the Acquisition Timing area)
- Benefits of flexible frequency matrix and phase FOV include:
  - Enhanced resolution with no increase in scan time.
  - Increased flexibility to match the patient size with the FOV size through more Phase FOV choices.

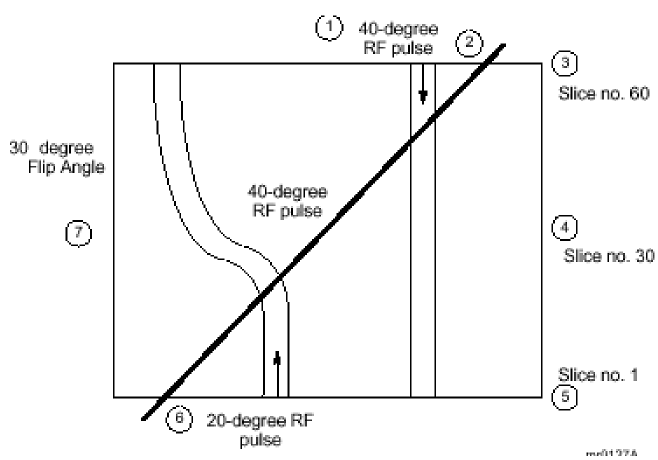
Additional 3DTOF benefits:

- An increase in the fraction of the echo sample and a special reconstruction technique resulting in improved image quality of vessels in regions of high susceptibility (e.g., in vessels near the sinuses).
- Improved SNR due to the increase in the fraction of the echo sample.
- Improved vessel to background contrast with MT -TOF.

Ramp Pulse

Ramp Pulse is an RF pulse that uses a variable flip angle over the imaging volume to reduce saturation of incoming flow. Ramped flip-angle excitation combines the benefits of custom-designed, minimum phase RF pulses with the flow selectivity and increased background suppression of larger flip angles. Ramp pulses are selected from the Vascular User CV screen.

No.	Description
1	Example of 30-degree Flip Angle Ramped RF
2	40-degree RF pulse [30 + (1/3 x 30) = 40]
3	Slice no. 60, Flip Angle 40 degrees
4	Slice no. 30, Flip Angle 30 degrees
5	Slice no. 1, Flip Angle 20
6	20-degree RF pulse [30 – (1/3 x 30) = 20]
7	30-degree Flip Angle



A ramped flip angle excitation pulse with slope 2 has a flip angle that doubles from entry to exit slice. The pulse center flip angle is prescribed; the entry and exit slice flip angles are 2/3 and 4/3 of the center flip angle, respectively. Spatially varying excitation flip angles prevent saturation of slowly flowing blood at the entry (low flip angle) part of the slab and provide suppression of venous flow with the large flip angle (exit) portion of the slab. These effects allow improved visualization of slow, in-plane, and tortuous flow, and eliminate the need for a spatial presaturation pulse to cancel venous blood signal.

Ramped Pulse Direction	Blood Flow Direction	Signal Intensity
I-S	I-S	Bright
	S-I	Dark
S-I	I-S	Dark
	S-I	Bright

Do not use Ramp Pulse when the flip angle in your protocol is between 46 and 90. In general, choose flip angles in the 20 to 45 degree range with Ramp Pulses.

Ramp Pulse offers four image quality improvements:

- improved slab profile through reducing wrap and improving image quality away from the center of the slab;
- reduced saturation of blood flow increasing the visibility of arteries;
- reduced sensitivity to venous signal; and
- shortened minimum TE.

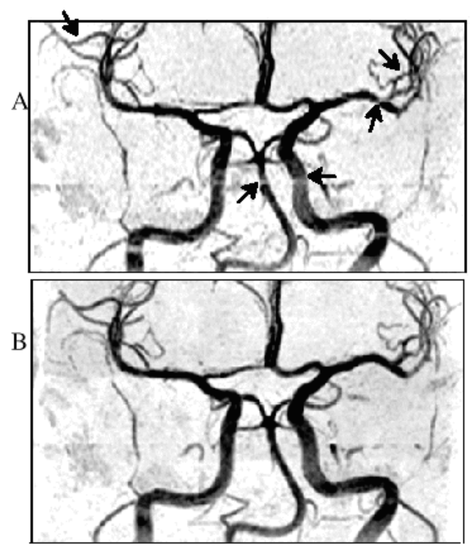
Select the Ramp Pulse flow direction based on the scan plane selected.

Scan Plane	Ramp Pulse Flow Direction
Axial	[I⟶S Flow] and [S⟶I Flow]
Head Coil Axials	[I⟶S Flow] is defaulted on. This is the only selection that the system defaults on.
Sagittal	[I⟶S Flow] and [R⟶L Flow]
Coronal	[P⟶A Flow] and [A⟶P Flow]

Applications

Uses for 3D TOF-GRE or TOF-SPGR include the following:

- AVMs
- Aneurysms of the Circle of Willis
- Intracranial carotid occlusive disease
- Imaging venous angiomas using contrast material
- With Mag Transfer to improve contrast between blood flow and surrounding tissue
- With Ramped RF to increase conspicuity of intracranial arteries
- Vessels near the sinuses where magnetic susceptibility can be a problem
- Anywhere 3DTOF is used
- To increase coverage with Slice ZIP without increasing scan time



Comparison of no slice ZIP and Slice ZIP with TR = 20ms, flow comp, TE = 2.6ms, 20 flip, 16kHz bandwidth, I S ramp, 14 x 14 cm FOV, 3 slabs, 32 slices/slab, 78 images, 256x192, 6 minutes, 19 seconds. a) Standard 3DTOF 0.9 mm thick, 3 overlaps, b) e3DTOF with 1.0 mm thick, 5 overlaps slice ZIP = 2, and ZIP 512 = 0. This comparison illustrates how Slice ZIP allowed equivalent coverage with increased overlaps in the same scan time. Also the stair-step artifact is reduced.

Something to Think About...

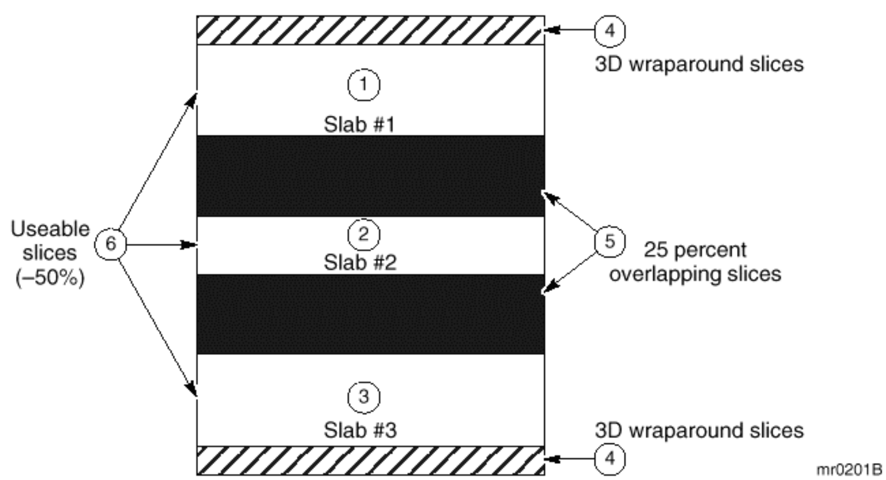
General

- 3DTOF is less sensitive to flow, which may become saturated as it passes through the imaging volume. The use of Ramp Pulses can offset some of this saturation.
- 3DTOF provides lower blood-background CNR.
- 3DTOF is effective only for relatively small volumes.
- It is not completely reliable for imaging venous anatomy without MRI contrast.
- Short T1 structures appear bright, simulating flow enhancement with 3DTOF.
- The system actually acquires two extra slices on either end of the imaging volume and throws them away due to slice aliasing.
- Deselecting projection images (i.e., selecting 0 projections) substantially increases the reconstruction speed. This can be useful with 512 and Slice ZIP.
- The minimum TR with MT is shorter with transmit/receive coils other than the body coil.
- Due to reduced minimum TR values (in particular with MT), the flip angle may be decreased to minimize saturation of small vessels.

Multi-Slab Considerations

- Ramp Pulses produce images with a variation in background suppression from entry to exit slice, and flow speed selectivity as a function of location within the slab.
- Slab boundary artifacts are more prominent with Ramped Pulses.
- Acquisition order influences the visibility of slow or in-plane flowing blood or blood flowing in tortuous vessels. Slab acquisition order is opposite that of blood flow (counter current), which improves visibility of these vessels. This allows the saturated blood to flow away from the next imaging volume. For example, a carotid artery exam prescribed superior to inferior, counter current, has improved vertebral and basilar artery conspicuity. Do not apply the superior spatial presaturation pulse with counter current acquisitions.
- If no overlap is prescribed between adjacent slabs, a substantial inter-slab boundary artifact (venetian blind) is created due to the decrease in blood-background signal to noise. An overlap of 25 percent is recommended, with uniform flip angle excitations to minimize the artifact.

Below is an example of a three-slab TOF exam.



No.	Description
1	Slab #1
2	Slab #2
3	Slab #3

No.	Description
4	3D wraparound slices 3D wraparound slices
5	25 percent overlapping slices
6	Usable slices (-50%)

Using uniform flip angle excitation and 16 slices per slab, optimal slab overlap is four slices (~ 25 percent). Because the slab excitation profiles are not perfect, it is necessary to remove two slices on the end of each slab; these contain 3D wraparound artifacts. Overlapping slices first are combined using the MIP technique, so the maximum signal, whether background or vessel, is saved in the combined image.

Imaging Considerations	
Scan Parameter	Effect of Scan Parameter.
Short TE	Reduces spin dephasing due to flow. Programs a TE that puts fat and water out of phase, e.g., 6.9 msec.
	Provides greater saturation of the stationary tissues, if the TR is shortened to 40 ms. If the TR is shorter than 40 ms, it causes spins flowing into the volume to become saturated, resulting in loss of intravascular signal intensity.
Slab orientation perpendicular to flow	Reduces partial saturation of flowing spins.
Short flip angles approximately 20°	Suppresses stationary spins if the flip angle is 15 – 20 degrees. The larger the flip angle the more saturated stationary tissue becomes, but large flip angles can affect the arterial flow, resulting in a lower signal intensity.
Flow Compensation	Reduces phase dispersion and maximizes intravascular signal when using the shortest TE possible.
Thin slices	Minimizes the effects of intravoxel dephasing.
Ramp pulses and magnetic transfer (in head)	Increases small intracranial vessel conspicuity when combined with a high-resolution acquisition.
MRI contrast agents	Visualizes venous anatomy.

This procedure is only for prescribing a 3D TOF scan. The purpose of the procedure is two-fold:

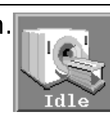
- To help understand the tradeoffs that occur when the values for a particular parameter are changed.
- To provide a framework within which a unique protocol may be built.

CAUTION: **Provide all patients with ear protection prior to any scan to help avoid possible hearing impairment.** Acoustic noise levels can exceed 99 dBA in the magnet bore.

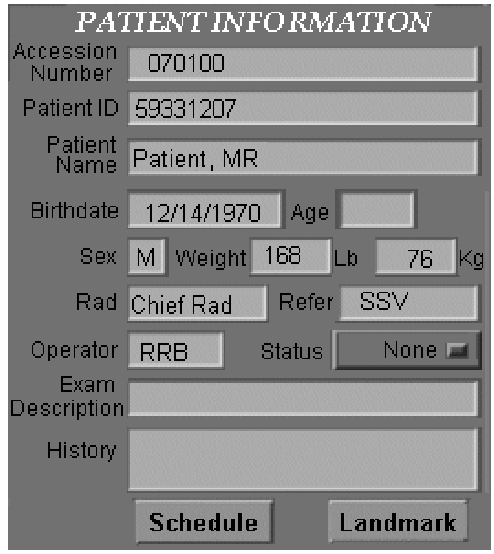
Setting up a 3D TOF pulse sequence

The decision matrix is only for prescribing a 3D Time of Flight scan. The purpose of the decision matrix to help you understand the trade-offs that occur when you change the values for a particular parameter and to provide a framework with which you may build you own unique protocol.

The selected values are only an example of what could be used for a TOF SPGR acquisition and are not to be considered recommendations by GE Medical Systems. For specific protocols, refer to the protocols on your system.

3D TOF - What you select	Selection Notes
SCAN DESKTOP screen	
	Select **Scan Desktop** icon. 

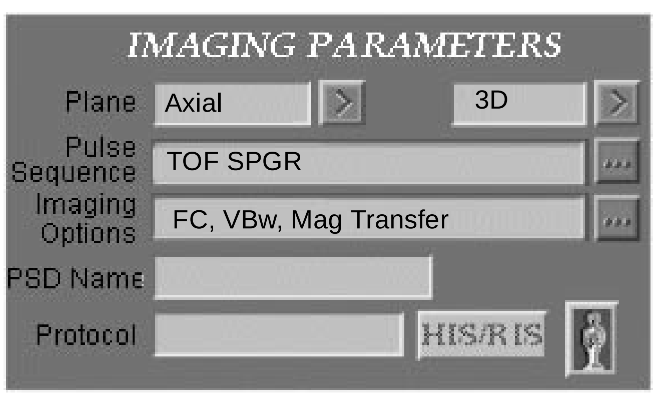
3D TOF - What you select		Selection Notes
		Click on **[New Patient]** and fill in the patient information.



PATIENT POSITION area

Patient Position	**[Supine]**	**Position and Entry:** A 3D TOF pulse sequence is compatible with any patient position and entry.
Patient Entry	**[Head First]**	
Coil	**[Body]**	**Coil:** Select the coil that produces the optimum coverage and SNR.
Series Description		**Series Description:** Enter a suitable series description. If you don not enter a description, the system enters one for you. The series description default is the selected scan mode, PSD, and imaging options.

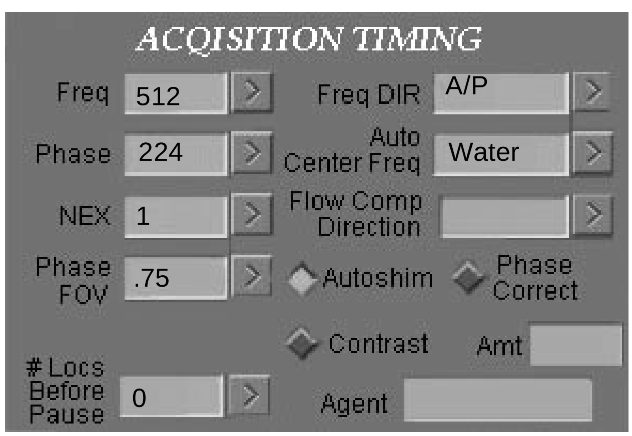
IMAGING PARAMETERS area



3D TOF - What you select		Selection Notes
Plane	**[Axial]**	**Plane:** 3D TOF is compatible with any orthogonal scan plane. Maximum flow-related enhancement occurs when blood flow is perpendicular to the scan plane.
Mode	**[3D]**	**Mode:** Select [3D].
Pulse Seq	**[TOF SPGR]**	**Pulse Seq:** Select [TOF-GRE] or [TOF-SPGR]. Click **[**Accept**]** to register the selection.
Imaging Options	**[FC, VBw, Mag Transfer]**	**Imaging Options:** Use of Flow Comp may increase the signal from blood by rephasing the moving spins. Use of Mag Transfer isn't necessary but improves visualization of vessels. Select ZIP 512 to enhance in-plane resolution with only a small decrease in SNR, but with a tradeoff in reconstruction time and disk storage (the image is reconstructed and stored as a 512x512 image data set). Select a Slice ZIP factor, ZIP x 2 or ZIP x 4, to increase the number of slices (by a factor of 2 or 4) without increasing the scan time. Selecting a Slice ZIP improves MIP and reformat image quality. Select other imaging options that optimizes SNR and spatial resolution. Click **[Accept]** to register the selections.
PSD Name	**N/A**	**PSD Name:** Not applicable for 3D TOF.
Protocol	**N/A**	
SCAN TIMING area		
# of echoes	**[1]**	**# of echoes:** Only one echo is allowed for vascular sequences.
TE	**[Min]**	**TE:** Select the minimum TE for minimum dephasing effects. This is the only selection when Flow Comp is not on. Alternatively select Flow Comp with TE= 6.9 at 1.5 or TE= 10.3 at 1.0T to reduce the fat signal. Minimum TE changes as RBw changes.
TE2	**N/A**	**TE2:** Long TEs produce: decreased # of slices, increased T2 contrast, and decreased SNR.
TR	**[40]**	**TR:** Minimum TR may be as low as 30 ms. As TR decreases background tissue saturation increases and signal from blood can decrease as it moves through the imaging volume. Selection of TR that is too short (< 33 ms) can result in suppression of smaller vessels.
TI	**N/A**	
Flip Angle	**[20]**	**Flip Angle:** Due to low minimum TR values (in particular with MT), the Flip Angle may be decreased to minimize saturation of small vessels.
Echo Train Length	**N/A**	

3D TOF - What you select		Selection Notes
Bandwidth	**[15.63]**	**Bandwidth:** As the RBw decreases, SNR increases and minimum TE increases. Choose a RBw that is a compromise between SNR and short TE requirements. Wider RBw is allowed with 512 frequency matrix.
Bandwidth 2	**N/A**	
SCANNING RANGE area		
FOV	**[24]**	**FOV:** Select a FOV that covers the anatomy of interest. Anatomy outside the FOV in the phase direction results in aliasing. Small FOVs produce: increased resolution, decreased SNR, and can increase the minimum TE value.
Slice Thickness	**[1]**	**Slice Thickness:** Increasing slice thickness results in increased SNR, decreased resolution, increased coverage, and increased saturation of flowing spins as they move through the volume.
# of Scan Locs	**[64]**	**# of Scan Locs:** Choose a value from 8 – 128 in multiples of 2 (e.g., 16, 18, 20, 22...). There is always 2 slices on either end of the slab that are discarded. Factor these 4 slices into the selection.
Start, End Locations		**Start, End Locations:** This area indicates the first and last location of the deposited slab(s) or volume(s) and includes two discard slices on either end of the slab(s). Graphic Rx must be used to deposit the slab(s).
# Slices	**[1]**	**# Slices:** This value is entered automatically when slabs are deposited in Graphic Rx. Multiple, smaller slabs decrease saturation of slow moving and in-plane flow. Increasing the # of Slabs, increases the scan time. Prescription of slabs outside the localizer FOV is not allowed. Multi-slab scans are not allowed with ZIP 512 or Slice ZIP.

ACQUISITION TIMING area



3D TOF - What you select		Selection Notes
Freq	**[512]**	**Freq:** As the frequency matrix increases, the resolution increases and SNR decreases. A frequency matrix from 128 – 512 can be selected in increments of 32.
Phase	**[224]**	**Phase:** As phase matrix increases, the resolution increases, SNR decreases, scan time increases.
NEX	**[1]**	**NEX:** Select a NEX value that produces sufficient SNR.
Phase FOV	**[0.75]**	**Phase FOV:** A PFOV less than 1 (range from 0.5 – 1.0) can be selected if it doesn't result in anatomy outside the phase FOV. PFOV automatically rounded to the nearest 1/16.
Freq DIR	**[A/P]**	**Freq DIR:** The direction displayed is the default frequency direction which is typically the long axis of the image. To swap phase and frequency, select the other direction.
Auto Center Freq	**[Water]**	**Auto Center Freq:** Select the CF peak that is set during prescan.
Flow Comp DIR	**N/A**	
Autoshim	**[On]**	**Autoshim:** Click **[Autoshim]** to improve homogeneity.
Phase Correct	**N/A**	
# of Acqs/Locs Before Pause	**N/A**	
Additional Parameters SAT Screen		
SAT	**N/A**	Use of a Ramp Pulse eliminates the need to spatially saturate unwanted flow.
GRAPHIC RX Screen		

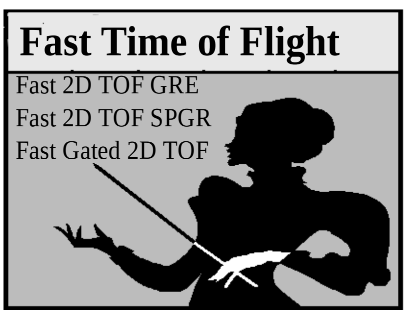
3D TOF - What you select		Selection Notes
Click on the image to display the line cursor for Graphic Rx.		The SAT band function can be accessed from the GRAPHIC Rx window and vice versa. If you had graphically prescribed the previous axial series the same prescription can be copied using the **[Copy RX]** button. Consider using an offset to center the anatomy in the middle of the screen so that you can use a PFOV less than 1 and therefore reduce the scan time. Multi-slab: Use cursor to define # of slabs. Move the crosshair cursor to the desired location for the center of the volume of the first slab. Click and hold the left mouse button. A box appears on the localizer image. The cursor turns into a pointer. Drag the pointer across the image to the desired end location, then release the left mouse button. As the cursor is dragged across the image, multiple 3D volumes are deposited. The number of volumes is based on the FOV, slab thickness, overlap, and the number of locations per slab. To adjust the location of the slab, place the cursor over one of the slabs and click and drag the set of slabs to a new location. Release the left mouse button to deposit the slabs. Click **[Accept]** to register the selection.
Vascular Options Screen		
Projection Images	**[19]**	**Projection Images:** Enter 19 or 37 to automatically create projection images.
Collapse	**[On]**	**Collapse:** Click [On] to get a collapsed view in the plane of acquisition.
Ramp Pulse	**[I-S]**	**Ramp Pulse:** Select a ramp pulse that is in the direction of the flow.
SCAN OPERATIONS area		
	[Save Series] **[Prep to Scan]** **[Auto Prescan]** **[Scan]**	Enter data in all the text boxes and click on **[Save Series]**. The series is saved as RXD.

Volume 2

Chapter 7

Imaging with Fast Time of Flight Pulse Sequences

Where Am I?



Introduction

This chapter explains the pulsing components and timing factors directly related to the Time of Flight pulse sequences. This chapter explains the concepts of each, and the step-by-step instructions to help you learn how to:

- Optimize Fast Time of Flight GRE images
- Optimize Fast Time of Flight SPGR images
- Optimize Fast Gated Time of Flight images
- Set up a Fast Time of Flight sequence
- Set up a Fast Gated Time of Flight sequence

In addition, this chapter answers the following questions:

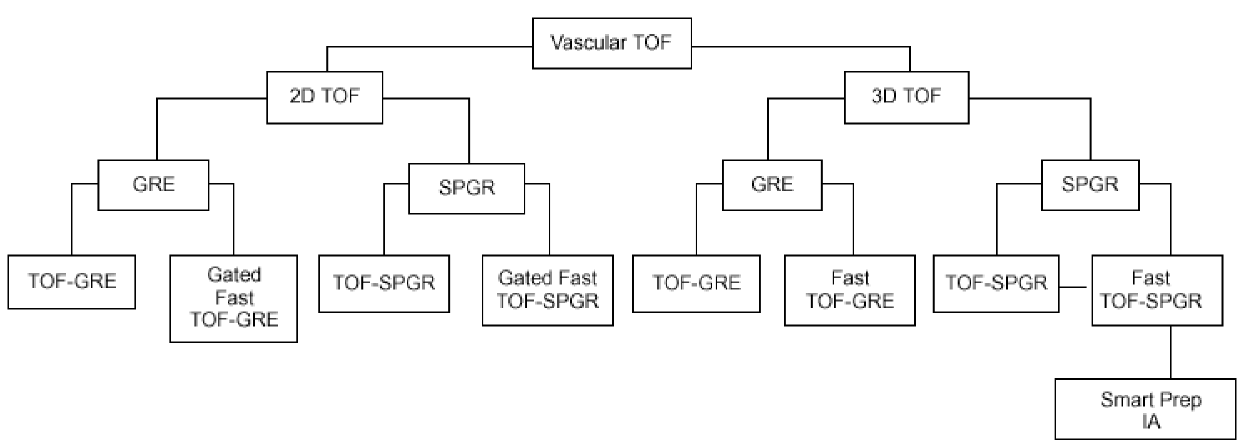
1. What is the RF pulsing pattern?
2. How do the timing factors control the RF pulsing?
3. How do TR and flip angle regulate saturation effects?
4. How does TE regulate dephasing effects?
5. What special imaging options are enabled by Fast TOF and how do they work?
6. How are the TOF sequences classified?
7. What are the image characteristics?
8. What are the applications?

About... Fast Time of Flight Pulse Sequences

This section presents the concepts necessary to understand Fast Time of Flight pulse sequences. Specifically you need to understand:

- Fast 2D Time of Flight GRE/SPGR
    - Fast Gated 2D TOF
        - Trigger Delay
        - SAT gap
    - Image characteristics
    - Associated imaging options
    - Applications for Fast TOF GRE/SPGR
- Fast Gated 3D TOF GRE/SPGR
    - Image characteristics
    - Associated imaging options
    - Applications for Fast Gated 2D TOF

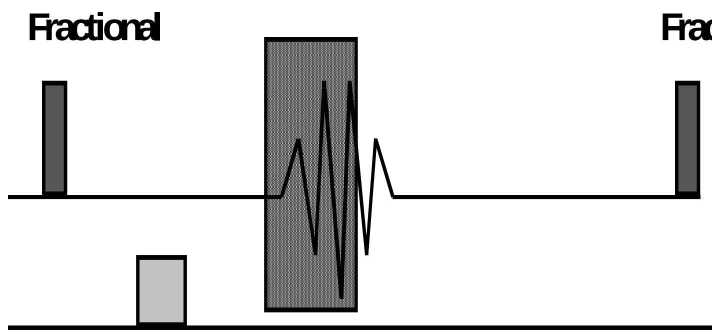
There are several different pulse sequences within the vascular TOF family they are all related to the gradient echo family of pulse sequences.



Fast 2D Time of Flight GRE/SPGR

Like Time of Flight (TOF), Fast Time of Flight (Fast TOF) imaging is based on conventional gradient echo scanning with Flow Compensation. This imaging technique relies primarily on flow-related enhancements to distinguish moving from stationary spins in creating MRI angiograms.

Fast Time of Flight uses fractional echo, fractional RF and wider receive bandwidth to obtain shorter TR and TE than standard TOF. By using a fractional RF this shortens the duration of the excitation pulse, along with the readout time, thus shorting the overall total time required to play out the sequence.



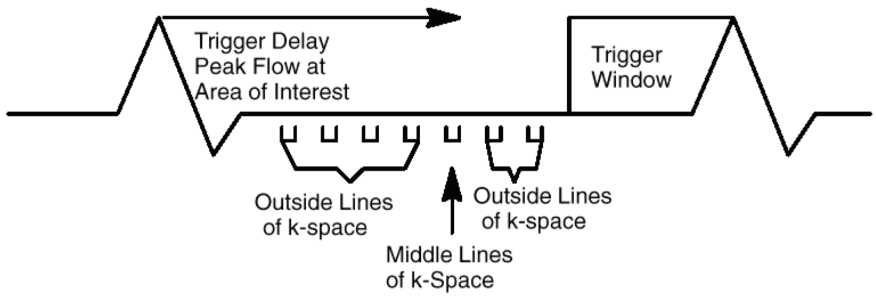
Gated 2D TOF

Gated 2DTOF is a Fast GRE pulse sequence designed to reduce pulsatile flow artifact for peripheral MRA exams. This is achieved by synchronizing the data acquisition with the heart rate and segmenting K-space within the cardiac cycle in a manner that optimizes image contrast (makes blood brighter).

Gated 2DTOF introduces a new definition for the gating parameter Delay After Trigger. Delay After Trigger is the parameter used by the system to determine when the center of K-space is acquired. The center of K-space contributes primarily to image signal and contrast while the outer edges of K-space contribute primarily to the image resolution (edge detail). Typically select a Delay After Trigger time to occur at the peak of the systolic phase which is when the blood flow is fastest.

Selections are made at the Gating screen for Gated TOF imaging. Either ECG or PG leads can be used depending on the area of interest.

Views Per Segment, one of the Gating scan parameters, is used to increase scan time by collecting multiple views (K-space lines) that contribute to a single image.



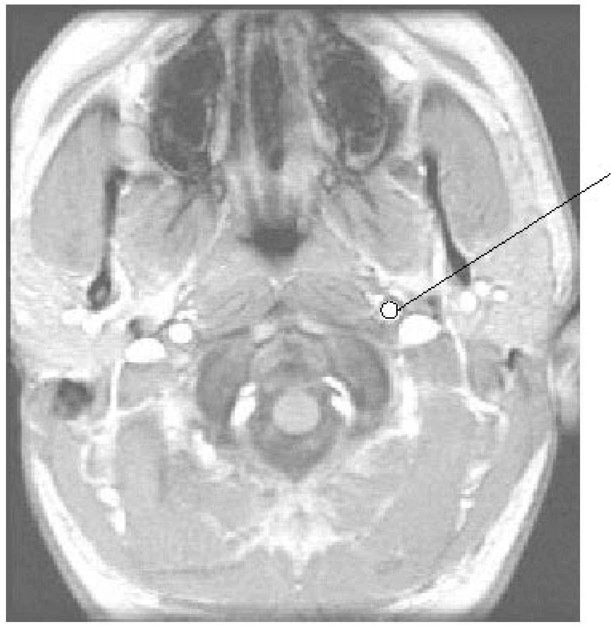
Program a delay time when blood flow is fastest — typically at end systole for the area of interest.

Center lines of K-space are filled during this data acquisition time. Selecting a Delay After Trigger time to coincide with the peak flow of the area of interest produces the best contrast between blood and background. To determine the optimum time, use a Fast Phase Contrast acquisition and the MIROI display program:

- Acquire a Fast 2DPC image set of the vessels of interest with reconstruction of flow direction images. For example: For a gated TOF of the Carotid arteries, acquire a 2DPC set of axial images with a S/I flow direction selected. Blood in the phase images is bright for flow moving superior to inferior. Inferior to superior flow is black (carotid artery flow is seen as black).
- Select the Fast 2DPC images and enter the MIROI program.

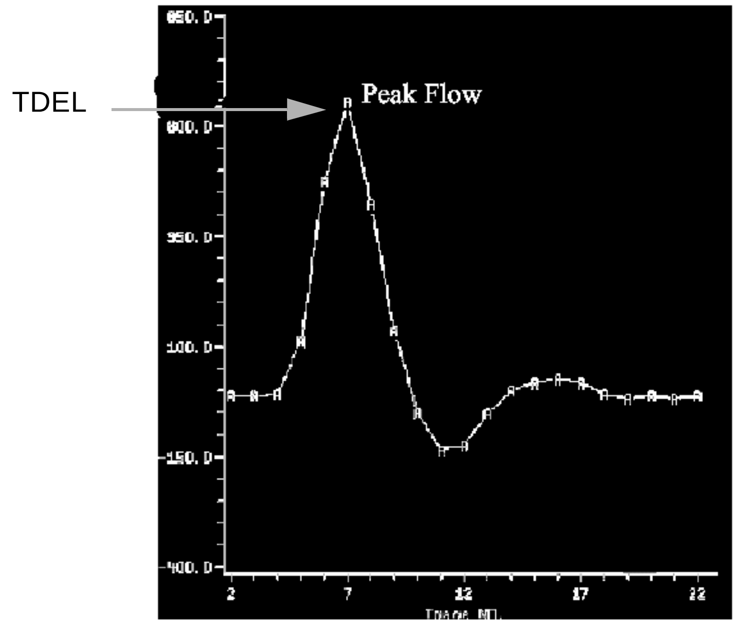
To Determine Trigger Delay:

1. Select a phase image from the Fast 2DPC image set and click MIROI.
2. Place ROI inside a vessel of interest and choose [Accept].



FastPC can help determine the trigger delay for gated 2D TOF. [Shown here: Axial magnitude image. You would normally select the equivalent S/I flow (phase) image.] When using the 2D PC phase image for the "localizer", remember that arterial flow is dark for vessels above the heart. This means that for a carotid scan, you would place *the ROI on a dark vessel and for iliacs you would place the ROI on a bright vessel.*

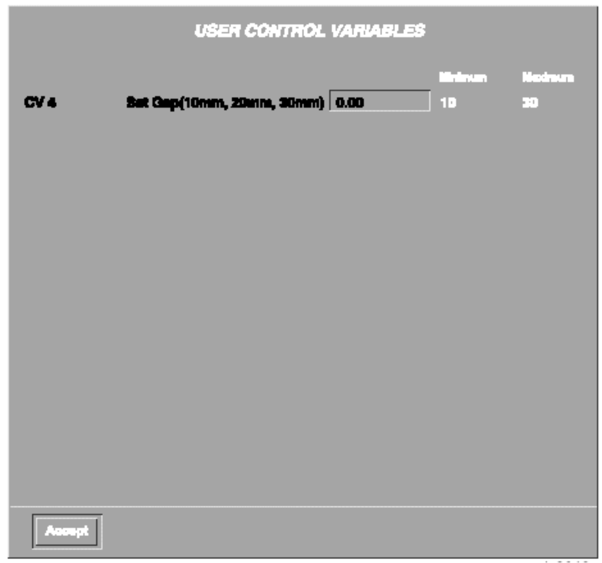
3. Each point on the graph represents a slice within the series.



4. Note the image number that is before the highest peak if white blood is being used. Use the lowest peak for black blood. For example: 2D PC phase images of the carotid arteries, with S/I flow selected, shows black carotids and the "peak" shows in the negative direction.

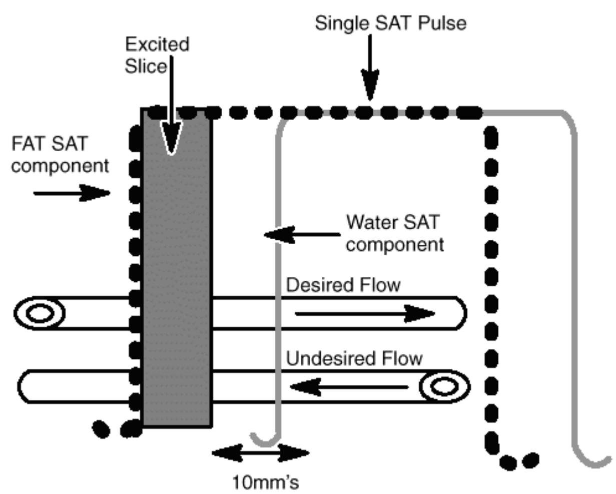
5. View the image and note the TDEL (time of delay) of the image number. Enter this time for the Trigger Delay on the Gating screen during your gated TOF prescription. If the time delay you enter is smaller than the minimum value allowed you will have to use the minimum value. For example, if the time delay noted in the MIROI program shows the peak systolic time to be 155 msec but the

minimum delay you can enter is may be 177 msec, then you must use 177 msec.



SAT Gap

Gated TOF spatial saturation pulses are designed to produce fat suppression. The effectiveness of the fat saturation is maximized at a 10 mm SAT gap. As the SAT gap increases, the fat suppression becomes less effective. In regions of highly pulsatile flow (e.g. popliteal, iliac) a narrow SAT gap can result in pulsatile artifacts due saturation of retrograde flow.



The very narrow bandwidth and chemical shift of 220 Hz between fat/water (at 1.5T) causes a spatial shift of the FAT SAT portion of the SAT pulse to "cover" the excited slice.

Something to Think About...

- A solution to the retrograde flow artifact, is to increase the SAT gap which moves the SAT pulse farther away from the slice. As the SAT gap increases, the ghosting from retrograde flow decreases but so does the fat suppression effects. Typically, a SAT gap greater than 10 mm is only used in areas where there is strong pulsatile flow, for example in the popliteal vessels.
- If the number of Views Per Segment results in the available imaging time being exceeded, a message is posted directing either the number of Views Per Segment be reduced or the trigger window be shortened.

Time of Flight Image Characteristics

Fast TOF posses the same image characteristics as conventional TOF images. They too, are inherently low in SNR. Intra-voxal phase dispersion decreases SNR and is affected by voxel size, sequence timing and flow dynamics.

Images with flowing nuclei are bright while stationary nuclei are dark. Stagnant, slow flow or in-plane flow produces decreased signal as it becomes saturated.

Associated Imaging Options

In the following table the X's indicate the option available for use with the Fast Time of Flight pulse sequences.

Imaging Options			
X	None	**X**	Variable Bandwidth
X	Flow Compensation	**X**	No Phase Wrap
	POMP		Extended Dynamic Range
X	Square Pixel		Surface Coil Intensity Correction
	Respiratory Compensation		Classic
X	Magnetization Transfer	**X**	Sequential
X	Cardiac Gating/Triggering		Respiratory Gating/Triggering
	Tailored RF	**X**	IR Prepared
X	DE Prepared		Multi-Phase

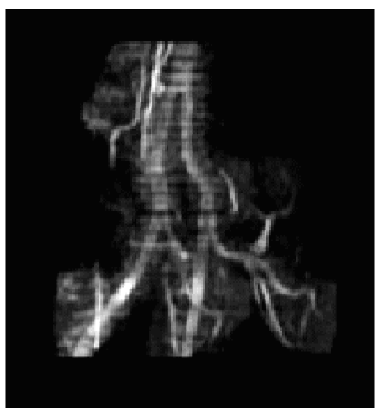
Imaging Options			
	Full Echo Train		CCOMP
X	ZIP 1024	**X**	ZIP 512
X	Zip x 2	**X**	ZIP x 4
	SmartPrep		Blood Suppression
	Multi Station		Real Time

NOTE: Magnetization Transfer, ZIP 512, 1024, ZIPx2, and ZIPx4 are not compatible with Fast 2D TOF pulse sequences.

Applications

Gated 2D TOF is used for:

- Reduce artifacts due to pulsatile flow
- Acquire aortic bifurcation and iliac images



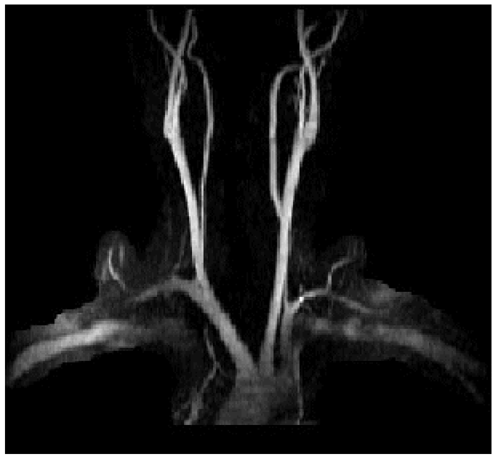
Standard TOF

Gated TOF

Standard TOF: TR = 35, TE = 4.4, Flip = 45, 100 slices, 6:47. Gated TOF: TR = 19, TE = 4.4, Flip = 45, 100 slices, 32 VPS, 9:23.

- Acquire popliteal artery images

- Acquire carotid images and images of the origins of the carotids



Fast Gated TOF 7:25

Standard TOF 6:32

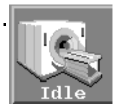
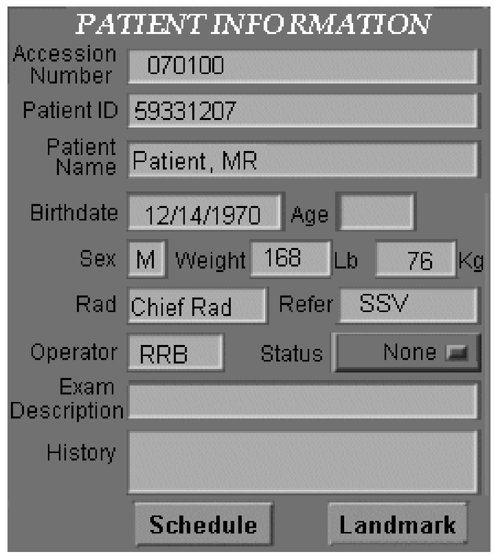
CAUTION: **Provide all patients with ear protection prior to any scan to help avoid possible hearing impairment.** Acoustic noise levels can exceed 99 dBA in the magnet bore.

Setting up a Gated 2D TOF pulse sequence

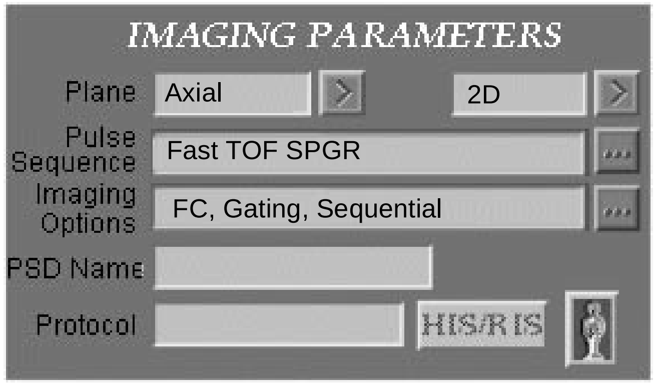
The decision matrix is only for prescribing a Gated 2D Time of Flight scan. The purpose of the decision matrix to help you understand the trade-offs that occur when you change the values for a particular parameter and to provide a framework with which you may build you own unique protocol.

The selected values are only an example of what could be used for a Gated 2D TOF acquisition and are not to be considered recommendations by GE Medical Systems. For specific protocols, refer to the protocols on your system.

.

Gated 2D TOF - What you select		Selection Notes
SCAN DESKTOP screen		
		Select **Scan Desktop** icon.  Click on **[New Patient]** and fill in the patient information. 
PATIENT POSITION area		
Patient Position	**[Supine]**	**Position and Entry:** A Gated TOF pulse sequence is compatible with any patient position and entry.
Patient Entry	**[Feet First]**	
Coil	**[Torso]**	**Coil:** Select the coil that produces the optimum coverage and SNR.
Series Description		**Series Description:** Enter a suitable series description. If you don not enter a description, the system enters one for you. The series description default is the selected scan mode, PSD, and imaging options.

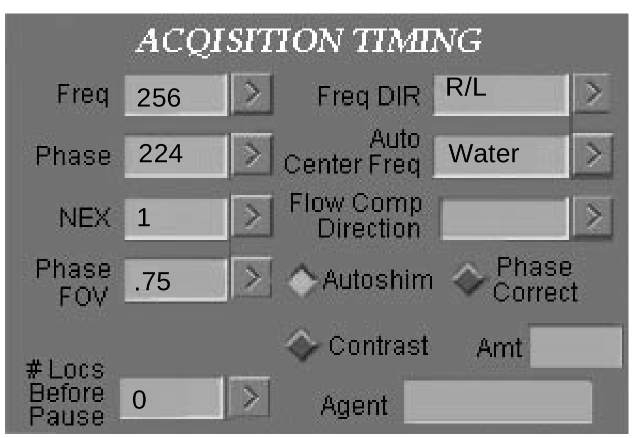
Gated 2D TOF - What you select		Selection Notes
	IMAGING PARAMETERS area	



Plane	**[Axial]**	**Plane:** Gated TOF is compatible with any scan plane except 3-Plane. Select the plane that best meets the clinical need.
Mode	**[2D]**	**Mode:** Select [2D].
Pulse Seq	**[Fast TOF SPGR]**	**Pulse Seq:** Gated TOF is only compatible with Fast TOF GRE or Fast TOF SPGR. SPGR typically reduces the signal from fat more than TOF. Click **[Accept]** to register the selection.
Imaging Options	**[FC, Gating, Sequential]**	**Imaging Options:** Select [Gating] and [Sequential]. Use of Flow Comp may increase the signal from blood by rephasing moving spins, but Flow Comp increases the minimum TE. Select other imaging options that optimizes SNR and spatial resolution. Click **[Accept]** to register the selections.
PSD Name	**N/A**	**PSD Name:** Not applicable for Gated TOF.
Protocol	**N/A**	
	SCAN TIMING area	
# of echoes	**[1]**	**# of echoes:** Only 1 echo is allowed.
TE	**[Min]**	**TE:** Use the minimum TE for minimal dephasing effects. Minimum TE changes as RBw changes.
TR	**[Min]**	**TR:** Use the minimum TR to allow the largest number of Views Per Segment which can reduce the scan time.
TI	**N/A**	
Flip Angle	**[60]**	**Flip Angle:** As the flow gets faster, the flip angle may be increased. Increased Flip Angle produces increased T1 contrast and increased SNR.
Echo Train Length	**N/A**	

Gated 2D TOF - What you select		Selection Notes
Bandwidth	**[16]**	**Bandwidth:** As Receive Bandwidth increases, the minimum TE decreases, but also the SNR decreases. Choose a RBw that is a compromise between SNR, TE and Views Per Segment.
Bandwidth 2	**N/A**	
SCANNING RANGE area		
FOV	**[36]**	**FOV:** Select a FOV that covers the anatomy of interest. Anatomy outside the FOV in the phase direction results in aliasing. Small FOVs produce: increased resolution, decreased SNR, and can increase the minimum TE value.
Slice Thickness	**[2.0]**	**Slice Thickness:** Thin slices produce increased flow-related enhancement, reduce effects of in-plane flow, increase resolution and decrease SNR. Consider the anatomy to be covered also.
Overlap	**[.7]**	**Overlap:** An overlap is prescribed to reduce partial volume effects. Decreasing the overlap results in decreased scan time since fewer slices are needed to cover the desired anatomy, however, increased partial volume artifacts result as overlap decreases.
Start, End Locations		**Start, End Locations:** Typically the start and end locations are programmed from the Graphic Rx program. As many slices as needed to cover the desired anatomy may be prescribed. As # of locations increases, total scan time increases.
# Slices	**[16]**	**# Slices:** This text box indicates the number of locations prescribed.

ACQUISITION TIMING area



Gated 2D TOF - What you select		Selection Notes
Freq	**[256]**	**Freq:** Increasing the frequency matrix produces: increased resolution and decreased SNR.
Phase	**[224]**	**Phase:** Phase controls scan time and may control resolution.
NEX	**[1]**	**NEX:** Select a NEX value that produces sufficient SNR. As NEX increases so does the SNR and scan time.
Phase FOV	**[.75]**	**Phase FOV:** Select .75 or .5 to reduce phase steps and thus decrease scan time, decreasing FOV in the phase direction, and decreasing SNR slightly. The phase FOV dimension is displayed next to the phase FOV factor.
Freq DIR	**[R/L]**	**Freq DIR:** The direction displayed is the default frequency direction which is typically the long axis of the image. To swap phase and frequency, select the other direction.
Auto Center Freq	**[Water]**	**Auto Center Freq:** Select the CF peak that is set during prescan.
Flow Comp DIR	**N/A**	
Autoshim	**[Off]**	**Autoshim:** Click **[Autoshim]** to improve the homogeneity.
Phase Correct	**N/A**	
# of Acqs/Locs Before Pause	**[None]**	**# of Acqs/Locs Before Pause:** Although this text box is available, pauses are generally not used with TOF scans. Breath-hold exams are usually not done due to differences in anatomical location from slice.
Additional Parameters SAT Screen 		
I	**[80]**	**SAT:** Select spatial SAT pulses perpendicular to the flow and in a direction that reduces unwanted flow. To suppress arterial flow above the heart use a superior SAT pulse, and to suppress arterial flow below the heart use an inferior SAT pulse. Only use the User CV screen to alter the SAT pulse location (gap). Entering a new location at the SAT screen eliminates Concatenated SAT.
Additional Parameters Vascular Options Screen		
Projection Images	**[19]**	**Projection Images:** Choose [19] or [37] to automatically create projection images.
Collapse	**[On]**	**Collapse:** Click [On] to get a collapsed view in the plane of acquisition.
GRAPHIC RX Screen		

Gated 2D TOF - What you select		Selection Notes
Click on the image to display the line cursor for Graphic Rx.		To optimize flow-related enhancement, prescribe the slices I S when imaging arterial flow below the heart, and from S I when imaging above the heart. To prescribe oblique slices **Oblique** must be selected in the Plane pull-down menu. If the previous coronal series was graphically prescribed, the same prescription can be copied using **[Copy Rx]**. Consider using an offset to center the anatomy in the middle of the screen so that you can use a PFOV less than 1 and therefore reduce the scan time. View the Advisory area to note the # of Acqs being prescribed. The scan time increases as the # of Acquisitions increases.
User CV Screen		
SAT Gap	**[10]**	**SAT Gap:** Increase the SAT Gap as the area to be scanned gets farther away from the heart. Increasing the SAT Gap and the fat suppression and the retrograde flow artifacts decreases. A 10 mm SAT Gap is typically used for carotid and iliac vessel exams and a 20 mm SAT Gap is typically used for distal femoral and popliteal vessel exams.
Gating Screen		
Trigger Type	**[Auto Lead]**	**Trigger Type:** Use ECG for all regions except carotids. PG may be used for carotids including the aortic arch. Click `Auto` lead to allow the system to choose the best ECG lead. Select `PG` for Peripheral gating.
Heart Rate (bpm)	**[Update bpm]**	**Heart Rate:** Click [Update bpm] to let the system obtain an automatic reading of the current heart rate or, the bpm may be manually entered by observing the monitor.
Trigger Window	**[Auto]**	**Trigger Window:** Auto Trigger Window adjusts the “waiting for the next R-wave” window based on the patient’s cardiac rhythm.
Trigger Delay	**[184]**	**Trigger Delay:** Choose the Trigger Delay based on the information acquired by viewing the patient’s Phase Contrast acquisition in the MIROI program.
Views Per Segment	**[28]**	**Views Per Segment:** As the # of Views Per Segment increases, scan time decreases. Typically the shortest scan time with the most slices possible is desirable.
SCAN OPERATIONS area		

Gated 2D TOF - What you select	Selection Notes
[Save Series] **[Prep to Scan]** **[Auto Prescan]** **[Scan]**	Enter data in all the text boxes and click on **[Save Series]**. The series is saved as RXD.

Fast 3D TOF GRE/SPGR

Fast 3D TOF is a Fast GR/SPGR sequence designed for use in vascular imaging.

Fast 3D TOF provides the benefits of a 3D acquisition with the use of faster TRs and TEs to decrease imaging time. Fast 3D TOF has the same expanded Imaging Option choices as 3DTOF, i.e., ZIP 512, Slice ZIP x 2 and Slice ZIP x 4.

Choose a TE from Minimum, Minimum Full, F/W out of phase or F/W in phase. Options:

- Select `Minimum` for fractional echo.
- Select `Minimum Full` for full echo.
- Select F/W in phase and the system automatically fits the TE into a fat/water in-phase range.
- Select F/W out of phase and the system automatically fits the TE in a fat/water out-of-phase range.

With either F/W in phase or F/W out of phase, the system uses a full echo if the minimum TE for the appropriate range can be achieved with a full echo. If not, the system uses a fractional echo with the shortest possible TE.

Depending on the sequence selected, the system automatically determines the minimum TR based on other parameter values.

Images are annotated `3D/TOF/FSPGR/Flip Angle`.

Something to Think About...

- Due to shorter TRs, Fast 3D TOF results in less SNR when compared to non-fast 3D TOF.
- Due to rapid changing of gradients there is an increased noise level.
- When using SAT, some restrictions apply:
  - SAT cannot be applied on more than one axis.
  - Two SAT bands cannot lie on the same axis at two different thicknesses.

  - ° The system does not allow prescribing one SAT band graphically and another explicitly. This limitation is due to timing constraints within the pulse sequence to allow for short TRs.

- Ramp pulses are not available with Fast 3D TOF.
- The number of slices available is 12 – 124 in steps of two.
- FGRE 3D's T1 weighting depends on the parameters selected. In general, T1 weighting increases as flip angle increases and TR and TE decrease. A smaller flip angle and low TE result in density-weighted images. With FGRE 3D, the flip angle is limited to 60 degrees.

Associated Imaging Options

In the following table the X's indicate the option available for use with the Fast 3D Time of Flight pulse sequences.

Imaging Options			
X	None	**X**	Variable Bandwidth
	Flow Compensation	**X**	No Phase Wrap
	POMP		Extended Dynamic Range
X	Square Pixel		Surface Coil Intensity Correction
	Respiratory Compensation		Classic
X	Magnetization Transfer		Sequential
	Cardiac Gating/Triggering	**X**	Respiratory Gating/Triggering
	Tailored RF		IR Prepared
	DE Prepared	**X**	Multi-Phase
	Full Echo Train		CCOMP
X	ZIP 1024	**X**	ZIP 512
X	Zip x 2	**X**	ZIP x 4
X	SmartPrep		Blood Suppression
X	Multi Station		Real Time

Applications

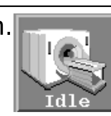
Provides the shortest TE and TR times possible for uncooperative or pediatric patients.

CAUTION: **Provide all patients with ear protection prior to any scan to help avoid possible hearing impairment.** Acoustic noise levels can exceed 99 dBA in the magnet bore.

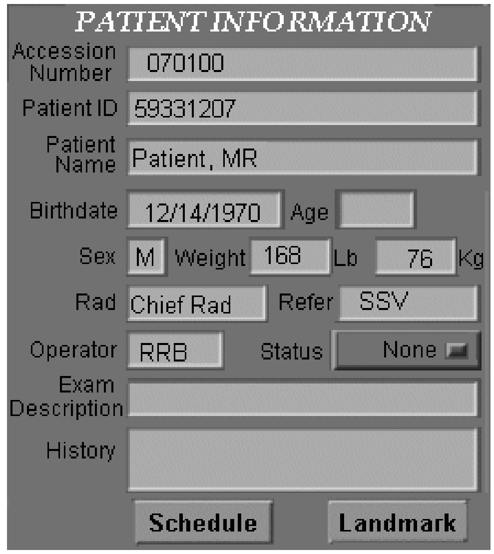
Setting up a Fast 3D TOF pulse sequence

The decision matrix is only for prescribing a Fast 3D Time of Flight scan. The purpose of the decision matrix to help you understand the trade-offs that occur when you change the values for a particular parameter and to provide a framework with which you may build you own unique protocol.

The selected values are only an example of what could be used for a Fast 3D TOF GRE acquisition and are not to be considered recommendations by GE Medical Systems. For specific protocols, refer to the protocols on your system.

Fast 3D TOF - What you select	Selection Notes
SCAN DESKTOP screen	
	Select **Scan Desktop** icon. 

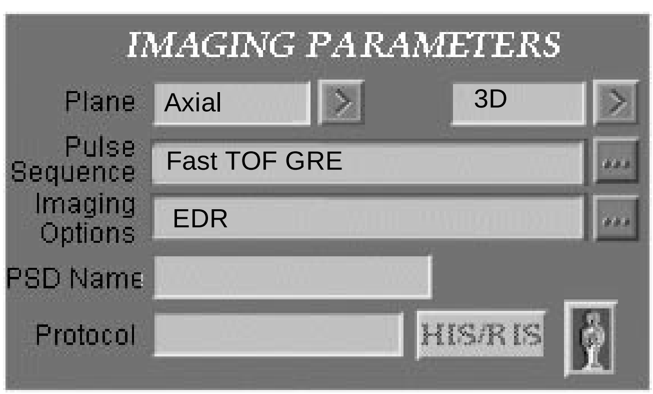
Fast 3D TOF - What you select		Selection Notes
		Click on **[New Patient]** and fill in the patient information.



PATIENT POSITION area

Patient Position	**[Supine]**	**Position and Entry:** A Fast 3D TOF pulse sequence is compatible with any patient position and entry.
Patient Entry	**[Head First]**	
Coil	**[Head]**	**Coil:** Select the coil that produces the optimum coverage and SNR.
Series Description		**Series Description:** Enter a suitable series description. If you don not enter a description, the system enters one for you. The series description default is the selected scan mode, PSD, and imaging options.

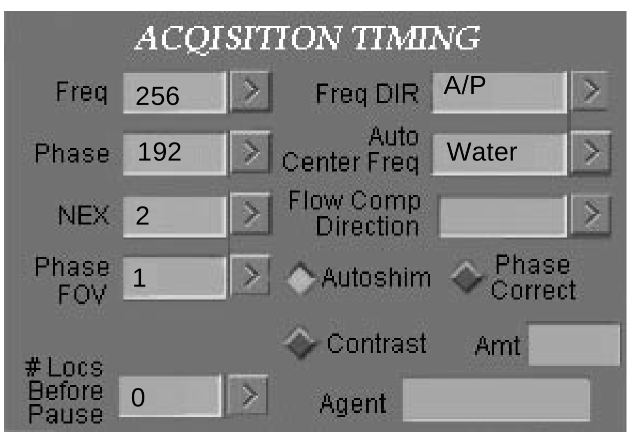
IMAGING PARAMETERS area



Fast 3D TOF - What you select		Selection Notes
Plane	**[Axial]**	**Plane:** Fast 3D TOF is compatible with any orthogonal scan plane. Maximum flow-related enhancement occurs when blood flow is perpendicular to the scan plane.
Mode	**[3D]**	**Mode:** Select [3D].
Pulse Seq	**[Fast TOF GRE]**	**Pulse Seq:** Select [Fast TOF-GRE] or [Fast TOF-SPGR]. Select **[**Accept**]** to register the selection.
Imaging Options	**[EDR]**	**Imaging Options:** Select other imaging options that optimizes SNR and spatial resolution. Use of Flow Comp and Mag Transfer is not allowed. These options would result in increased TEs and TRs. Select ZIP 512 to enhance in-plane resolution with only a small decrease in SNR, but with a tradeoff in reconstruction time and disk storage (the image is reconstructed and stored as a 512x512 image data set). Select a Slice ZIP factor, ZIP x 2 or ZIP x 4, to increase the number of slices (by a factor of 2 or 4) without increasing the scan time. Selecting a Slice ZIP improves MIP and reformat image quality. Select other imaging options that optimizes SNR and spatial resolution. Click **[Accept]** to register the selections.
PSD Name	**N/A**	**PSD Name:** Not applicable for 3D TOF.
Protocol	**N/A**	
	SCAN TIMING area	
# of echoes	**[1]**	**# of echoes:** Only one echo is allowed for vascular sequences.
TE	**[Min]**	**TE:** Use the minimum TE for minimum dephasing effects. Select F/W out of phase to decrease fat signal. Higher TEs may increase minimum TR and increase scan time. Minimum TE changes as RBw changes.
TE2	**N/A**	**TE2:** Long TEs produce: decreased # of slices, increased T2 contrast, and decreased SNR.
TR	**N/A**	**TR:** The minimum TR is set by the system based other parameters such as TE, RBw, FOV and Matrix.
TI	**N/A**	
Flip Angle	**[20]**	**Flip Angle:** Choose a Flip Angle to produce the desired contrast. Due to reduced minimum TR values the Flip Angle may be decreased to minimize saturation of small vessels.
Echo Train Length	**N/A**	

Fast 3D TOF - What you select		Selection Notes
Bandwidth	**[15.63]**	**Bandwidth:** RBw can only be changed if it was selected from the Imaging Options window. As the RBw decreases, SNR increases, chemical shift artifact increases, and minimum TE increases (which can increase Minimum TR).
Bandwidth 2	**N/A**	
	SCANNING RANGE area	
FOV	**[24]**	**FOV:** Select a FOV that covers the anatomy of interest. Anatomy outside the FOV in the phase direction results in aliasing. Small FOVs produce: increased resolution, decreased SNR, and can increase the minimum TE value.
Slice Thickness	**[1.5]**	**Slice Thickness:** Increasing slice thickness results in increased SNR, decreased resolution, increased coverage, and increased saturation of flowing spins as they move through the volume.
# of Scan Locs	**[140]**	**# of Scan Locs:** Enter a value from 12 - 124 in multiples of 2 (e.g., 16, 18, 20, 22...). There will always be 2 slices on either end of the slab that are discarded. Factor these 4 slices into the selection.
Start, End Locations		**Start, End Locations:** This text box indicates the first and last location of the deposited slab(s) or volume(s) and includes two discard slices on either end of the slab(s). Graphic Rx must be used to deposit the slab(s).
# Slabs	**[1]**	**# Slabs:** Multi-slab is not allowed.

ACQUISITION TIMING area



Freq	**[256]**	**Freq:** As the frequency matrix increases, the resolution increases and SNR decreases.
Phase	**[192]**	**Phase:** Phase controls scan time and resolution.

Fast 3D TOF - What you select		Selection Notes
NEX	**[2]**	**NEX:** Select a NEX value that produces sufficient SNR yet doesn't compromise scan time.
Phase FOV	**[1]**	**Phase FOV:** Select 0.75 or 0.5 to reduce phase steps and thus decreases scan time, decreases FOV in the phase direction, and decreases SNR slightly. The phase FOV dimension is displayed next to the phase FOV factor.
Freq DIR	**[A/P]**	**Freq DIR:** The direction displayed is the default frequency direction which is typically the long axis of the image. To swap phase and frequency, select the other direction.
Auto Center Freq	**[Water]**	**Auto Center Freq:** Select the CF peak that is set during prescan.
Flow Comp DIR	**N/A**	
Autoshim	**[On]**	**Autoshim:** Click **[Autoshim]** to improve homogeneity.
Phase Correct	**N/A**	
# of Acqs/Locs Before Pause	**N/A**	
Additional Parameters **SAT Screen**		
S	**[80]**	**SAT:** Use SAT to decrease signal from unwanted flow, such as venous flow when imaging the Circle of Willis.
GRAPHIC RX Screen		
Click on the image to display the line cursor for Graphic Rx.		The SAT band function can be accessed fro the GRAPHIC Rx window and vice versa. Consider using an offset to center the anatomy in the middle of the screen so that a PFOV less than 1 may be used and therefore reduce the scan time. Move the crosshair cursor to the desired location for the center of the volume. Click and release the left mouse button. A box appears on the localizer which represents the deposited volume. The size of the volume is based on the FOV, slice thickness and number of locations per slab. To adjust the location of the slab, place the cursor over the slab and click and drag the slab to a new location. Release the left mouse button to deposit the slabs. Click **[Accept]** to register the selection.
Vascular Options Screen		

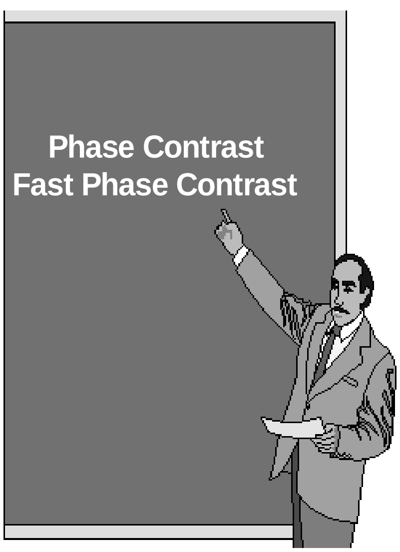
Fast 3D TOF - What you select		Selection Notes
Projection Images	**[19]**	**Projection Images:** Enter 19 or 37 to automatically create projection images.
Collapse	**[On]**	**Collapse:** Click [On] to get a collapsed view in the plane of acquisition.
Ramp Pulse	**N/A**	
SCAN OPERATIONS area		
	[Save Series] **[Prep to Scan]** **[Auto Prescan]** **[Scan]**	Enter data in all the text boxes and click on **[Save Series]**. The series is saved as RXD.

Volume 2

Chapter 8

Imaging with Phase Contrast Pulse Sequences

Where Am I?



Introduction

This chapter explains the pulsing components and timing factors directly related to the Phase Contrast (PC) and Fast Phase Contrast (Fast PC) pulse sequences. This chapter explains the concepts of each, and the step-by-step instructions to help you learn how to:

- Selecting Vascular Screen parameters
- Optimizing 2DPC images
- Optimizing 3DPC images
- Optimizing Fast 2DPC images

In addition, this chapter answers the following questions:

1. What is the contrast mechanism in PC?
2. What is the RF pulsing pattern?
3. How do the timing factors control the RF pulsing?
4. How does VENC affect the appearance of flow?
5. How does flow direction affect the appearance of flow?
6. How does recon type affect image appearance?
7. How does 3D collect data?
8. How are PC sequences classified?
9. What are the image characteristics?
10. What are the applications?

About... Phase Contrast Sequences

This section presents the concepts necessary to understand PC and Fast PC pulse sequences. Specifically you need to understand:

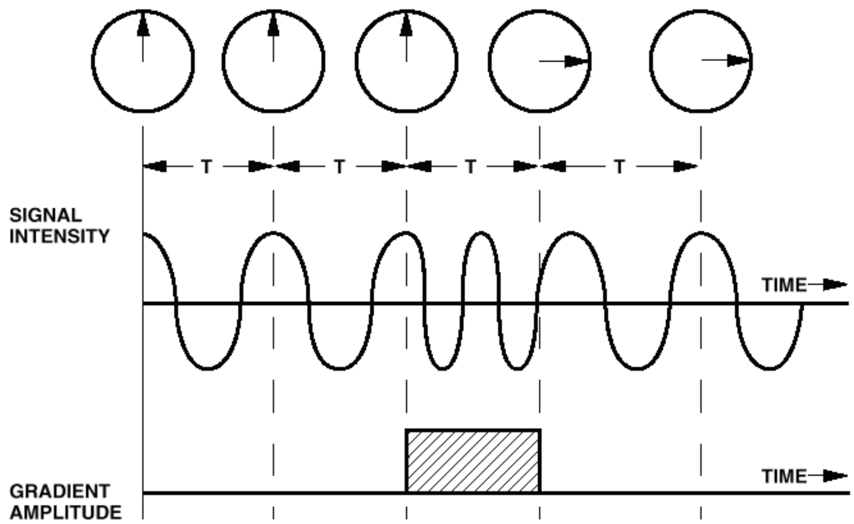
- Phase Contrast (PC)
  - Contrast mechanism
  - Pulsing components and timing factors
  - Velocity encoding
  - 2D acquisition
  - 3D acquisition
  - Image characteristics
  - Associated imaging options
  - Applications for PC
- Fast Phase Contrast (Fast PC)
  - Contrast mechanism
  - Pulsing components and timing factors
  - Fast Cardiac Triggered Data
  - K-space Segmentation
  - Views-per-segment
  - Velocity encoding
  - Associated imaging options
  - Applications for Fast PC

Phase Contrast (PC)

Phase Contrast (PC) imaging is an optional 2D and 3D imaging technique that relies on velocity-induced phase shifts to distinguish flowing blood from stationary tissues. Access to the Phase Contrast pop-up window is through the Vascular Icon in the additional parameters area.

The system applies an RF excitation pulse to the volume of interest. It then applies two equal-but-opposite, bipolar gradients along either slice, phase, or frequency encoding gradients. This combination causes phase shifts, which subtract equally in stationary tissue. Protons moving along the selected gradient direction experience phase shifts between the application of the two gradients. These phase shifts make up the Phase Contrast images.

The size of these phase shifts varies according to how far the flowing protons have traveled between the bipolar gradient pulses. Faster flow exhibits greater phase shift.



The arrow in the circle at the top represents the phase of the transverse magnetization. The temporary application of a positive gradient produces a local magnetic field, lending to an increase in the frequency of precession. When the gradient amplitude returns to zero, the frequency returns to its original value, but the phase of the signal has been changed.

The system then obtains a second acquisition, with the amplitude of the bipolar gradient pair inverted. Again, these bipolar gradients have no net effect on stationary tissue, but cause a phase shift in flowing protons, opposite to that of the first acquisition.

Finally, the system subtracts the first phase shift from the second, to suppress background signal from stationary tissue. The only remaining data are from the signal that is different in the two acquisitions, an intravascular signal from moving blood.

A Bipolar gradient is applied to a selected gradient to encode the flow along that gradient. To encode flow moving in more than one direction, select `ALL` for Flow Direction Images in the Vascular pop-up window for Phase Contrast. Otherwise, flow is encoded only along the selected gradient.

As a result, PC imaging greatly reduces signal from stationary tissue, while remaining very sensitive to flow. The system collects a large amount of data, the equivalent of up to four raw data sets. PC imaging is fast in 2D mode.

Velocity Encoding (VENC) is a value entered to prescribe the highest velocities to be encoded, without aliasing, in Phase Contrast angiography.

VENC is the parameter that defines this ceiling. Set the VENC high enough to include all the velocities likely to be encountered within the vessels of interest. Valid values are 5 to 400cm/sec, in increments of 0.1cm/sec.

Intracranial Peak Velocities	
Artery	**Velocity (cm/sec)**
Middle cerebral artery	62 +/- 12
Anterior cerebral artery	52 +/- 12
Posterior cerebral artery	42 +/- 10
Internal carotid siphon	54 +/-13
Vertebral artery	36 +/- 9
Basilar artery	42 +/- 10

Transcranial Doppler measurements of arterial flow velocity. (Adapted from Dewitt and Wechsler, Stroke Vol. 19 No. 7, July 1988.)

Peak Velocities of Peripheral Arteries	
Artery	**Velocity (cm/sec)**
Internal iliac	119 +/- 21
Common femoral	114 +/- 24
Superficial femoral (proximal)	90 +/- 13
Superficial femoral (distal)	93 +/- 14
Popliteal	69 +/- 13
Aorta (thoracic)	100 to 175
Common carotid artery	80 to 120
Internal carotid artery	80 to 120

"Peak velocities measured by duplex scanning." (Adapted from Jager, Ricketts, Strandness, Jr., "Duplex scanning for the Evaluation of lower Limb Arterial Disease," in Bernstein EF [eds] Non-Inavasive Disagnostic Techniques in Vascular Disease, Mosby & Co., St. Louis, 1985.)

Velocities higher than the VENC are "aliased," that is, incorrectly represented as lower velocities, with lower image intensities. Since higher velocities are normally found at vessel center, Phase Contrast aliasing can result in decreased image intensity in the center of a vessel.

Phase aliasing produces flow that appears to have changed direction, identifiable by a group of adjacent black and white pixels. Aliasing is sometimes acceptable. For this effect, deliberately set the VENC below a vessel's peak velocities. This technique may be useful for highlighting slower flow along arterial walls, or for emphasizing venous anatomy.

2D Phase Contrast (2D PC)

In 2D PC, the system collects and displays the data as a series of thick slices or a single slab. The slices or slab, are then projected into a single plane.

2D PC studies are conducted using the shortest possible TR and many multiple excitations from 2 – 16 NEX. The excitations are averaged for each set of flow-encoding gradients. The resulting image provides a measure of average flow, with minimizing ghosting artifacts.

With 2D PC, a variety of velocity encodings may be tried in a short period of time. Images can be generated emphasizing the arteries or the veins. Signal intensity is related to the velocity.

Slice thickness from 3 – 99 mm inclusive in whole numbers are accepted. 2D PC images have the following characteristics:

- They can be acquired in both orthogonal and oblique planes.
- They may be obtained without the use of Flow Compensation, to minimize echo time.

The two Flow Recon Type modes are:

- Phase Difference, which provides directional flow information. Use this reconstruction when the images are used for temporal analysis. It is the default mode. Phase difference is recommended for slices/slabs less than 20mm thick.
- Complex Difference, where the system automatically applies a slab dephasing gradient to help suppress stationary tissue. Background suppression is very good with this acquisition. It is recommended for thick slab (20mm or greater) acquisitions.

PC images are annotated `PC/GR/Flip Angle`, with both flow axis and VENC value noted.

The type-in option is **`PC`** and is not case sensitive.

2D PC Oblique Imaging

2D PC oblique imaging is a technique in which coaxial planes are rotated about a specific axis and prescribed explicitly or graphically.

The acquisition flow direction defaults to Slice when oblique is selected as the scan plane. Use Slice for through-the-plane flow direction. Select either `All` or `Slice` for the flow direction, but not both at the same time. Selecting other additional images can only be done if `All` is selected. Choose any combination of the additional images, O R/L, O A/P, or O S/I. These individual flow axes show the flow along the axis most like an orthogonal individual flow axis. The system highlights the additional image selection `Mag` when `Slice` is selected.

Oblique vascular images are annotated with an O prefix, for example `OMAG`.

Something to Think About...

- 2D PC is not compatible with projection images, nor with IVI.
- A large voxel size results in increased intravoxel dephasing.
- As the slice thickness increases above 20 mm, Complex Difference reconstruction is recommended for optimal background suppression.
- 2D PC oblique imaging requires a localizer. Single-axis and double-axis obliques (obliques from obliques) can be used, but not multi-angle obliques. Single-axis obliques are sometimes referred to as simple obliques or one-angle obliques.
- Multi-angle obliques are also known as clusters. Multi-angle oblique imaging is not permitted in 2D PC scanning.
- A full grid cannot be displayed on an oblique image.
- Select a collapsed image to be created in addition to any number of projection images. This is not available for Single Slab 2D PC.

Associated Imaging Options

In the following table the X's indicate the option available for use with the Phase Contrast pulse sequence.

Imaging Options			
X	None		Variable Bandwidth
X	Flow Compensation	X	No Phase Wrap
	POMP	X	Extended Dynamic Range
X	Square Pixel		Surface Coil Intensity Correction
	Respiratory Compensation		Classic
	Magnetization Transfer	X	Sequential
	Cardiac Gating/Triggering		Respiratory Gating/Triggering
	Tailored RF		IR Prepared
	DE Prepared		Multi-Phase
	Full Echo Train		CCOMP
	ZIP 1024		ZIP 512
	Zip x 2		ZIP x 4
	SmartPrep		Blood Suppression
	Multi Station		Real Time

Applications

2D Phase Contrast images are acquired for the following applications:

- For Indicating flow direction and velocity for intracranial and extracranial vasculature.
- For detecting slow flow states in arterial venous malformations and aneurysms, using variable velocity encoding.
- For assessing portal and hepatic vein anatomy.
- For generating a vascular localizer prior to more lengthy 3D PC angiography.
- As an alternative to 3D PC collapsed images.

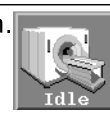
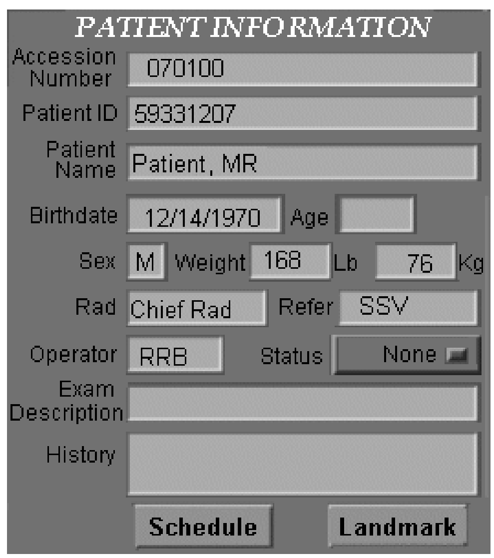
- When the imaging plane for anatomy is known and the exam does not need to be re-projected into different planes at a later date.
- For acquiring several quick images at various VENCs, in order to get a rough idea of the range of flows represented.
- When prescribing a slice thickness greater than 20 mm in a 2D PC prescription, and the study does not need directional flow information.
- Select 2D PC oblique plane when the scan plane is to be perpendicular to the blood flow and the vessel is not in an orthogonal plane.

CAUTION: **Provide all patients with ear protection prior to any scan to help avoid possible hearing impairment.** Acoustic noise levels can exceed 99 dBA in the magnet bore.

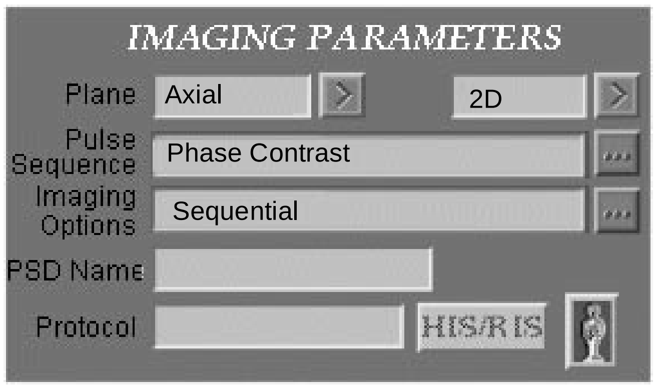
Setting up a 2D Phase Contrast pulse sequence

The decision matrix is only for prescribing a 2D PC scan. The purpose of the decision matrix to help you understand the trade-offs that occur when you change the values for a particular parameter and to provide a framework with which you may build you own unique protocol.

The selected values are only an example of what could be used for a 2D PC acquisition and is not to be considered recommendations by GE Medical Systems. For specific protocols, refer to the protocols on your system.

2D PC - What you select	Selection Notes
SCAN DESKTOP screen	
	Select **Scan Desktop** icon.  Click on **[New Patient]** and fill in the patient information. 
PATIENT POSITION area	
Patient Position **[Supine]**	**Position and Entry:** A 2DPC pulse sequence is compatible with any patient position and entry.
Patient Entry **[Head First]**	

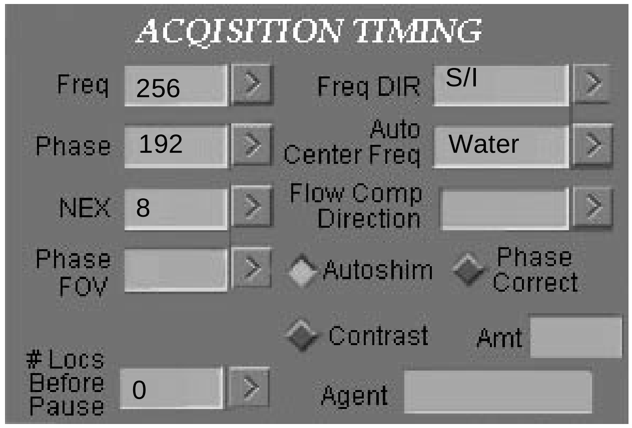
2D PC - What you select		Selection Notes
Coil	**[Head]**	**Coil:** Select the coil that produces the optimum coverage and SNR.
Series Description		**Series Description:** Enter a suitable series description. If you don not enter a description, the system enters one for you. The series description default is the selected scan mode, PSD, and imaging options.
	IMAGING PARAMETERS area	



Plane	**[Axial]**	**Plane:** 2D PC is compatible with any scan plane except 3 plane; select the plane that best meets the clinical need.
Mode	**[2D]**	**Mode:** Select [2D].
Pulse Seq	**[Phase Contrast]**	**Pulse Seq:** Select [Phase Contrast]. Click on the [Accept] button in the window to register the selection.
Imaging Options	**[Sequential]**	**Imaging Options:** Select `Sequential`. Flow Comp is useful in vessels with pulsatile flow to decrease flow/motion artifacts. This benefit outweighs the subsequent increase in TE and TR with Flow Comp. Select other imaging options that optimizes SNR and spatial resolution. Click [Accept] to register the selections.
PSD Name	**N/A**	
Protocol	**N/A**	
	SCAN TIMING area	
# of echoes	**[1]**	**# of echoes:** Only one echo is allowed.
TE	**N/A**	**TE:** The minimum TE is set by the system based on parameter selections such as FC, FOV, RBw, and Frequency matrix.
TE2	**N/A**	

2D PC - What you select		Selection Notes
TR	**[30]**	**TR:** TRs are generally kept at a minimum value. Increasing TR results in increased scan time, increased SNR, and decreased blood/background contrast.
TI	**N/A**	
Flip Angle	**[30]**	**Flip Angle:** Moderate Flip Angles (20° – 40°), improve signal in flowing vessels and improve the background vessel contrast. As Flip Angle increases, there is greater saturation of small vessels that have slower flow. In areas of fast flow, increasing the Flip Angle may cause pixel overranges and thus reduce the measured flow rate and velocity in Flow Analysis. Larger Flip Angles may increase the severity of pulsatile flow artifacts.
Echo Train Length	**N/A**	
Bandwidth	**[9.21]**	**Bandwidth:** Variable Bandwidth is not allowed in 2D PC. RBw is set by the system.
Bandwidth 2	**N/A**	
SCANNING RANGE area		
FOV	**[24]**	**FOV:** Select a FOV that covers the anatomy of interest. Anatomy outside the FOV in the phase direction results in aliasing. Small FOVs produce: increased resolution, decreased SNR, and can increase the minimum TE value.
Slice Thickness	**[30]**	**Slice Thickness:** Single, thick slab or smaller (3 – 5 mm) multiple slices can be prescribed. Thin slices result in increased partial volume effects and decreased intravoxel dephasing. Images to be used for flow analysis cannot exceed 20 mm.
Spacing	**[0]**	**Spacing:** Enter `0`. Slices are acquired sequentially and crosstalk is not an issue.
Start, End Locations		**Start, End Locations:** Typically the start and end locations are programmed from the Graphic Rx program.
# Slices	**[1]**	**# Slices:** The maximum number of slices prescribed is shown here after Start/End locations are entered.

2D PC - What you select		Selection Notes
	ACQUISITION TIMING area	



Freq	**[256]**	**Freq:** Increasing the frequency matrix produces: increased resolution and decreased SNR.
Phase	**[192]**	**Phase:** Phase controls scan time and may control resolution. High resolution 2D PC images can be acquired in relatively short scan times.
NEX	**[8]**	**NEX:** Select a NEX value that produces sufficient SNR. Use high NEX values, 4 – 8, for sufficient SNR on high resolution acquisitions.
Phase FOV	**[1]**	**Phase FOV:** Select .75 or .5 to reduce phase steps and thus decrease scan time, decreasing FOV in the phase direction, and decreasing SNR slightly. The phase FOV dimension is displayed next to the phase FOV factor.
Freq DIR	**[S/I]**	**Freq DIR:** The direction displayed is the default frequency direction which is typically the long axis of the image. To swap phase and frequency, select the other direction.
Auto Center Freq	**[Water]**	**Auto Center Freq:** Select the CF peak that is set during prescan.
Flow Comp DIR	**N/A**	
Autoshim	**[On]**	**Autoshim:** Click Autoshim to improve homogeneity and on the first series of an exam.
Phase Correct	**N/A**	
# of Acqs/Locs Before Pause	**N/A**	**# of Acqs/Locs Before Pause:** Do not use a pause for breath-hold imaging even in the chest or abdomen. Inconsistencies in breath-holding may cause misregistration of anatomy from slice to slice.

2D PC - What you select		Selection Notes
Additional Parameters SAT Screen Vascular Phase Contrast screen		
I	**None**	SAT pulses are generally not used in PC imaging due to the ability to obtain directional flow information.
S	**None**	
Projection Images	**N/A**	**Projection Images:** Projection images are not allowed in 2D PC.
Collapse	**[On]**	**Collapse**: Click `On` to get a collapsed view in the plane of acquisition.
Flow Recon Type	**[Phase Diff]**	**Flow Recon Type:** Select Phase Diff to obtain images with flow direction information. Complex Diff can be selected but results in bright signal for all flow regardless of direction. Complex Diff provides increased background suppression in thick slab scans.
Flow Analysis	**[Off]**	**Flow Analysis:** Select Phase Diff and Flow Analysis `On` if images are to be used for flow measurements.
Velocity Encoding	**[40]**	**Velocity Encoding:** In general, set the VENC to allow for the highest velocities in the vessel of interest. A VENC value set too low results in flow aliasing.
Acq Flow Direction Images	**[All]**	**Acq Flow Direction Images:** Select the flow direction images. Select a single direction, decrease scan time and decrease recon time. Select `All` and directional flow images are available if Phase Diff or Flow Analysis recon was selected.
Additional Flow Images	**[Magnitude]**	**Additional Flow Images:** Select `Magnitude` to reconstruct these images. If `All` was selected for Acq Flow Dir, additional flow direction images can be selected. Selecting **[Additional Images]** results in increased reconstruction time. If `Complex Diff` reconstruction was selected, additional flow direction images results in white blood images.
GRAPHIC RX Screen		
Click on the image to display the line cursor for Graphic Rx.		To prescribe oblique slices **Oblique** must be selected in the Plane pull-down menu. Consider using an offset to center the anatomy in the middle of the screen so that you can use a PFOV less than 1 and therefore reduce the scan time. View the Advisory area to note the # of Acqs being prescribed. The scan time increases as the # of Acquisitions increases.
SCAN OPERATIONS area		

2D PC - What you select	Selection Notes
[Save Series] **[Prep to Scan]** **[Auto Prescan]** **[Scan]**	Enter data in all the fields and click on **[Save Series]**. The series is saved as RXD.

Fast 2D Phase Contrast

Fast Phase Contrast referred to as Fast 2DPC adds the following new capabilities to the phase contrast pulse sequence:

- Single slice multi-phase and multi-slice multi-phase capability
- Shorter TR and TE values
- Fast Cardiac Triggered data acquisition
- Segments K-space for reduced motion artifact
- Variable Receive Bandwidth Compatibility

Fast 2DPC is a combination of FastCard and Phase Contrast scanning. Fast Card produces multiple cardiac phases in a breath-hold time frame, and Phase Contrast provides quantitative data from a multi-phase cardiac acquisition.

A User CV: Perform Arrhythmia Rejection screen appears with Fast 2D PC.

Something to Think About...

- If more than four arrhythmia occur for a scan time less than 25 seconds, (a typical breath-hold time frame), or 10 arrhythmia in greater than 25 seconds, the scan aborts and posts a message.
- When adjusting the Views per Segment on the Gating screen, observe the Scanning Range and Advisory areas to see the effect the change has on the # of cardiac phases and scan time. As the # of views per segment increases, scan time and # of cardiac phases decreases.

Associated Imaging Options

In the following table the X's indicate the option available for use with the Fast Phase Contrast pulse sequence.

Imaging Options			
X	None	X	Variable Bandwidth
X	Flow Compensation	X	No Phase Wrap
	POMP	X	Extended Dynamic Range
X	Square Pixel	X	Surface Coil Intensity Correction
	Respiratory Compensation		Classic
	Magnetization Transfer	X	Sequential
X	Cardiac Gating/Triggering	X	Respiratory Gating/Triggering
	Tailored RF		IR Prepared
	DE Prepared		Multi-Phase
	Full Echo Train		CCOMP
	ZIP 1024		ZIP 512
	Zip x 2		ZIP x 4
	SmartPrep		Blood Suppression
	Multi Station		Real Time

Applications

Fast 2D PC images are acquired for the following applications:

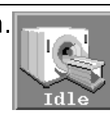
- A cardiac gated multi-phase data set within a breath-hold time frame.
- When used with Flow Analysis, to provide the ability to quantify flow in the great vessels, carotids and extremity vasculature.
- In conjunction with the MIROI display program, to be used as a localizer for gated TOF acquisitions when looking for peak flow.

CAUTION: **Provide all patients with ear protection prior to any scan to help avoid possible hearing impairment.** Acoustic noise levels can exceed 99 dBA in the magnet bore.

Setting up a Fast 2D Phase Contrast pulse sequence

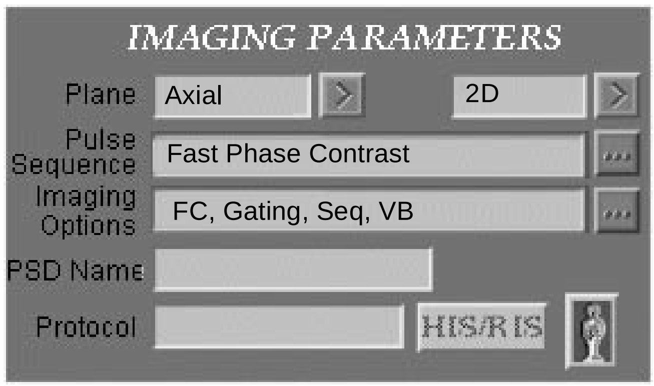
The decision matrix is only for prescribing a Fast 2D PC scan. The purpose of the decision matrix to help you understand the trade-offs that occur when you change the values for a particular parameter and to provide a framework with which you may build you own unique protocol.

The selected values are only an example of what could be used for a Fast 2D PC acquisition and is not to be considered recommendations by GE Medical Systems. For specific protocols, refer to the protocols on your system.

Fast 2D PC - What you select	Selection Notes
SCAN DESKTOP screen	
	Select **Scan Desktop** icon.  Click on **[New Patient]** and fill in the patient information. 
PATIENT POSITION area	
Patient Position **[Supine]** Patient Entry **[Head First]**	**Position and Entry:** A Fast 2DPC pulse sequence is compatible with any patient position and entry.

Fast 2D PC - What you select		Selection Notes
Coil	**[Body]**	**Coil:** Select the coil that produces the optimum coverage and SNR.
Series Description		**Series Description:** Enter a suitable series description. If you don not enter a description, the system enters one for you. The series description default is the selected scan mode, PSD, and imaging options.

IMAGING PARAMETERS area



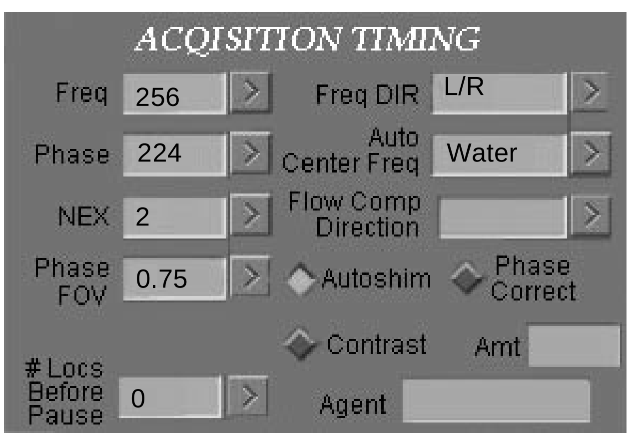
Plane	**[Axial]**	**Plane:** Fast 2D PC is compatible with any scan plane except 3 plane; select the plane that best meets the clinical need.
Mode	**[2D]**	**Mode:** Select [2D].
Pulse Seq	**[Fast 2D Phase Contrast]**	**Pulse Seq:** Fast 2DPC is only compatible with Vasc PC.
Imaging Options	**[FC, Gating, Seq, VB]**	**Imaging Options:** Select `Gating`. Select `Sequential` for multi-slice, multi-phase. Do not select `Sequential` for multi-slice, single-phase. Select other imaging options that optimizes SNR and spatial resolution. Click **[Accept]** to register the selections.
PSD Name	**N/A**	
Protocol	**N/A**	

SCAN TIMING area

# of echoes	**[1]**	**# of echoes:** Only one echo is allowed.
TE	**[Min]**	**TE:** The only selections are Minimum and Min Full. Select `Minimum` for a shorter TR. Decrease TE to produce decrease dephasing.
TE2	**N/A**	
TR	**N/A**	**TR:** The minimum TR is set by the system based on other parameters selected such as RBw, Frequency, Phase Matrix, FOV, and slice thickness.

Fast 2D PC - What you select		Selection Notes
TI	**N/A**	
Flip Angle	**[20]**	**Flip Angle:** As Flip Angle increases, there is greater saturation of small vessels that have slower flow.
Echo Train Length	**N/A**	
Bandwidth	**[32]**	**Bandwidth:** As the RBw decreases, the following occurs: increased SNR, increased chemical shift artifact and increased minimum TE which can potentially increase TR and decrease views per segment.
Bandwidth 2	**N/A**	
	SCANNING RANGE area	
FOV	**[40]**	**FOV:** Select a FOV that covers the anatomy of interest. Anatomy outside the FOV in the phase direction results in aliasing. Small FOVs produce: increased resolution, decreased SNR, and can increase the minimum TE value. Smaller FOVs also produce decreased voxel size and this decreases intravoxel dephasing.
Slice Thickness	**[7]**	**Slice Thickness:** Select all scanning range values based on the desired resolution and coverage.
Spacing	**[0]**	**Spacing:** Enter `0`. Slices are acquired sequentially and crosstalk is not an issue.
Start, End Locations		**Start, End Locations:** Prescribe Start/End locations. Adjust as needed. Typically the start and end locations are programmed from the Graphic Rx program.
# Slices	**[4]**	**# Slices:** The more slices being prescribed the longer the scan time. Remember that if this is a breath hold scan, and the scan time is longer than 25 seconds, it will be very difficult for the patient to hold his/her breath.

ACQUISITION TIMING area



Fast 2D PC - What you select		Selection Notes
Freq	**[256]**	**Freq:** As the matrix values increases, the resolution increases, the SNR decreases and scan time can increase due to possible increase in TE and TR.
Phase	**[224]**	**Phase:** Phase controls scan time, resolution and SNR. Increased phase value produces decreased intravoxel dephasing and decreased partial volume effects.
NEX	**[2]**	**NEX:** As NEX increases so does the SNR and scan time.
Phase FOV	**[0.75]**	**Phase FOV:** A PFOV less than 1 can be selected if it doesn’t result in anatomy outside the PFOV. As the PFOV decreases, so does the SNR and scan time.
Freq DIR	**[L/R]**	**Freq DIR:** The direction displayed is the default frequency direction which is typically the long axis of the image. To swap phase and frequency, select the other direction.
Auto Center Freq	**[Water]**	**Auto Center Freq:** Select the CF peak that is set during prescan.
Flow Comp DIR	**N/A**	
Autoshim	**[On]**	**Autoshim:** Click Autoshim to improve homogeneity and on the first series of an exam.
Phase Correct	**N/A**	
# of Acqs/Locs Before Pause	**None**	**# of Acqs/Locs Before Pause:** Select a value here to automatically pause the scanning for breath-hold.
Additional Parameters SAT Screen Vascular Phase Contrast screen		
I	**None**	SAT pulses are generally not used in PC imaging due to the ability to obtain directional flow information.
S	**None**	
Projection Images	**N/A**	**Projection Images:** Projection images are not allowed in 2D PC.
Collapse	**[On]**	**Collapse:** Click `On` to get a collapsed view in the plane of acquisition.
Flow Recon Type	**[Phase Diff]**	**Flow Recon Type:** Select `Phase Diff` as the Flow Recon Type, unless the images in Flow Analysis are post processed. In that case, select Flow Analysis `On` with `Phase Diff`. Complex Diff is generally used for thick slabs providing increased background suppression. It is not recommended in Fast 2D PC.
Flow Analysis	**N/A**	

Fast 2D PC - What you select		Selection Notes
Velocity Encoding	**[100]**	**Velocity Encoding:** In general, set the VENC to allow for the highest velocities in the vessel of interest. A VENC value set too low results in flow aliasing.
Acq Flow Direction Images	**[S/I]**	**Acq Flow Direction Images:** Select the Acq. Flow Direction based on the number of cardiac phases being acquired. The fewer directions, the more cardiac phases acquired.
Additional Flow Images	**[Magnitude]**	**Additional Flow Images:** Select `Magnitude` which is the only option available when a single acquisition flow direction has been selected. If `All` was selected additional flow direction images may be selected.
Gating Screen		
Heart Rate (bpm)	**Update bpm**	
Trigger Type	**[Auto lead]**	**Trigger Type:** Select ECG if possible, if not use PG. Auto lead automatically selects the lead with the strongest signal. ECG Gating provides more accurate cardiac information when precise systolic and diastolic data is needed.
Trigger Window	**[Auto]**	**Trigger Window:** Auto automatically adjusts the waiting for the next R-wave window based on the patient's cardiac arrhythmia. Alternatively, a value can be entered manually.
Trigger Delay	**[Minimum]**	**Trigger Delay:** Select `Minimum`. Increasing Trigger Delay, decreases available imaging time.
Views per Segment	**[4]**	**Views per Segment:** As the # of view per segment increases, scan time and # of cardiac phases decreases.
Additional Parameters User CV screen		
Perform Arrhythmia Rejection	**[1]**	**Perform Arrhythmia Rejection:** Turn on Perform Arrhythmia Rejection to insure image quality by rejecting data with an incorrect trigger. `0` is off. `1` is on.
GRAPHIC RX Screen		
Click on the image to display the line cursor for Graphic Rx.		To prescribe oblique slices **Oblique** must be selected in the Plane pull-down menu. Consider using an offset to center the anatomy in the middle of the screen so that you can use a PFOV less than 1 and therefore reduce the scan time. View the Advisory area to note the # of Acqs being prescribed. The scan time increases as the # of Acquisitions increases.
SCAN OPERATIONS area		
	[Save Series] **[Prep to Scan]** **[Auto Prescan]** **[Scan]**	Enter data in all the fields and click on **[Save Series]**. The series is saved as RXD.

3D Phase Contrast (3D PC)

3D PC imaging provides the advantages of PC imaging plus the ability to acquire many thin slices, minimizing signal dropout from vessel overlap and magnetic susceptibility artifacts.

3D PC imaging is a volume 3D acquisition obtained with flow encoding and displayed as weighted-phase and magnitude images with collapsed image and multiple MIPs. Select from two different flow reconstruction types: Phase Difference or Complex Difference.

Scan locations of 12 – 124, in steps of two can be prescribed. 3D PC Phase reconstructions have the following characteristics:

- They are sensitive to in-plane flow.
- They reduce intravoxel dephasing.
- They provide excellent background suppression.
- They offer improved SNR as compared with 2D PC.
- They minimize saturation effects over large volumes as compared with 3D TOF.
- They generate weighted-phase, magnitude, collapsed, and projection images.
- When used with IV contrast SNR is improved.
- They provide optimal thin slice large volume studies.
- They are slightly more sensitive than TOF to signal loss from turbulent flow.

Images are annotated 3D/PC/GR/Flip Angle with both the flow axis and VENC value noted.

Something to Think About...

- 3D PC Phase and Complex Difference reconstruction call for relatively long scan times. They may require pre-evaluation with 2D PC to determine the optimal VENC value.
- 3D PC Complex Difference reconstruction does not provide directional flow information.
- 3D PC studies take longer to reconstruct than 3D TOF exams. Consider arranging the scanning protocols to place 3D PC at the end of the exam.
- The number of slices acquired depends partly on the number of flow-encoding axes prescribed and partly on the matrix chosen.

The system may delay acquisition of a new series until reconstruction is complete and memory is available.

Associated Imaging Options

In the following table the X's indicate the option available for use with the 3D Phase Contrast pulse sequence.

Imaging Options			
X	None	**X**	Variable Bandwidth
X	Flow Compensation	**X**	No Phase Wrap
	POMP	**X**	Extended Dynamic Range
X	Square Pixel		Surface Coil Intensity Correction
	Respiratory Compensation		Classic
	Magnetization Transfer		Sequential
	Cardiac Gating/Triggering		Respiratory Gating/Triggering
	Tailored RF		IR Prepared
	DE Prepared		Multi-Phase
	Full Echo Train		CCOMP
	ZIP 1024		ZIP 512
	Zip x 2		ZIP x 4
	SmartPrep		Blood Suppression
	Multi Station		Real Time

Applications

3D PC images are acquired for the following applications:

- Imaging renal arteries
- Identifying arteriovenous malformations (AVM)
- Imaging intracranial vasculature, including flow direction, if desired.

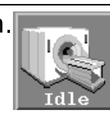
CAUTION: **Provide all patients with ear protection prior to any scan to help avoid possible hearing impairment.** Acoustic noise levels can exceed 99 dBA in the magnet bore.

Setting up a 3D Phase Contrast pulse sequence

The decision matrix is only for prescribing a 3D PC scan. The purpose of the decision matrix to help you understand the trade-offs that occur when you change the values for a particular parameter and to provide a framework with which you may build you own unique protocol.

The selected values are only an example of what could be used for a 3D PC head acquisition and are not to be considered recommendations by GE Medical Systems. For specific protocols, refer to the protocols on your system.

.

<table>
<tr><th>3D PC - What you select</th><th>Selection Notes</th></tr>
<tr><td colspan="2">SCAN DESKTOP screen</td></tr>
<tr><td></td><td>Select Scan Desktop icon.

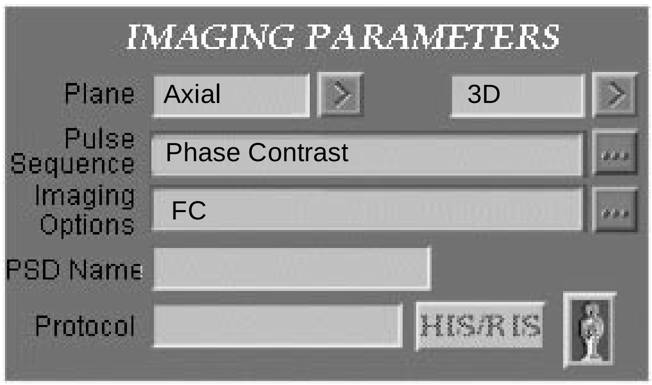
Click on [New Patient] and fill in the patient information.

</td></tr>
<tr><td colspan="2">PATIENT POSITION area</td></tr>
<tr><td>Patient Position [Supine]

Patient Entry [Head First]</td><td>Position and Entry: A 3D PC pulse sequence is compatible with any patient position and entry.</td></tr>
</table>

3D PC - What you select		Selection Notes
Coil	**[Head]**	**Coil:** Select the coil that produces the optimum coverage and SNR.
Series Description		**Series Description:** Enter a suitable series description. If you don not enter a description, the system enters one for you. The series description default is the selected scan mode, PSD, and imaging options.

IMAGING PARAMETERS area



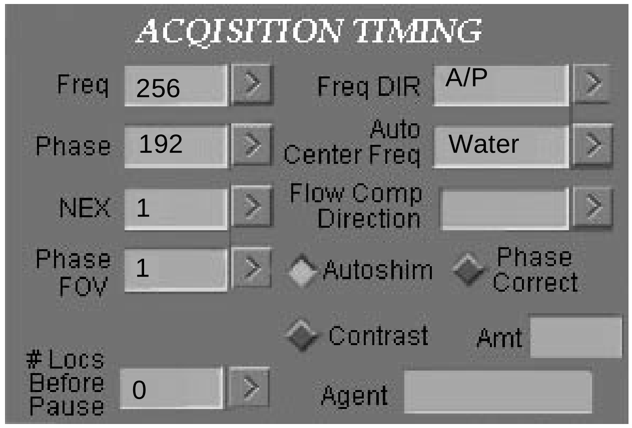
Plane	**[Axial]**	**Plane:** 3D Phase Contrast is compatible with any scan plane except 3 plane; select the plane that best meets the clinical need.
Mode	**[3D]**	**Mode:** Select [3D] for thin contiguous images.
Pulse Seq	**[Phase Contrast]**	**Pulse Seq:** Select [Phase Contrast]. Click on the [Accept] button in the window to register the selection.
Imaging Options	**[FC]**	**Imaging Options:** Flow Comp is helpful in vessels with pulsatile flow, but increases the minimum TE and TR. The benefit of Flow Comp may outweigh these increases. Select other imaging options that optimizes SNR and spatial resolution. Click on the [Accept] button to register the selections.
PSD Name	**N/A**	**PSD Name:** Not applicable for this pulse sequence.
Protocol	**N/A**	

SCAN TIMING area

# of echoes	**[1]**	**# of echoes:** Only 1 echo is allowed.
TE	**N/A**	**TE:** The minimum TE is set by the system based on parameter selections such as selection of FC, FOV, RBw, and Frequency matrix. Decrease TE to decrease dephasing.

3D PC - What you select		Selection Notes
TR	**[34]**	**TR:** TRs are generally kept at a minimum value. Increased TR results in increased scan time, increased SNR, decreased blood/background contrast.
TI	**N/A**	
Flip Angle	**[20]**	**Flip Angle:** Use smaller flip angles. Values range from 15°–25°. As Flip Angle increases, there is greater saturation of small vessels that have slower flow. In areas of fast flow, increased flip angle may cause pixel overranges and reduce the measured flow rate and velocity. Larger flip angles may increase the severity of pulsatile flow artifacts.
Echo Train Length	**N/A**	
Bandwidth	**N/A**	Variable bandwidth is not allowed with 3D PC.
Bandwidth 2	**N/A**	
SCANNING RANGE area		
FOV	**[24]**	**FOV:** Select a FOV that covers the anatomy of interest. Anatomy outside the FOV in the phase direction results in aliasing. Small FOVs produce: increased resolution, decreased SNR, and can increase the minimum TE value. Smaller FOVs also produce decreased voxels and this decreases intravoxel dephasing.
Slice Thickness	**[1.5]**	**Slice Thickness:** Thin slices produce: increased resolution and decreased SNR, decreased partial volume effects, and decreased intravoxel dephasing.
# of Scan Locs	**[60]**	**#of Scan Locs:** Scan locations 12 to 124, in steps of two can be prescribed.
Start, End Locations		**Start, End Locations:** Typically the start and end locations are programmed from the Graphic Rx program. 3D explicit Rx can be done in either L-I-P or R-S-A direction. 3D graphic Rx can only be done in L-I-P direction for orthogonal planes (note that oblique scan planes are not allowed with 3D PC).
# of Slabs	**[1]**	**# of Slabs:** Multi-slab is not available in 3D PC.

3D PC - What you select		Selection Notes
ACQUISITION TIMING area		



Freq	**[256]**	**Freq:** Only `256` is available in 3D PC.
Phase	**[192]**	**Phase:** Phase controls scan time, resolution and SNR. Increased phase value decreases to intravoxel dephasing.
NEX	**[1]**	**NEX:** 3D PC generally uses 1 NEX due to longer scan times.
Phase FOV	**[1]**	**Phase FOV:** Select .75 or .5 to reduce phase steps and thus decrease scan time, decreasing FOV in the phase direction, and decreasing SNR slightly. The phase FOV dimension is displayed next to the phase FOV factor.
Freq DIR	**[A/P]**	**Freq DIR:** The direction displayed is the default frequency direction which is typically the long axis of the image. To swap phase and frequency, select the other direction.
Auto Center Freq	**[Water]**	**Auto Center Freq:** Select the CF peak that is set during prescan.
Flow Comp DIR	**N/A**	
Autoshim	**[On]**	**Autoshim:** Select Autoshim to improve homogeneity.
Phase Correct	**N/A**	
# of Acqs/Locs Before Pause	**N/A**	

Additional Parameters
SAT Screen
Vascular Phase Contrast screen

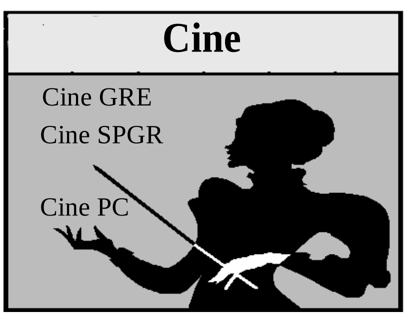
I	**None**	SAT pulses are not generally used with PC exams.
S	**None**	
Projection Images	**[19]**	**Projection Images:** Choose `19` or `37` to automatically reconstruct projection, MIP, images.

3D PC - What you select		Selection Notes
Collapse	**[On]**	**Collapse:** Click `On` to get a collapsed view in the plane of acquisition.
Flow Recon Type	**[Phase Diff]**	**Flow Recon Type:** Select `Phase Diff` for 3D images unless images are used for evaluating vessel flow. In that case, select Flow Analysis `On` with `Phase Diff`. Complex Diff is used in 2D PC thick slab scans.
Flow Analysis	**[Off]**	
Velocity Encoding	**[40]**	**Velocity Encoding:** In general, set the VENC to allow for the highest velocities in the vessel of interest. A VENC value set too low results in flow aliasing.
Acq Flow Direction Images	**[All]**	**Acq Flow Direction Images:** Select the flow direction images. Select a single direction, decrease scan time and decrease recon time. Select `All` and directional flow images are available if Phase Diff or Flow Analysis recon was selected.
Additional Flow Images	**[Magnitude]**	**Additional Flow Images:** Select `Magnitude` to reconstruct these images. If `All` was selected for Acq Flow Dir, additional flow direction images may be selected. Selecting Additional Images results in increased reconstruction time. If Complex Diff reconstruction was selected, Additional flow direction images results in white blood images.
GRAPHIC RX Screen		
Click on the image to display the line cursor for Graphic Rx.		Consider using an offset to center the anatomy in the middle of the screen so that you can use a PFOV less than 1 and therefore reduce the scan time. 3D explicit Rx can be done in either L-I-P or R-S-A direction. 3D graphic Rx can only be done in L-I-P direction for orthogonal planes (note that oblique scan planes are not allowed with 3D PC).
SCAN OPERATIONS area		
	[Save Series] **[Prep to Scan]** **[Auto Prescan]** **[Scan]**	Enter data in all the fields and click on **[Save Series]**. The series is saved as RXD.

Chapter 9

Imaging with Cine Pulse Sequences

Where Am I?



Introduction

This chapter explains the pulsing components and timing factors directly related to the Cine pulse sequences. This chapter explains the concepts of each, and the step-by-step instructions to help you learn how to:

- Optimize Cine GRE images
- Optimize Cine SPGR images
- Selecting Cine Screen parameters
- Selecting Vascular Screen parameters

In addition, this chapter answers the following questions:

1. How does Cine collect data?
2. What pulse sequences are compatible with Cine?
3. What affects the effective TR?
4. What affects the number of cardiac phases?
5. What are the image characteristics?
6. What are the applications?
7. What types of images sets can be processed with Flow Analysis?
8. How are velocity data calculated?
9. What are flow ROI?
10. What are baseline ROI?
11. When should baseline ROI be used?
12. How are flow and baseline ROI matched?
13. How do you optimize image acquisition?
14. What are the applications of Flow Analysis?

About... Cine Pulse Sequences

This section presents the concepts necessary to understand Cine pulse sequences. Specifically you need to understand:

- Cine GRE
  - Trigger type
  - Update bpm
  - Locations per acquisition
  - Cardiac phases
  - Image characteristics
  - Associated imaging options
  - Applications for Cine GRE
- Cine SPGR
  - Associated imaging options
  - Applications for Cine SPGR
- Cine PC
  - Flow Analysis
    - Parameter selection
  - Image characteristics
  - Associated imaging options
  - Applications for Cine PC

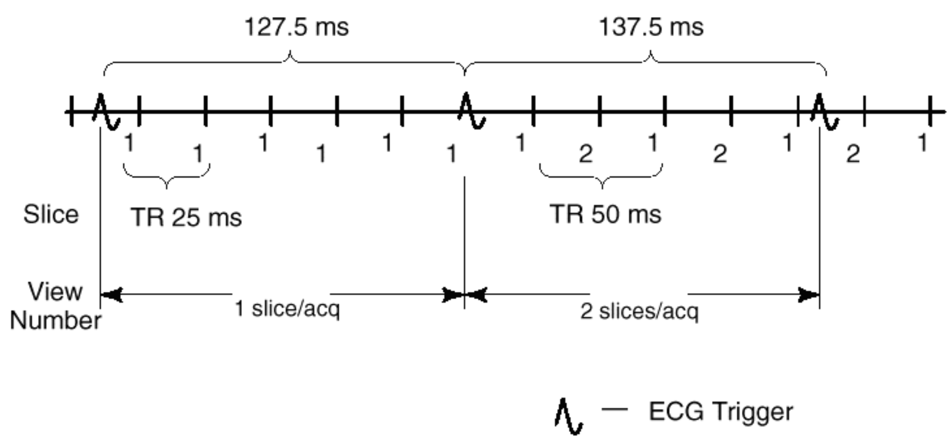
Cine GRE

Cine images are acquired using retrospective gating techniques and differ from conventional gated exams in that:

- Cine scans employ a short TR GRE pulse sequence that produce a bright blood and dark myocardium image with fairly high contrast.
- Certain processes, like high-velocity flow through orifices, such as vascular regurgitation, cause signal loss due to turbulence.
- Cine scans execute pulse sequences continuously rather than waiting for triggers.

In Cine imaging, effective TR is a function of the number of slices and the time between excitations. For example, a TR of 25 ms with one slice per acquisition has an effective TR of 25 ms. If two slices per acquisition are acquired, the system excites the first location, then the second, and the effective TR doubles to 50 ms.

The patient's R-R interval changes during the scan, as do the actual number of samples acquired during each R-R interval. The first data acquisition point in each R-R interval occurs at a slightly different point after the QRS trigger. The system considers this factor as it sorts data for reconstruction.



Cine annotation includes: `CINE/ GR/ XX`, (`XX` equals flip angle), the flow axes, and `VENC`.

The type-in option for Cine is **c** and is not case sensitive.

Trigger Type

There are three choices for trigger type: ECG Lead, PG for peripheral gating and Auto Lead. ECG Lead assigns a particular lead to control the trigger. Click it until the desired lead, either I, II or III appears. Auto Lead automatically selects the best lead, I, II, or III to control the trigger. It is typically the most reliable trigger selection for ECG leads. If the signal from the selected Auto Lead is temporarily lost, the system selects a different signal to trigger the scans.

Something to Think About...

- The signals from the ECG leads are not always consistent. In ECG Lead, if a signal is temporarily lost, the user must choose a new lead to resume scanning.
- At the Cine menu, the system might not choose the lead that is giving the best signal at this time. If Auto Lead is selected, check the Waveform Display to be sure the system-selected lead is giving the best signal.

- If the system detects a total loss of trigger, during either download or data acquisition, the system may pause and display a message. Correct the problem or stop the scan completely by pressing Stop Scan.

Update bpm

Update bpm updates the display of the patient's current heart rate in beats-per-minute (bpm). To change the heart rate that the system uses, enter the desired heart rate over the displayed heart rate. The average heart rate represents the patient's heart rate during the actual scan and is independent of the downloaded heart rate. The downloaded heart rate is the rate sampled by the system when the transition is made from the Rx Manager to the Scan Operations area. This feature is used before starting the scan to insure the best trigger.

Something to Think About...

- Use the patient's actual heart rate before starting to scan to insure the best trigger.
- The system gives one of the following lead status messages:
  - `OK` if the peripheral pulse or ECG signal is adequate.
  - `Missing` if a pulse or lead is not adequate.
  - `Cardiac initializing` if the system is still in Trigger Window calculations.

Locations per Acquisitions

Locations per Acquisition is the maximum number of slice locations that can be acquired in every acquisition. The number of locations per acquisition determine the Effective TR and affect the contrast between blood and muscle tissue. For example, the Locations per Acq. with an eight-slice scan are:

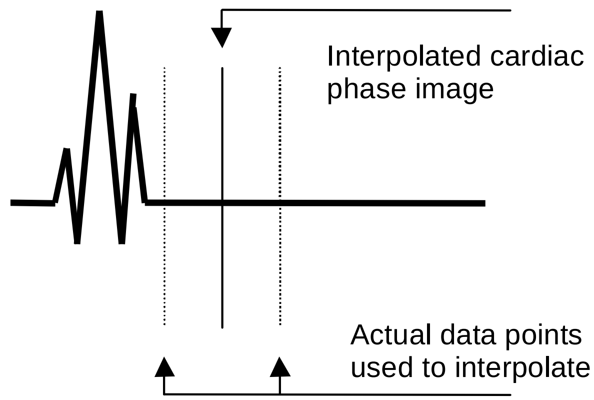
- 2 Locations per Acq., wherein the system acquires two locations in four acquisitions.
- 4 Locations per Acq., wherein the system acquires four locations in two acquisitions.

Something to Think About...

- Two slice locations per acquisition produce images exhibiting the best compromise between image quality and scan time. However, it takes twice as ling to cover the anatomy.

Cardiac Phases to Reconstruct

Cine uses an interpolation process to reconstruct the number of cardiac phases. The two data points closest to the desired phase contribute to the image, based on a weighting algorithm.



The number of phases to reconstruct determines the temporal resolution of the image reconstruction process. The temporal resolution of the image reconstruction process can be independent of the temporal resolution of the acquisition.

It is important not to enter too few or too many phases to reconstruct because:

- if not enough phase images are reconstructed, portions of the cardiac cycle are not sampled. If too many images are reconstructed, Flow analysis cannot use the excess information to make it's calculations and, consequently, the images are a waste of disk space and processing time.
- the time between phase images is roughly equal to the RR-interval divided by the number of phases to be reconstructed. The actual delay after trigger of each image varies from acquisition to acquisition. Usually, the first image occurs at 33 ms and each subsequent image follows at the interval calculated above.
- each phase image is interpolated from the two data points closest to the desired time for the phase image to occur.

- the SNR is the same regardless of the number of phases to be reconstructed. Each image is a snapshot in time during the cardiac cycle.
- as the number of phases reconstructed is reduced, the larger the portion of the RR interval the individual phase image represents.

Something to Think About...

- Since image quality may deteriorate with higher numbers, 16 cardiac phases are standard. The numbers recommended are based on this formula:

$$\text{Number of Phases} = \frac{60000\text{ms}}{\text{BPM}} /(\text{TR msec x loc per acq})$$

Recommended Number of Phases at 1 Location per Acquisition.

Selected TR	Heart rate (BPM) 40	50	60	70	80	90	100	110	120	130
20	32	32	32	32	32	32	30	27	25	23
25	32	32	32	32	30	26	24	22	20	18
30	32	32	32	29	25	22	20	18	17	15
35	32	32	29	24	21	19	17	16	14	13
40	32	30	25	21	19	17	15	14	13	12
45	32	27	22	19	17	15	13	12	11	10
50	30	24	20	17	15	13	12	11	10	9

Recommended Number of Phases at 2 Locations per Acquisition

Selected TR	Heart rate (BPM) 40	50	60	70	80	90	100	110	120	130
20	32	30	25	21	19	17	15	14	13	12
25	30	24	20	17	15	13	12	11	10	9
30	25	20	17	14	13	11	10	9	8	8
35	21	17	14	12	11	10	9	8	7	7
40	19	15	13	11	9	8	8	7	6	6
45	17	13	11	10	8	7	7	6	6	5
50	15	12	10	9	8	7	6	5	5	5

Recommended Number of Phases at 3 Locations per

Acquisition

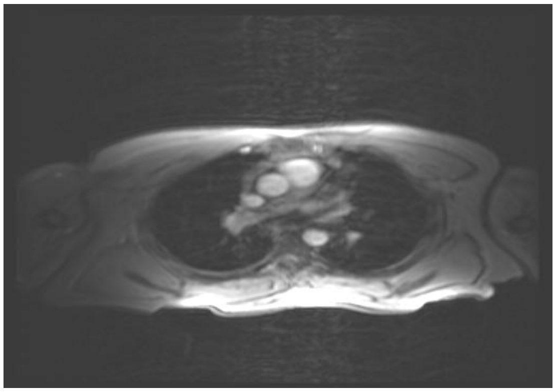
	Heart rate (BPM)									
Selected TR	40	50	60	70	80	90	100	110	120	130
20	25	20	17	14	13	11	10	9	8	8
25	20	16	13	11	10	9	8	7	7	6
30	17	13	11	10	8	7	7	6	6	5
35	14	11	10	8	7	6	6	5	5	4
40	13	10	8	7	6	6	5	5	4	4
45	11	9	7	6	6	5	4	4	4	4
50	10	8	7	6	5	4	4	4	4	3

Recommended Number of Phases at 4 Locations per Acquisition

	Heart rate (BPM)									
Selected TR	40	50	60	70	80	90	100	110	120	130
20	19	15	13	11	9	8	8	7	6	6
25	15	12	10	9	8	7	6	5	5	5
30	13	10	8	7	6	6	5	5	4	4
35	11	9	7	6	5	5	4	4	4	4
40	9	8	6	5	5	4	4	4	4	3
45	8	7	6	5	4	4	4	3	3	3
50	8	6	5	4	4	4	3	3	3	3

Cine GRE Image Characteristics

Cine is a white blood imaging sequence. In Cine images, flowing nuclei are bright while stationary nuclei are bright dark. Stagnant, slow flow or in-plane flow produces decreased signal as it becomes saturated. Signal form the myocardium may increase as the number of slices per acquisition increases or the selected TR increases.



Cine image

Something to Think About...

- Cine is not synchronized with the cardiac cycle and does not use Gating from the Imaging Options area.
- For gradient echo Cine, as the flip angle is increased beyond 30 degrees, the images tend to become more heavily T1-weighted. The signal from blood remains unchanged, but the myocardial signal may decrease until wall motion evaluation becomes increasingly difficult.
- Cine entails the same tradeoffs as any other gradient-recalled pulse sequence, including:
- Reduced SNR
- Increased susceptibility to artifacts and loud operation
- The greater the number of slice locations per acquisition, the shorter the scan time. The system cannot acquire more than eight slices per scan time. The closer the slices are to each other, the weaker the signal from the blood, because the blood becomes saturated.
- As the number of locations per acquisition increases, the effective TR increases, causing the signal from the myocardium to increase. As a result, contrast between blood and the heart decreases with multiple locations/acquisitions.
- Auto Pause may engage during a Cine study, especially with a one- memory-board configuration. The memory holds 60 to 240 images. Should it become full, this

message appears: Scan paused because acquisition memory is full. The system prompts when its ready to resume with this message: Press the Start Scan button.

- Cine studies abort if:
- **[Stop Scan]** is selected.
- **[Move to Scan]** is inadvertently selected.
- During a multiple acquisition scan with low bpm, a scan setup is followed by a bpm increase of more than 25 percent at scan time.
- If a scan stops, the system reconstructs any available images.
- Stop a Cine study if the clock runs longer than 30 seconds after zero, and the heartbeat is weak. If there is a reasonable ECG signal on the Waveform Display, continue the scan. This is a normal arrhythmia rejection process.
- A Cine scan may finish before the clock counts down, if the patient's heart rate increases.

Associated Imaging Options

In the following table the X's indicate the option available for use with the Cine pulse sequences.

Imaging Options			
X	None	**X**	Variable Bandwidth
X	Flow Compensation	**X**	No Phase Wrap
	POMP	**X**	Extended Dynamic Range
X	Square Pixel	**X**	Surface Coil Intensity Correction
X	Respiratory Compensation	**X**	Classic
	Magnetization Transfer	**X**	Sequential
X	Cardiac Gating/Triggering		Respiratory Gating/Triggering
	Tailored RF		IR Prepared
	DE Prepared		Multi-Phase
	Full Echo Train		CCOMP
	ZIP 1024		ZIP 512
	Zip x 2		ZIP x 4

Imaging Options			
	SmartPrep		Blood Suppression
	Multi Station		Real Time

Applications

Cine GRE generates images that can be displayed in a movie loop, temporal mode, for dynamic views of the heart or vasculature.

CAUTION: **Provide all patients with ear protection prior to any scan to help avoid possible hearing impairment.** Acoustic noise levels can exceed 99 dBA in the magnet bore.

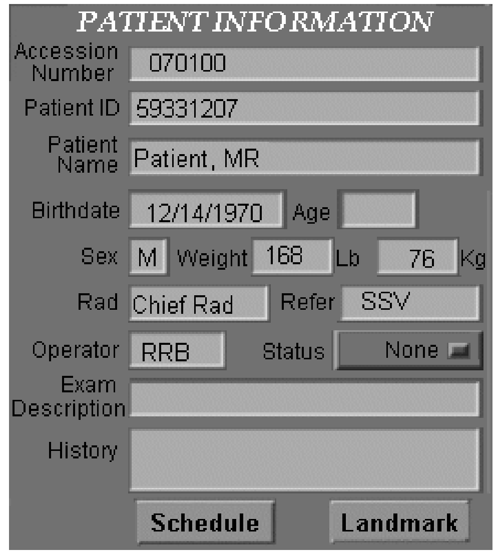
Setting up a Cine pulse sequence

The decision matrix is only for prescribing a Cine scan. The purpose of the decision matrix to help you understand the trade-offs that occur when you change the values for a particular parameter and to provide a framework with which you may build you own unique protocol.

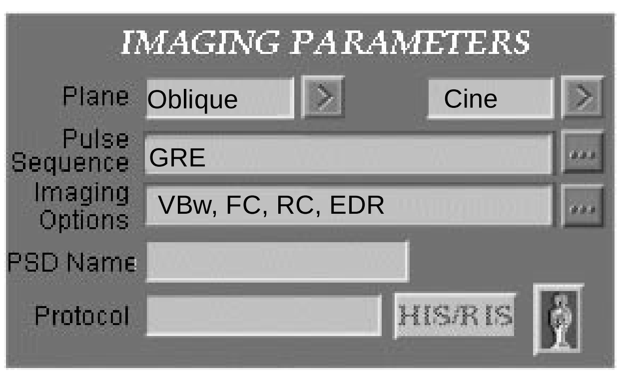
The selected values are only an example of what could be used for a T2* Cine acquisition and is not to be considered a recommendation by GE Medical Systems. For specific protocols, refer to the protocols on your system.

.

Cine - What you select	Selection Notes
SCAN DESKTOP screen	
	Select **Scan Desktop** icon. 

Cine - What you select		Selection Notes
		Click on **[New Patient]** and fill in the patient information. 
PATIENT POSITION area		
Patient Position	**[Supine]**	**Position and Entry:** A Cine acquisition is compatible with any patient position and entry.
Patient Entry	**[Feet First]**	
Coil	**[Body]**	**Coil:** Select the coil that produces the optimum coverage and SNR.
Series Description		**Series Description:** Enter a suitable series description. If you don not enter a description, the system enters one for you. The series description default is the selected scan mode, PSD, and imaging options.

IMAGING PARAMETERS area

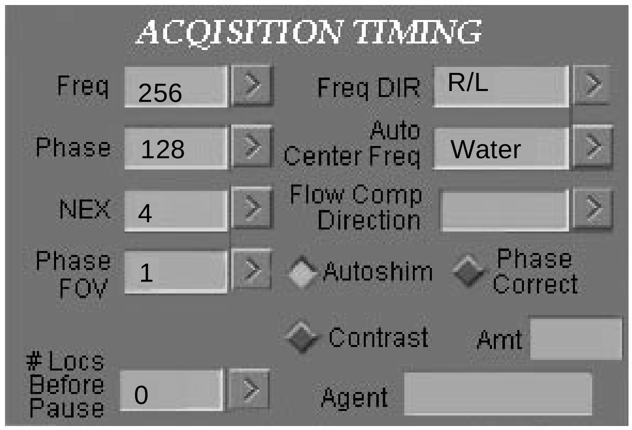


Plane	**[Oblique]**	**Plane:** Cine is compatible with any scan plane except 3-Plane. Choose the plane that best meets the clinical need.

Cine - What you select		Selection Notes
Mode	**[Cine]**	**Mode:** Select `Cine`.
Pulse Seq	**[GRE]**	**Pulse Seq:** Select `GRE` for T2*, or `SPGR` for more T1 contrast. Click **[Accept]** to register the selection.
Imaging Options	**[VBw, FC, RC, EDR]**	**Imaging Options:** Select imaging options that optimizes SNR, spatial resolution, and reduce motion artifacts. Flow Comp may increase signal from blood. Use ECG or PG leads but do not select Gating. Click **[Accept]** to register the selections.
PSD Name	**N/A**	**PSD Name:** Not applicable for Cine.
Protocol	**N/A**	
	SCAN TIMING area	
# of echoes	**[1]**	**# of echoes:** Only 1 echo is allowed.
TE	**[Min]**	**TE:** Increase the TE to produce increased T2* contrast, decreased SNR, signal changes at fat/ water interfaces, and increased magnetic susceptibility effects. Short TEs produce increased T1 contrast, and increased SNR. Minimum TE changes as RBw changes.
TR	**[20]**	**TR:** Short TRs produce decreased SNR and decreased scan time.
TI	**N/A**	
Flip Angle	**[30]**	**Flip Angle:** Given a constant TR, if Flip Angle is increased T1 weighting increases. If Flip Angle is decreased, T2* weighting increases and SNR decreases.
Echo Train Length	**N/A**	
Bandwidth	**[16]**	**Bandwidth:** RBw can only be changed if it was selected from the Imaging Options window. As the RBw decreases, the following occurs: increased SNR, increased chemical shift artifact, increased minimum TE which can potentially decreases # of slices and increased motion artifact.
Bandwidth 2	**N/A**	
	SCANNING RANGE area	
FOV	**[24]**	**FOV:** Select a FOV that covers the anatomy of interest. Anatomy outside the FOV in the phase direction results in aliasing. Small FOVs produce: increased resolution, decreased SNR, and can increase the minimum TE value.
Slice Thickness	**[7]**	**Slice Thickness:** Thin slices produce: increased resolution and decreased SNR. Select a thickness based on SNR, resolution and coverage.
Spacing	**[2.0]**	**Spacing:** Interslice cross-talk is eliminated on sequential gradient echoes. Typical spacing is 0-20% of the slice thickness.

Cine - What you select		Selection Notes
Start, End Locations		**Start, End Locations:** Typically the start and end locations are programmed from the Graphic Rx program.
# Slices	**[4]**	**# Slices:** The number of slices is shown after entering start/end locations. A maximum of 16 slices can be prescribed.

ACQUISITION TIMING area

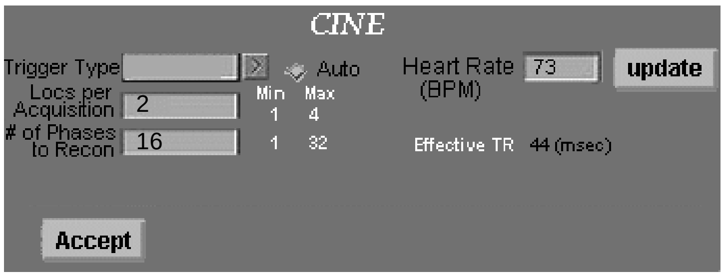


Freq	**[256]**	**Freq:** As the Frequency matrix increases, resolution increases and SNR decreases.
Phase	**[128]**	**Phase:** Phase controls scan time and may control resolution.
NEX	**[1]**	**NEX:** Select a NEX value that produces sufficient SNR. Breath-hold acquisitions may require lower NEX values to decrease scan time. SNR also decreases.
Phase FOV	**[1]**	**Phase FOV:** Select 0.75 or 0.5 to reduce phase steps and thus decrease scan time, decrease FOV in the phase direction, and decrease SNR slightly. The phase FOV dimension is displayed next to the phase FOV factor.
Freq DIR	**[R/L]**	**Freq DIR:** The direction displayed is the default frequency direction which is typically the long axis of the image. To swap phase and frequency, select the other direction.
Auto Center Freq	**[Water]**	**Auto Center Freq:** Select the CF peak that is set during prescan.
Flow Comp DIR	**N/A**	
Autoshim	**[On]**	**Autoshim:** Click Autoshim when using an FOV off center.
Phase Correct	**N/A**	
# of Acqs/Locs Before Pause	**N/A**	

Additional Parameters
SAT Screen

Cine - What you select		Selection Notes
I	**[80]**	**SAT:** SAT pulses may increase the minimum TE and decrease SAR. SAT pulses decrease signal from blood. This may be helpful when not imaging blood flow, for example, in examinations of the myocardium or liver.

Additional Parameters
Cine screen



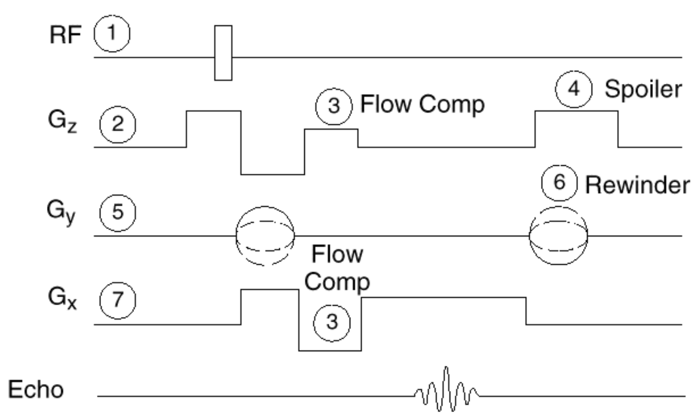
Trigger Type	**[Auto Lead]**	**Trigger Type:** Either PG or ECG can be used. ECG provides a more accurate waveform for cardiac imaging and anatomy near the heart. If `Auto Lead` is selected with an ECG set-up, the system looks for signal from all leads (ECGI, II, or III), if the signal is lost during acquisition.
Heart Rate (bpm)	**[Update bpm]**	**Heart Rate (bpm):** Click `Update bpm` before each acquisition to be sure the selected heart rate reflects the patient's current heart rate. Alternatively, the heart rate can be entered manually by observing the waveform on the PC.
Locations per Acq	**[2]**	**Locations per Acq:** Increasing the # of Locs per Acq results in increased Effective TR, decreased scan time and decreased blood/ myocardium contrast.
Effective TR	**N/A**	**Effective TR:** This value is automatically entered and depends on the TR selected and # of Locs per Acquisition.
# of Cardiac Phases to Reconstruct	**[16]**	**# of Cardiac Phases to Reconstruct:** Increasing the # of phases increases temporal resolution, but decreases image quality. Up to 32 phases is allowed, but the maximum for any given acquisition is dependent on the selected TR and R-R interval.

GRAPHIC RX Screen

Cine - What you select	Selection Notes
Click on the image to display the line cursor for Graphic Rx.	The SAT band function can be accessed from the GRAPHIC Rx window and vice versa. If you had graphically prescribed the previous axial series the same prescription can be copied using the **[Copy RX]** button. Consider using an offset to center the anatomy in the middle of the screen so that you can use a PFOV less than 1 and therefore reduce the scan time. View the Advisory panel to note the # of Acqs you are prescribing. The scan time increases as the # of Acquisitions increase.
SCAN OPERATIONS area	
[Save Series] **[Prep to Scan]** **[Auto Prescan]** **[Scan]**	Enter data in all the fields and click on **[Save Series]**. The series is saved as RXD.

Cine SPGR

Cine can be combined with SPGR which uses RF excitation pulses instead of gradients to spoil the residual signal in preparation for subsequent excitations. SPGR acquires T1-weighted scans, making tissue with short T1 times, like fat, brighter. Cine compliments this capability by employing a short TR pulse sequence to produce images exhibiting bright blood and dark myocardium.



No.	Description
1	RF
2	G_z
3	Flow Comp
4	Spoiler
5	G_y
6	Rewinder
7	G_x

Something to Think About...

- For Cine SPGR, the higher the flip angle and the lower the TE and effective TR, the greater the T1 weighting.

NOTE: The same Something to Think Abouts for Cine GRE apply for Cine SPGR.

Associated Imaging Options

In the following table the X's indicate the option available for use with the Cine pulse sequences.

Imaging Options			
X	None	**X**	Variable Bandwidth
X	Flow Compensation	**X**	No Phase Wrap
	POMP	**X**	Extended Dynamic Range
X	Square Pixel	**X**	Surface Coil Intensity Correction
X	Respiratory Compensation	**X**	Classic
	Magnetization Transfer	**X**	Sequential
X	Cardiac Gating/Triggering		Respiratory Gating/Triggering
	Tailored RF		IR Prepared
	DE Prepared		Multi-Phase
	Full Echo Train		CCOMP
	ZIP 1024		ZIP 512
	Zip x 2		ZIP x 4
	SmartPrep		Blood Suppression
	Multi Station		Real Time

Applications

Cine SPGR is used for: dynamic views of anatomy, such as the liver, brain, or heart; and examining cardiac anatomy rather than blood flow.

Cine PC

Cine with Phase Contrast (Cine PC) captures vascular information at different phases of the cardiac cycle. On Cine PC images, signal is proportional to flow velocity for each phase of the cardiac cycle and the direction of the flow. For example, select [R/L Flow] and blood flowing from right to left appears bright, while blood flowing from left to right appears dark.

During Cine PC, TR remains constant and each phase encoding step is initiated by the ECG trigger. Flow encoding is done via bipolar gradients similar to those used in a non-gated 2D PC study. The Cine GRE pulse sequence includes these gradients.

Cine PC scan data can be acquired in Multi-slice or projection/slab formats. Up to 32 cardiac phases can be created and displayed, just like conventional Cine. Magnitude and weighted-phase images can be generated for each phase in the cardiac cycle.

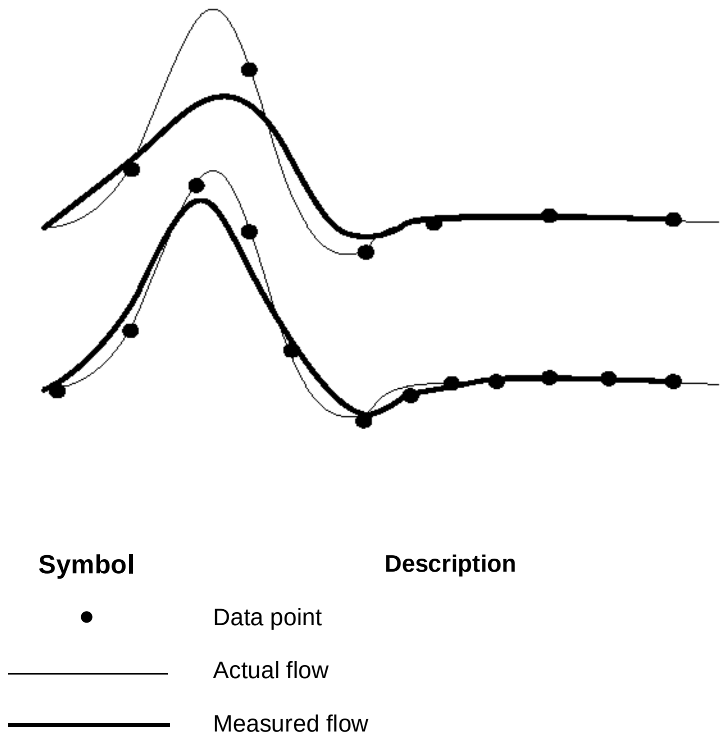
There are two different types of Cine PC flow reconstruction:

- Phase Diff. This provides black and white directional flow information. Background noise is suppressed. Use phase difference when the images are intended for temporal analysis.
- Complex Diff. This does not provide black and white flow direction information. Use complex difference when the images are intended for temporal diagnosis regardless of slice thickness.

When a single flow axis is prescribed, Cine PC scans produce directional images. Select [All] for the flow axis and [Phase Diff] for the flow recon type, and then additional flow images can be selected.

Cine PC is compatible with both oblique and orthogonal imaging techniques.

The diagram below demonstrates the importance of temporal resolution. This is a representation of the impact that temporal resolution has on the measurement of pulsatile flow. Each dot shows where the waveform was sampled for that phase encoding step.



Notice how the lower example, with twice the temporal resolution, more accurately demonstrates the true flow pattern. As a result, the more often the vessel is sampled, the more accurate the results. For the best temporal resolution, acquire only 1 loc/acq and increase the # of cardiac phases.

Something to Think About...

- A reduction in temporal accuracy can occur with an increase in the effective TR or the reconstruction of an insufficient number of phases.
- More than one location per acquisition can greatly reduce the temporal resolution of the acquisition.
- Cine PC is limited to eight slices per scan. Cine PC can produce signal loss.
- Enter the real heart rate or use [Update bpm] because:
  - arrhythmia rejection is used to eliminate irregular heart beats. Any heart beat that is more or less than 20 percent of the average RR interval is rejected.

Two good heart beats are required before the system starts accepting heart beats again.

  ° if, during a Cine PC acquisition, the patient’s heart rate increases by more than 25 percent of the downloaded heart rate, the system displays the message `The patients RR-interval too long. Image quality may suffer.` Arrhythmia rejection may not correct for this problem because the patient’s heart rate may be slowed down by more than 25 percent from the downloaded heart rate, but still remain constant throughout the acquisition.

- Patients with arrhythmias do not produce good quality Cine PC or Cine acquisitions.
- If using more than one location per acquisition, the temporal resolution of the acquisition is greatly reduced, doubling the effective TR in the case of one of one location per acquisition, or quadrupling the TR in the case of four locations per acquisition.
- When the effective TR is increased, the acquisition’s sensitivity to pulsatile flow is reduced. The less often the flow in the vessel is sampled, the more the measurements are averaged (reduced).
- The less often the flow in the vessel is sampled, the less accurate is the phase information about flow patterns in the vessel.
- The more pulsatile the flow pattern is in the vessel, the more important is the temporal resolution of the acquisition.
- The scan time is reduced when more than one location per acquisition is done.
- Two locations per acquisition may be satisfactory if the flow in the vessel is not pulsatile.
- If the flow is pulsatile, acquiring two locations per acquisition may result in different flow and velocity values because of changes in the patient’s heart rate or blood pressure. This happens because the acquisitions are done sequentially. Acquiring two locations per acquisition does not result in different flow and velocity values, because the acquisition is acquired in an interleaved fashion.
- If too many images are reconstructed, Flow Analysis can not use the excess information to make its

calculations and, consequently, the images are a waste of disk space and processing time.

Associated Imaging Options

In the following table the X's indicate the option available for use with the Cine PC pulse sequences.

Imaging Options			
X	None	**X**	Variable Bandwidth
X	Flow Compensation	**X**	No Phase Wrap
	POMP	**X**	Extended Dynamic Range
X	Square Pixel	**X**	Surface Coil Intensity Correction
X	Respiratory Compensation	**X**	Classic
	Magnetization Transfer	**X**	Sequential
X	Cardiac Gating/Triggering		Respiratory Gating/Triggering
	Tailored RF		IR Prepared
	DE Prepared		Multi-Phase
	Full Echo Train		CCOMP
	ZIP 1024		ZIP 512
	Zip x 2		ZIP x 4
	SmartPrep		Blood Suppression
	Multi Station		Real Time

Applications

Cine PC is used to acquire images for the following applications:

- assessing blood flow in the aorta;
- imaging triphasic flow in the arteries of the legs; and

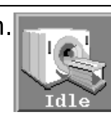
CAUTION: imaging regions with complex flow patterns that vary throughout the cardiac cycle, for example the carotid bulb or aneurysms.**Provide all patients with ear protection prior to any scan to help avoid possible hearing impairment.** Acoustic noise levels can exceed 99 dBA in the magnet bore.

Setting up a Cine PC pulse sequence

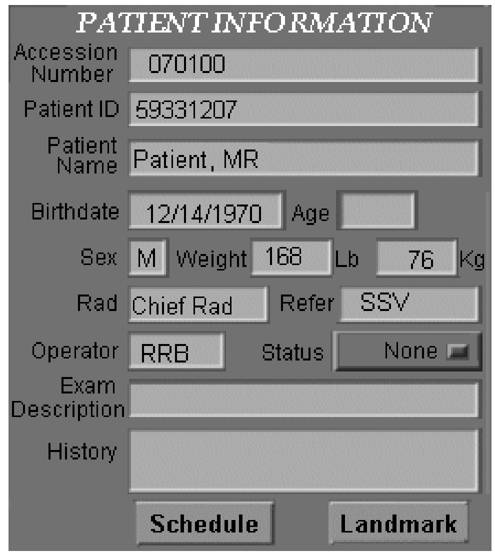
The decision matrix is only for prescribing a Cine PC scan. The purpose of the decision matrix to help you understand the trade-offs that occur when you change the values for a particular parameter and to provide a framework with which you may build you own unique protocol.

The selected values are only an example of what could be used for a Cine PC acquisition and is not to be considered a recommendation by GE Medical Systems. For specific protocols, refer to the protocols on your system.

.

Cine PC- What you select	Selection Notes
SCAN DESKTOP screen	
	Select **Scan Desktop** icon. 

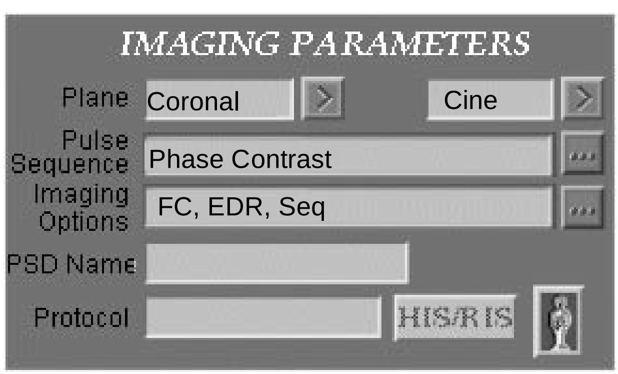
Cine PC- What you select		Selection Notes
		Click on **[New Patient]** and fill in the patient information.



PATIENT POSITION area

Patient Position	**[Supine]**	**Position and Entry:** A Cine PC acquisition is compatible with any patient position and entry.
Patient Entry	**[Feet First]**	
Coil	**[Body]**	**Coil:** Select the coil that produces the optimum coverage and SNR.
Series Description		**Series Description:** Enter a suitable series description. If you don not enter a description, the system enters one for you. The series description default is the selected scan mode, PSD, and imaging options.

IMAGING PARAMETERS area

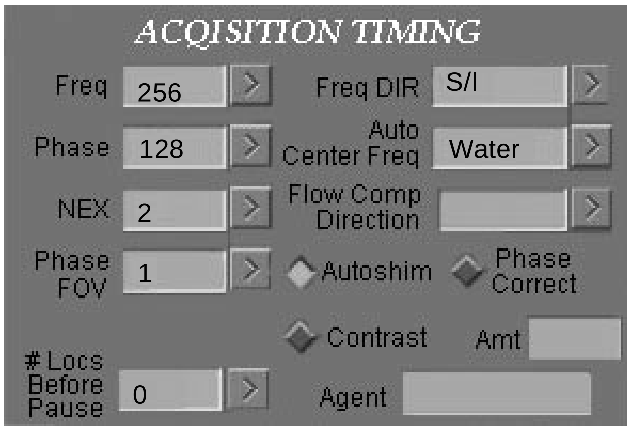


Plane	**[Coronal]**	**Plane:** Cine PC is compatible with any scan plane except 3-Plane. Select the plane that best meets the clinical need.

Cine PC- What you select		Selection Notes
Mode	**[Cine]**	**Mode:** Select Cine
Pulse Seq	**[Phase Contrast]**	**Pulse Seq:** Select [Phase Contrast]. Click on the **[Accept]** button in the window to register the selection.
Imaging Options	**[FC, EDR, Seq]**	**Imaging Options:** Select imaging options that optimizes SNR, spatial resolution, and reduce motion artifacts. Flow Comp may increase signal from blood. Use ECG or PG leads but do not select Gating. Click **[Accept]** to register the selections.
PSD Name	**N/A**	**PSD Name:** Not applicable for Cine PC.
Protocol	**N/A**	
SCAN TIMING area		
# of echoes	**[1]**	**# of echoes:** Only 1 echo is allowed.
TE	**N/A**	**TE:** The minimum TE is set by the system based on parameter selections such as: FC, FOV, RBw, and Frequency matrix.
TR	**[30]**	**TR:** As TR increases, temporal accuracy decreases. TRs are generally in the range of 20-40 ms.
TI	**N/A**	
Flip Angle	**[20]**	**Flip Angle:** Moderate Flip Angles, 20-40 provide sufficient vessel signal and good background-vessel contrast.
Echo Train Length	**N/A**	
Bandwidth	**[16]**	**Bandwidth:** Variable Bandwidth is not allowed. RBw is set by the system.
Bandwidth 2	**N/A**	
SCANNING RANGE area		
FOV	**[40]**	**FOV:** Select a FOV that covers the anatomy of interest. Anatomy outside the FOV in the phase direction results in aliasing. Small FOVs produce: increased resolution, decreased SNR, and can increase the minimum TE value.
Slice Thickness	**[30]**	**Slice Thickness:** Single thick slices or multiple, thin (3-5 mm) slices can be acquired. Decrease slice thickness to produce decrease intravoxel dephasing.
Spacing	**[0]**	**Spacing:** Zero spacing is allowed. Slices are acquired sequentially and cross-talk between slices is not a problem.
Start, End Locations		**Start, End Locations:** Typically the start and end locations are programmed from the Graphic Rx program.
# Slices	**[1]**	**# Slices:** The graphically prescribed number of slices is shown here. Cine PC allows a maximum of 8 slices.

Cine PC- What you select		Selection Notes

ACQUISITION TIMING area

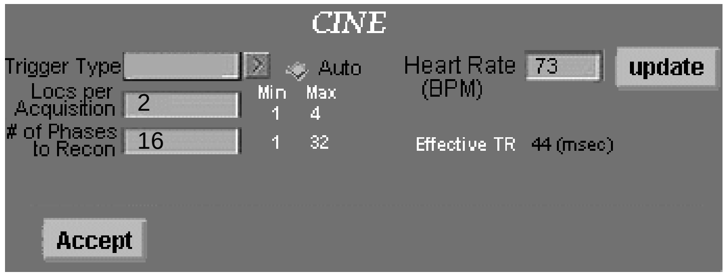


Freq	**[256]**	**Freq:** As the Frequency matrix increases, resolution increases and SNR and intravoxel decreases.
Phase	**[128]**	**Phase:** Increased phase matrix produces: decreased intravoxel dephasing, increased resolution, and increased scan time.
NEX	**[2]**	**NEX:** Select a NEX value that produces sufficient SNR, yet does not compromise scan time.
Phase FOV	**[1]**	**Phase FOV:** Select 0.75 or 0.5 to reduce phase steps and thus decrease scan time, decrease FOV in the phase direction, and decrease SNR slightly. The phase FOV dimension is displayed next to the phase FOV factor.
Freq DIR	**[S/I]**	**Freq DIR:** The direction displayed is the default frequency direction which is typically the long axis of the image. To swap phase and frequency, select the other direction.
Auto Center Freq	**[Water]**	**Auto Center Freq:** Select the CF peak that is set during prescan.
Flow Comp DIR	**N/A**	
Autoshim	**[On]**	**Autoshim:** Click Autoshim to improve homogeneity.
Phase Correct	**N/A**	
# of Acqs/Locs Before Pause	**N/A**	

Additional Parameters
SAT Screen

SAT	**None**	**SAT:** SAT pulses are not necessary with PC exams.

Cine PC- What you select		Selection Notes
Additional Parameters Cine screen		



Cine PC- What you select		Selection Notes
Trigger Type	**[PG]**	**Trigger Type:** Either PG or ECG can be used. However there is a pulse delay with Peripheral Gating. As a result, ECG may provide a more accurate trigger.
Heart Rate (bpm)	**[Update bpm]**	**Heart Rate (bpm):** Click [Update bpm] before each acquisition to be sure the selected heart rate reflects the patient's current heart rate. Alternatively, the heart rate can be entered manually by observing the waveform on the PC.
Locations per Acq	**[1]**	**Locations per Acq:** For a single flow direction, 1 or 2 Locs per Acq are allowed. If [All] is selected only 1 Loc per Acq is allowed. Increasing the # of Locs per Acq results in: increasing effective TR, decreasing temporal resolution and scan time.
# of Cardiac Phases to Reconstruct	**[16]**	**# of Cardiac Phases to Reconstruct:** As # of phases increase, temporal resolution increases. Up to 32 phases can be acquired.
Vascular Options Screen		
Projection Images	**N/A**	**Projection Images:** Projection images are not allowed in 2D PC.
Collapse	**[On]**	**Collapse:** Click [On] to get a collapsed view in the plane of acquisition.
Flow Recon Type	**[Phase Diff]**	**Flow Recon Type:** Select [Phase Diff] to obtain images with flow direction information. [Complex Diff] can be selected but results in bright signal for all flow regardless of direction.
Flow Analysis	**[Off]**	**Flow Analysis:** Turn Flow Analysis [ON] if images are to be used for flow measurements.
Velocity Encoding	**[130]**	**Velocity Encoding**: Set the VENC to allow for the highest velocities in the vessel of interest. A VENC value set too low, results in flow aliasing.

Cine PC- What you select		Selection Notes
Acq Flow Dir Images	**[S/Flow]**	**Acq Flow Direction Images:** Generally, one flow direction is selected to obtain multiple phase flow information within a particular vessel(s). [All] can be selected, however, temporal resolution is cut in half.
Additional Flow Images	**[Mag]**	**Additional Flow Images:** Magnitude images automatically reconstruct. If [All] was selected for Acq Flow Direction, then additional flow direction images can be selected.
GRAPHIC RX Screen		
Click on the image to display the line cursor for Graphic Rx.		To prescribe oblique slices you must select [Oblique] in the Plane pull-down menu. Consider using an offset to center the anatomy in the middle of the screen so that you can use a PFOV less than 1 and therefore reduce the scan time. View the Scanning Range area to note the # of slices you are prescribing. Cine PC allows a maximum of 8 slices.
SCAN OPERATIONS area		
	[Save Series] **[Prep to Scan]** **[Auto Prescan]** **[Scan]**	Enter data in all the fields and click on **[Save Series]**. The series is saved as RXD.

Flow Analysis

The accuracy of Flow Analysis measurements depends on the quality of the Phase Contrast acquisitions used to acquire the image set. This section explains how the scan parameters can impact the quality of the data sets used with Flow Analysis.

Three Phase Contrast PSDs are suitable for Flow Analysis processing:

- Cine Phase Contrast (Cine-PC)
- 2D Phase Contrast (2D PC)
- 3D Phase Contrast (3D PC)

Scan Parameters: TR

The TR in a Phase Contrast acquisition for Flow Analysis has the same influence on image contrast, SNR, and acquisition time, as it would in any other acquisition. In addition, the TR is important for Flow Analysis because shorter TRs influence the number of samples acquired. Generally, the more often the flow in the vessel is sampled, the more accurate the results. Keep in mind that:

- Short TRs reduce acquisition times in 2D and 3D Phase Contrast acquisitions.
- Short TRs increase the number of data points collected in an R-R interval on Cine-PC acquisitions. This improves the acquisition’s potential for accurately measuring pulsatile flow.

Something to Think About...

- In general, the TR should be the minimum TR allowed. Extremely short TRs could cause some problems in 2D PC acquisitions on patients with very slow heart rates. In this situation, the acquisition is acquired over a small number of heart beats. The image contrast is based on when the center of K-space is acquired during the cardiac cycle. The echoes collected at the center of K-space have the most influence on the resulting image. If the center of K-space is acquired during systole, the average velocity and flow rates are weighted towards systolic values. If the center of K-space is collected during diastole, the average velocity and flow rates are weighted more towards diastolic values.

Scan Parameter: TE

Use the Minimum TE to minimize the effects of intravoxel dephasing.

Scan Parameter: Flip Angle

Moderate flip angles of 20 – 40 degrees work well for Cine-PC and 2D PC Flow Analysis acquisitions. Use the standard flip angle for 3D PC acquisitions.

Something to Think About...

When selecting a flip angle, keep in mind that:

- Moderate flip angles improve signal in flowing vessels and improve the background vessel contrast.
- The flow is always through the plane for Flow Analysis acquisitions. Because the saturation caused by in-plane flow is reduced, SNR can be increased for higher resolution.
- Increased flip angles increase the effects of partial voluming.
- In areas of very slow flow, high flip angles may saturate the flow in vessel and reduce background-to-vessel contrast.

- In areas of high flow, large flip angles may cause pixel overranges and reduce the measured flow rate and velocity. A reduced flip angle may be used as a way to correct this problem.
- Larger flip angles may increase the severity of pulsatile flow artifacts.

Scan Parameter: Slice Thickness and Position

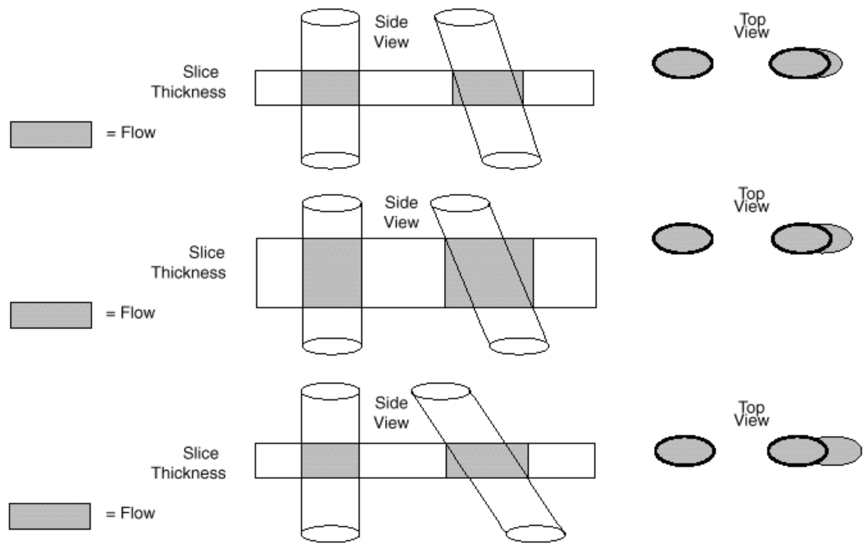
Use the thinnest practical slice thickness. Slices 3 – 5 mm thick work well for most 2D PC and Cine-PC acquisitions. Slices 1 – 3 mm thick work well for 3D PC acquisitions. The slice should not be placed in an area of complex or extremely high velocity flow.

Something to Think About...

When choosing a slice thickness remember that:

- Thin slices reduce the effects of partial voluming.
- Thin slices reduce the effect of intravoxel dephasing.
- The penalty for thin slices in an increase in TR.
- Flow Analysis does not process slices thicker than 20 mm.
- For the best results, place the slice proximal or distal to an area of complex or high velocity flow.
- In areas of high flow, thick slices may cause pixel overranges and reduce the measured flow rate and velocity. Use a reduced slice thickness to correct this problem.

Orient slices perpendicular to the flow direction in the vessel.



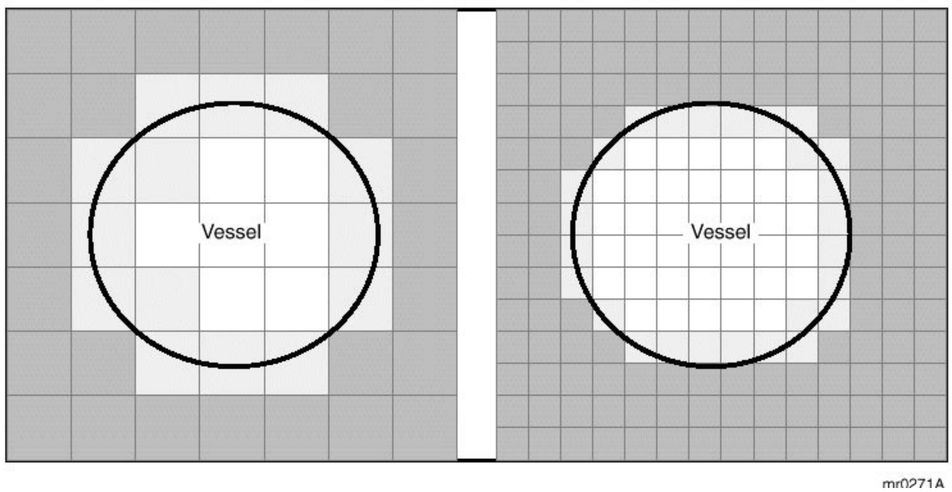
As the slice thickness or angle away from perpendicular increases, the overestimation of the area of the vessel increases.

Something to Think About...

- To accurately measure the velocity of the flowing protons the direction of movement must be along the axis of the gradient.
- Partial voluming effects due to the slice thickness are minimized if the slice is perpendicular to the vessel.
- The minimum TR increases with oblique acquisitions.
- An oblique acquisition increases the penalties for thin slices and small FOVs.
- If the vessel is less than ten degrees away from perpendicular to an orthogonal slice plane, the benefits of an orthogonal acquisition may outweigh the benefits of an oblique slice.
- If possible, place the slice location at a position in the vessel where the flow is perpendicular to an orthogonal plane.
- A cross section area of the vessel increases as angle away from perpendicular increases. This tends to overestimate flow.
- The measured velocity is reduced as the angle away from perpendicular increases. This tends to underestimate velocity.
- Multi-slice multi-angle Cine-PC scan prescriptions are not allowed.

Scan Parameter: Matrix and FOV

Selecting a FOV for Flow Analysis acquisitions is similar to that of other vascular acquisitions. It is a balance of acquisition time, SNR, resolution and the impact on the other important scan parameters such as TR and TE.



Left illustration: Vessel Voxel Size = 2 sq. mm Total Flow Area = 42 sq. mm 21 voxels are flow or partial flow

Right illustration: Voxel Size = 0.5 sq. mm Total Flow Area = 32 sq. mm 64 voxels are flow or partial flow

The illustration above demonstrates the impact resolution can have on Flow Analysis measurements. The darkest voxels represent stationary tissue. The gray voxels represent voxels with both flow and stationary tissue. Finally, the clear voxels represent voxels that are all flow. Voxels that contain part flow and part stationary tissue show up as clear voxels. This results in the area of the vessel being overestimated.

For example, the two vessels shown here are of equal size. Assuming that the ROI for this vessel is at the vessel wall, any of the pixels within or touching the ROI are included. The result is that the area of flow rate would be substantially overestimated in the vessel on the left. When available, the Asymmetric FOV options can be used to reduce scan times while maintaining resolution.

When available, the Asymmetric FOV options can be used to reduce scan time while maintaining resolution.

Something to Think About...

Benefits

- The smaller the voxel size, the more accurate the measurements, provided that adequate SNR is maintained.
- Small voxels reduce the effects of intravoxel dephasing.
- Small voxels reduce the effect of partial voluming.
- Small voxels reduce the effect of chemical shift in vessels embedded in fat.
- Accuracy increases as the number of voxels contained within the vessel measured increase.

Trade-offs

- Increasing the resolution of the acquisition costs SNR and acquisition time.
- Increased resolution does little without accurately defining the edge of the vessel.
- In areas of high flow, large voxels may cause pixel overranges, and reduce the measured flow rate and velocity. Use reduced FOV or a larger matrix selection to correct this problem.

Scan Parameter: VENC

For best results, enter a VENC value as close as possible to, but never less than, the peak velocity in the vessel. Velocity aliasing reverses the direction of flow that exceeds the VENC. This causes the flow rate and peak velocity to be underestimated in the vessel with aliased voxels.

Something to Think About...

- Velocity aliasing is unacceptable for Flow Analysis image sets.
- If the VENC is substantially higher than the velocities in the vessel, the acquisition is not sensitive to the slow flow in the vessel. This may cause the flow in the vessel to be underestimated because the acquisition does not see the voxels with slow flow. The result of a VENC value that is too high is a decreased signal.
- As the VENC value is reduced, the stress on the flow-encoding gradients is increased, causing the minimum TR and TE to increase.
- As the VENC is increased, the overall SNR of the acquisition is increased.

- Acquisitions with a VENC greater than 50 cm/sec and a slice thickness of less than 10 mm is scaled back during reconstruction, to prevent voxel overranges. This reduction in scale reduces the dynamic range of the gray scale. This may result in a smoother appearance of background (stationary) tissue, but should not alter the results of Flow Analysis measurements.

Scan Parameter: Vessel Motion

Vessel motion is a source of error in Flow Analysis acquisitions because of the partial voluming that may occur.

Common sources of motion include respiratory motion, voluntary patient motion, peristalsis, and vessel translation.

Something to Think About...

- Respiratory motion can be controlled with a breath-held 2D PC acquisition.
- Respiratory motion can be compensated for by using Resp Comp on Cine-PC acquisitions.
- Voluntary patient motions cannot be compensated for. Acquisitions with patient motion should be re-acquired.
- For body applications, motion of vessels due to peristalsis or bowel motion may have errors due to partial voluming effects.
- Vessel translation due to cardiac-induced motion, is a potential source of error in 2D and 3D PC acquisitions.
- Cine-PC acquisitions compensate for cardiac-induced motion.

Scan Parameter: Flow Encoding Axis

Choose the flow-encoding axis, or acquisition flow direction, that is perpendicular to the slice plane.

For Flow Analysis image sets, the flow-encoding axis MUST include the direction perpendicular to the slice plane. For example:

- An axial slice flow-encoding axis must be S/I.
- A coronal slice flow-encoding axis must be A/P.
- A sagittal slice flow-encoding axis must be R/L.
- An oblique slice flow-encoding axis must be Slice.

Only the through-plane images may be processed if `All` is selected. For example, if acquiring an axial slice and All flow encoding direction is selected, only the S/I flow images can be processed. The R/L and A/P images are rejected by the Flow Analysis software.

Something to Think About...

- Do not use the All flow-encoding axis option when acquiring Flow Analysis image sets. There is no benefit to selecting All for Flow Analysis images sets, from a quantification standpoint, because:
  - Blood flowing from posterior to anterior is black
  - Blood flowing from left to right is black
  - Blood flowing from inferior to superior is black
- Selecting All flow-encoding axis instead of a single axis reduces, by half, the rate at which the flow is sampled in a vessel.
- Selecting All flow-encoding axis cuts the temporal resolution of a Cine-PC acquisition in half. This can cause the user to miss important pulsatile flow information.

Scan Parameter: Additional Images

When a single flow-encoding axis is selected, flow direction images are automatically reconstructed. Choose `Magnitude` if desired. If `All` was selected, additional images must be selected that contain flow perpendicular to the scan plane.

Scan Parameter: Reconstruction Type

The Flow Analysis option on the vascular options screen should always be selected for Flow Analysis acquisitions.

Something to Think About...

- Selecting the Flow Analysis option enables a phase difference reconstruction and turns off phase correction.
- Phase correction is an algorithm used to correct for shading across an image. This correction could cause errors in velocity measurements.
- Flow Analysis only accepts images that have been reconstructed using the Flow Analysis or Phase Diff reconstruction methods.
- Phase difference acquisitions can be processed with Flow Analysis if a proper background correction is done.

Scan Parameter: Flow Compensation

Flow Compensation is helpful in vessels with pulsatile flow.

Flow Compensation improves the quality of acquisitions in most applications by reducing the flow artifacts. This helps the user define the edges of the vessels. Flow Compensation increases the minimum TR and TE allowed, but the benefits outweigh these negatives in most cases. In cases of non-pulsatile flow, Flow Compensation is of reduced benefit.

Scan Parameter: Respiratory Compensation

Respiratory compensation is helpful in reducing the motion artifacts caused by respiration.

Scan Parameter: Image Intensity Correction

Image Intensity Correction is not compatible with Phase Contrast acquisitions.

Scan Parameter: Square Pixel

This option is used for fine-tuning resolution, SNR, and scan time.

Scan Parameter: Sequential

Sequential mode must be selected with 2D PC acquisitions.

Scan Parameter: Extended Dynamic Range

Extended Dynamic Range may improve SNR in some acquisitions. The penalties for using EDR includes increased image reconstruction times and an increase in BAM requirements.

Applications

Flow Analysis is used to generate flow and velocity information that may be useful in evaluating flow/velocity patterns, quantifying collateral flow, planning therapy or quantifying the effectiveness of therapy.

Flow Analysis is not a substitute for standard cardiac and vascular analysis procedures. It may not be directly comparable to Ultrasound data.

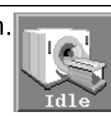
CAUTION: imaging regions with complex flow patterns that vary throughout the cardiac cycle, for example the carotid bulb or aneurysms.**Provide all patients with ear protection prior to any scan to help avoid possible hearing impairment.** Acoustic noise levels can exceed 99 dBA in the magnet bore.

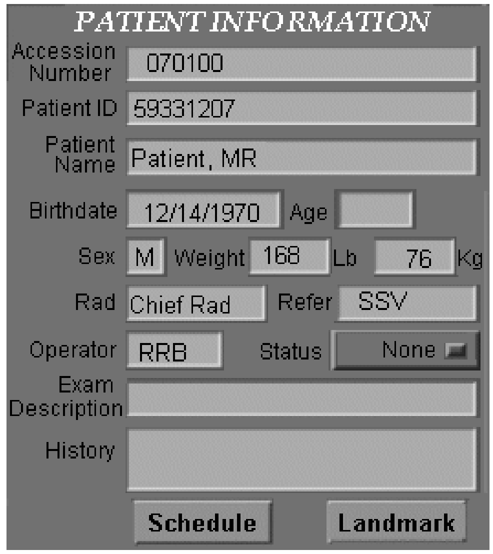
Setting up a Flow Analysis pulse sequence

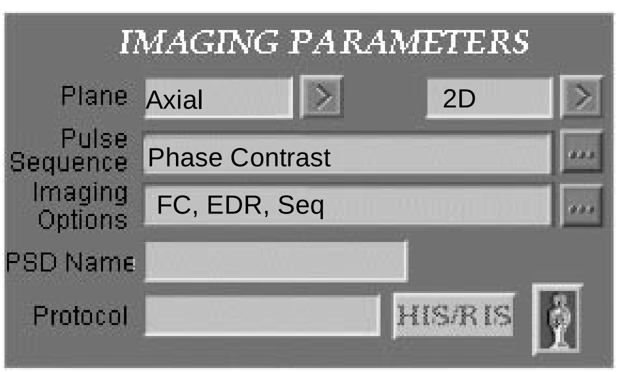
The decision matrix is only for prescribing a Flow Analysis scan. The purpose of the decision matrix to help you understand the trade-offs that occur when you change the values for a particular parameter and to provide a framework with which you may build you own unique protocol.

The selected values are only an example of what could be used for a flow analysis acquisition and is not to be considered a recommendation by GE Medical Systems. For specific protocols, refer to the protocols on your system.

.

Flow Analysis - What you select	Selection Notes
SCAN DESKTOP screen	
	Select **Scan Desktop** icon. 

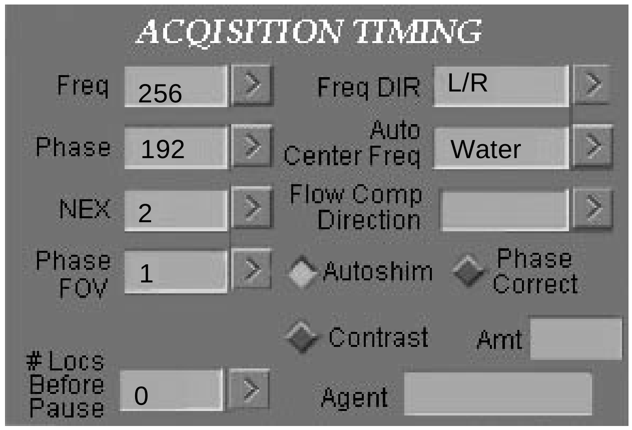
Flow Analysis - What you select		Selection Notes
		Click on **[New Patient]** and fill in the patient information. 
PATIENT POSITION area		
Patient Position	**[Supine]**	**Position and Entry:** A Flow Analysis acquisition is compatible with any patient position and entry.
Patient Entry	**[Head First]**	
Coil	**[Anterior Neck]**	**Coil:** Select the coil that produces the optimum coverage and SNR.
Series Description		**Series Description:** Enter a suitable series description. If you don not enter a description, the system enters one for you. The series description default is the selected scan mode, PSD, and imaging options.
IMAGING PARAMETERS area		



Flow Analysis - What you select		Selection Notes
Plane	**[Axial]**	**Plane:** Flow Analysis is done with a Vascular Phase Contrast acquisition. 2D Phase Contrast is compatible with any scan plane except 3-Plane, and 3D is not compatible with oblique. Choose the plane that best meets the clinical need. Slices should be perpendicular to the flow direction of the vessel.
Mode	**[2D]**	**Mode:** Flow Analysis can be done on 2D, 3D and CINE acquisitions. 2D provides oblique capabilities and decreases scan times. 3D allows thinner slices to decrease partial volume effects, decrease intravoxel dephasing, and provides the ability to reformat and analyze reformatted vessels. Cine can provide multiple phases of the vessel(s) of interest for time resolved flow information.
Pulse Seq	**[Phase Contrast]**	**Pulse Seq:** Select [Phase Contrast]. Click on the **[Accept]** button in the window to register the selection.
Imaging Options	**[FC, EDR, Seq]**	**Imaging Options:** `Sequential` must be selected with 2D. Select imaging options that optimizes SNR, spatial resolution and reduce motion artifacts. Flow Compensation is helpful in vessels with pulsatile flow and can increase vessel edge definition. Click **[Accept]** to register the selections.
PSD Name	**N/A**	**PSD Name:** Not applicable for this pulse sequence.
Protocol	**N/A**	
	SCAN TIMING area	
# of echoes	**[1]**	**# of echoes:** Only 1 echo is allowed.
TE	**N/A**	**TE:** The minimum TE is set by the system based on parameter selections such as: FC, FOV, RBw, and Frequency matrix.
TR	**[30]**	**TR:** Short TRs decrease acquisition times and increase the number of data points collected in R-R interval on Cine-PC acquisitions.
TI	**N/A**	
Flip Angle	**[30]**	**Flip Angle:** For 2D and CINE, Moderate Flip Angles increase signal in flowing vessels and increase background vessel contrast. For 3D, Flip Angles from 10 – 20 are sufficient.
Echo Train Length	**N/A**	
Bandwidth	**[16]**	**Bandwidth:** Variable Bandwidth is not allowed. RBw is set by the system.
Bandwidth 2	**N/A**	
	SCANNING RANGE area 2D/Cine	

Flow Analysis - What you select		Selection Notes
FOV	**[16]**	**FOV:** Select a FOV that covers the anatomy of interest. Anatomy outside the FOV in the phase direction results in aliasing. Small FOVs produce increased resolution, decreased SNR, can increased the minimum TE value and decreased voxel size which decreases intravoxel dephasing and partial volume effects.
Slice Thickness	**[4]**	**Slice Thickness:** Use the thinnest practical slice thickness, slices 3 – 5 mm thick work well for most 2D PC and Cine-PC. Flow Analysis does not process slices thicker than 20 mm. Thin slices decrease partial voluming and decrease effects of intravoxel dephasing.
Spacing	**[0]**	**Spacing:** Zero is used to obtain contiguous slices.
Start, End Locations		**Start, End Locations:** Typically the start and end locations are programmed from the Graphic Rx program.
# Slices	**[1]**	**# Slices:** The number of slices is determined by how much of the vessel is analyzed for flow measurements, often it is only one location.
	SCANNING RANGE area 3D	
FOV	**[16]**	**FOV:** Select a FOV that covers the anatomy of interest. Anatomy outside the FOV in the phase direction results in aliasing. Small FOVs produce increased resolution, decreased SNR, can increased the minimum TE value and decreased voxel size which decreases intravoxel dephasing and partial volume effects.
Slice Thickness	**[1.0]**	**Slice Thickness:** Use the thinnest practical slice thickness, 1 to 3 mm. Thin slices decrease partial voluming and intravoxel dephasing.
# of Scan Locs	**[32]**	**# of Scan Locs:** Scan locations from 12 – 124, in steps of two, can be prescribed.
Start, End Locations		**Start, End Locations: The** start and end locations are programmed from the Graphic Rx program when the volume is deposited.
# Slabs	**[1]**	**# Slabs:** Multi-slab is not allowed in 3D PC.

Flow Analysis - What you select		Selection Notes
ACQUISITION TIMING area		



Freq	**[256]**	**Freq:** Only 256 is available with 3D PC
Phase	**[192]**	**Phase:** Phase controls scan time, resolution and SNR. Increased phase value produces decreased intravoxel dephasing and decreased partial volume effects.
NEX	**[2]**	**NEX:** Select a NEX value that produces sufficient SNR, yet does not compromise scan time.
Phase FOV	**[1]**	**Phase FOV:** Select 0.75 or 0.5 to reduce phase steps and thus decrease scan time, decrease FOV in the phase direction, and decrease SNR slightly. The phase FOV dimension is displayed next to the phase FOV factor.
Freq DIR	**[L/R]**	**Freq DIR:** The direction displayed is the default frequency direction which is typically the long axis of the image. To swap phase and frequency, select the other direction.
Auto Center Freq	**[Water]**	**Auto Center Freq:** Select the CF peak that is set during prescan.
Flow Comp DIR	**N/A**	
Autoshim	**[On]**	**Autoshim:** Click Autoshim to improve homogeneity.
Phase Correct	**N/A**	
# of Acqs/Locs Before Pause	**N/A**	
Additional Parameters SAT Screen		
SAT	**None**	**SAT:** SAT pulses are not necessary with PC exams.
GRAPHIC RX Screen		

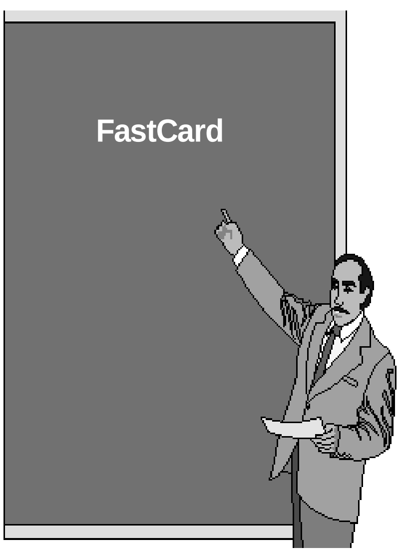
Flow Analysis - What you select		Selection Notes
Click on the image to display the line cursor for Graphic Rx.		To prescribe oblique slices you must select [Oblique] in the Plane pull-down menu. Consider using an offset to center the anatomy in the middle of the screen so that you can use a PFOV less than 1 and therefore reduce the scan time. View the Scanning Range area to note the # of slices you are prescribing. Cine PC allows a maximum of 8 slices.
Vascular Options Screen		
Projection Images	**[0]**	Projection Images: Projections are not allowed in 2D PC and CINE PC. Select `19` or `37` to automatically reconstruct projections with 3D.
Collapse	**[On]**	**Collapse:** Click `On` to get a collapsed view in the plane of acquisition.
Flow Recon Type	**[Phase Diff]**	**Flow Recon Type:** Select Flow Analysis On with Phase Diff. Always select Flow Analysis On if the images is used for flow measurements. Flow Analysis turns off phase correction which, if left on, can cause errors in measurements. Complex Diff images cannot be used for flow analysis.
Flow Analysis	**[On]**	
Velocity Encoding	**[120]**	**Velocity Encoding:** Choose a VENC value as close as possible to, but never less than, the peak velocity in the vessel.
Acq Flow Direction Images:	**[All]**	**Acq Flow Direction Images:** Select the flow-encoding axis, or acquisition flow direction, that is perpendicular to the slice plane. For an oblique slice, the flow encoding axis must be Slice. Selecting `All` reduces the rate at which the flow is sampled and cuts the temporal resolution of a Cine-PC acquisition in half.
Additional Flow Images	**[S/I Flow]**	**Additional Flow Images:** If `All` was selected for Acq Flow Direction, additional images must be selected that contain flow perpendicular to the slice plane. Select `Magnitude` if desired, these images are not necessary for flow analysis.
SCAN OPERATIONS area		
	[Save Series] **[Prep to Scan]** **[Auto Prescan]** **[Scan]**	Enter data in all the fields and click on **[Save Series]**. The series is saved as RXD.

Volume 2

Chapter 10

Imaging with FastCard Pulse Sequence

Where Am I?



Introduction

This chapter explains the pulsing components and timing factors directly related to the FastCard pulse sequence. This chapter explains the concepts of each, and the step-by-step instructions to help you learn how to:

- Optimize FastCard images
- Select optimal parameters

In addition, this chapter answers the following questions:

1. How does FastCard collect data?
2. What pulse sequences are compatible with FastCard?
3. How does arrhythmia rejection work?
4. What are the image characteristics?
5. What are some of the applications for FastCard?

About... FastCard Pulse Sequence

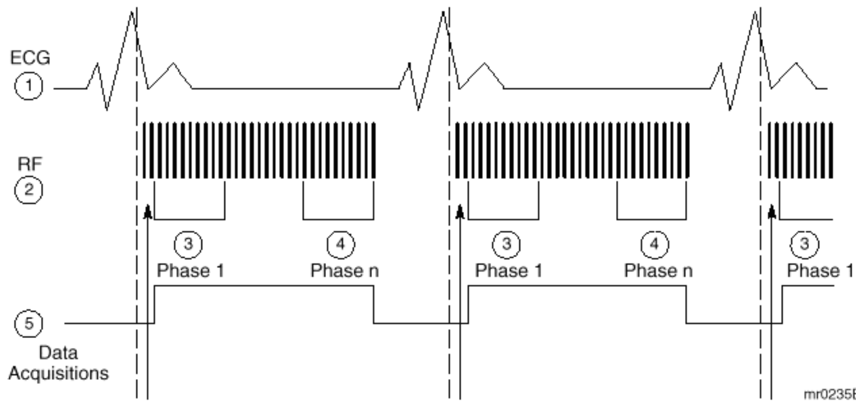
This section presents the concepts necessary to understand GRE and SPGR pulse sequences. Specifically you need to understand:

- FastCard (Fast Cardiac Gating)
  - Data acquisition
  - Views per segment
  - Sequential versus non-sequential
  - Arrhythmia rejection

FastCard

FastCard is a fast, 2D Gradient Echo sequence that acquires multiple phases of the cardiac cycle at single or multiple locations. Two forms of FastCard are available: sequential and non-sequential. Each can be acquired utilizing FastCard GRE or FastCard SPGR.

In standard Cine acquisitions, one view per cardiac trigger is obtained. An entire image (256x128) requires 128 heartbeats to acquire all the necessary K-space data. FastCard segments the number of views into groups of views per segment, with each group of views acquired after a cardiac trigger. Views per segment are the number of K-space lines acquired per cardiac phase, during one R-R period. The views per segment choice affects the temporal resolution, blurring and scan time of a fast cardiac scan. As the views per segment increase, scan time decreases, the number of cardiac phases decreases and blurring increases.



ECG RF Phase 1 Phase n Phase n Phase 1 Phase 1 Data Acquisitions

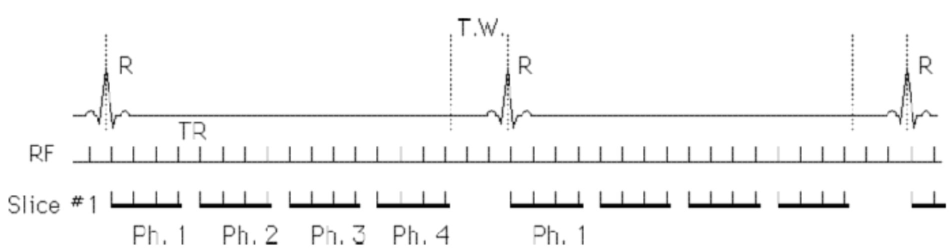
A Trigger Window of up to 50 percent is allowed. FastCard calculates the phases based on the heart rate, minimum TR, Trigger Window, and views per segment.

Uniform TR, or “Continuous RF,” is a technique designed to eliminate the lightning-flash artifact that makes the cardiac phase appear brighter than subsequent cardiac phases. With Uniform TR, RF is played at regular intervals throughout the scan, even during the trigger window. Gradient waveforms are also played continuously, so that gradient eddy currents maintain a steady state. FGRE acquisitions feature minimum TE/ TR, with TEs 31.0 ms, and TRs 35.0 ms.

Chemical Saturation, or Fat/Sat, can be used primarily to suppress fat, making the coronary arteries more conspicuous. The segmented K-space nature of FastCard places spatial requirements on the implementation of chemical saturation.

FastCard Sequential

Fastcard Sequential acquires prospectively gated data with a continuous RF excitation on the same location.



A multi-slice scan can be acquired one image at a time with the option to pause after completion of each slice.

The TR and TE values are much shorter than standard cine, less than 5 ms for TE and less than 14 ms for TR, and 2 – 98 views are collected for each trigger. This allows a complete acquisition, up to 12 phases of the cardiac cycle, to be acquired in a single breath-hold.

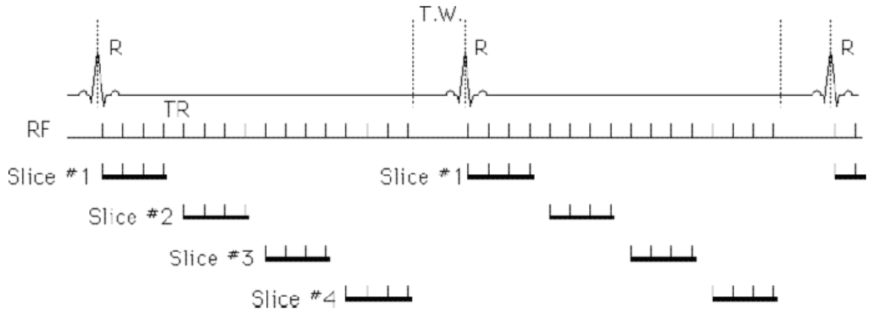
Delay after trigger and intersequence delay are set to the minimum available time to maintain the fastest acquisition time possible.

Fastcard Sequential has short TR and the continuous RF excitation on the same slice, creates a strong T1 saturation.

Reduces the Time of Flight effect, especially for slow flows or in-plane flows.

FastCard Non-sequential

Rather than applying RF excitation pulses at the same slice location throughout the cardiac cycle, the non-sequential acquisition acquires data from different slice locations.



The effective repetition time (TR) for each slice is essentially an RR interval. The Time of Flight effect now depends on the R-R interval and not on the TR. In the diagram above, slice #1 is excited during the first segment with four views, then nothing happens on this slice until the next R wave, same phase.

T1 contrast is attained by the use of a short preparation RF pulse. FastCard differs from a conventional Cine acquisition in that several successive TRs are grouped or views to form a segment.

This sequence is more sensitive either to very slow flow or almost in-plane flow and can be used to acquire data in the longitudinal axis in addition to cross-section.

Arrhythmia Rejection

Arrhythmia rejection is available with 2D gradient echo pulse sequences (GRE and SPGR), when the Fast and Gating options are selected. It is accessed through the Additional Parameters screen as a User CV screen.

It's function is to improve image quality by rejecting data with an incorrect trigger. If a trigger is detected outside of the Trigger Window, the scan continues, but discards data from the arrhythmia trigger. The data is re-acquired on the next R-wave. The system displays an error message after the scan is complete.

Image Characteristics

With FastCard images, flowing nuclei are bright while stationary nuclei are dark. Stagnant, slow flow or in-plane flow produces decreased signal as it becomes saturated.

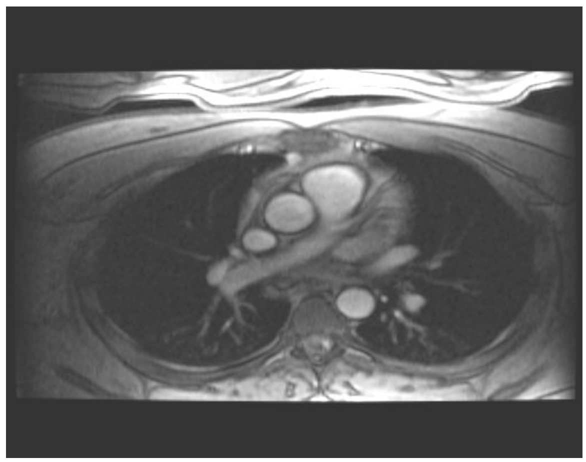
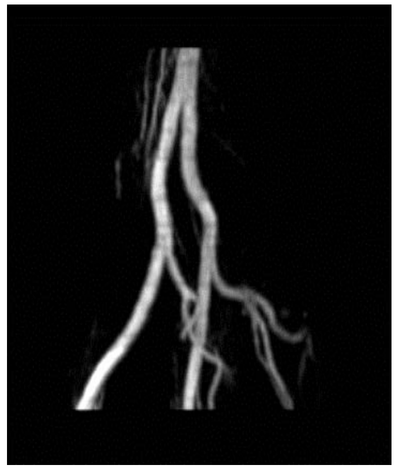


Image using FastCard

Gated 2D TOF is a combination of FastCard and 2D TOF. The portion responsible for FastCard allows multi-phase imaging at single or multiple slice locations; the gated portion is responsible for reducing pulsatile effects.

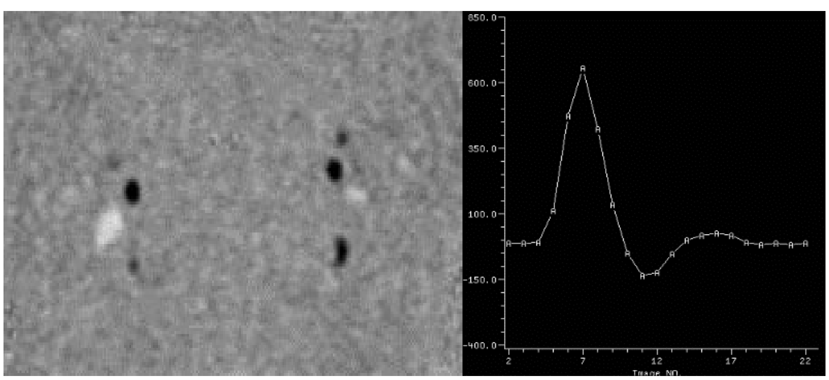
Gated 2D TOF collects the center lines of K-space at the trigger delay which allows you to control where in the RR-interval the center lines are collected. The center lines of K-space have the greatest effect on contrast. If the center lines of K-space are collected during peak flow, flow enhancement effects are improved.

Non-gated



Gated

Fast 2D PC is a combination of FastCard and 2D PC. The FastCard portion of Fast 2D PC allows multi-phase imaging at single or multiple slice locations. The gated portion of Fast 2D PC allows the quantification of flow direction and velocity at multiple points in the cardiac cycle.



Something to Think About...

- Unless the heart rate varies and causes a trigger outside of the Trigger Window, the RF signal is not maintained through the QRS complex.
- If the system does not detect the expected signal, it pauses.
- Effective TR and trigger delay are not available with FastCard.

- The total number of phases to be acquired is dependent on the patient’s heart rate.
- The number of cardiac phases is posted on the Scan Operations (prescan) area.

FastCard Sequential

- It always gives poor flow contrast when used in the long axis where in-plane flow is predominant.

FastCard Non-sequential

- Since slices are acquired at different instants or phases of the cardiac cycle, some slices show almost no flow-related enhancements whereas, other slices present a bright flow signal.
- Increasing the number of acquisitions to two, splits the slices into two acquisitions and decreases the crosstalk artifact and slice to slice flow artifact.
- Long time intervals between two successive data segments on the same slice results in a strong signal from the background tissue.

Views Per Segment

- The VPS must be 1 or an even number between two and 98 (e.g., 2,4, 6, 8...98).
- VPS selection only appears with FastCard SPGR or FastCard GRE.

	Scan Time	**# Cardiac Phases**	**Edge Blurring**
VPS increases	decreases	decreases	increases

- Increasing VPS decreases overall scan time, but reduces the number of cardiac phase images allowed. This occurs because acquisition time is used to collect views rather than cardiac phases. The trade-off is temporal resolution for speed.

Arrhythmia Rejection

- If more than four arrhythmias occur for scan times less than 25 ms, the scan aborts and the system posts a message.

Associated Imaging Options

In the following table the X's indicate the option available for use with the FastCard pulse sequence.

Imaging Options			
X	None	X	Variable Bandwidth
X	Flow Compensation	X	No Phase Wrap
	POMP	X	Extended Dynamic Range
X	Square Pixel	X	Surface Coil Intensity Correction
	Respiratory Compensation		Classic
	Magnetization Transfer	X	Sequential
X	Cardiac Gating/Triggering		Respiratory Gating/Triggering
	Tailored RF		IR Prepared
	DE Prepared		Multi-Phase
	Full Echo Train		CCOMP
	ZIP 1024		ZIP 512
	Zip x 2		ZIP x 4
	SmartPrep		Blood Suppression
	Multi Station		Real Time

Applications

FastCard Sequential:

- It allows imaging of the full R-R interval to acquire images at the end-diastolic cardiac phase.
- It is used for breath-hold cardiac imaging.
- Flow Comp with FastCard achieves a gated exam with blood of high signal intensity which is especially useful for imaging sagittal spines with a myelographic effect.
- Multiple NEX with FastCard removes the motion in pediatric studies because breath-hold cannot be enforced in pediatric cases.
- It is used with Fat SAT for coronary arteries.
- This technique is well suited for cross-sectional studies of the cardiac chambers or the aortic arch.

FastCard Non-sequential

- It is used to image the upper torso, and the peripheral and abdominal vasculature.
- It is used to acquire a large number of thin and contiguous slices over a wide region of interest.

View per segment

- Use FastCard to acquire a collection of successive views that contribute to one phase image.
- Use FastCard when improved temporal resolution is desired.

CAUTION: **Provide all patients with ear protection prior to any scan to help avoid possible hearing impairment.** Acoustic noise levels can exceed 99 dBA in the magnet bore.

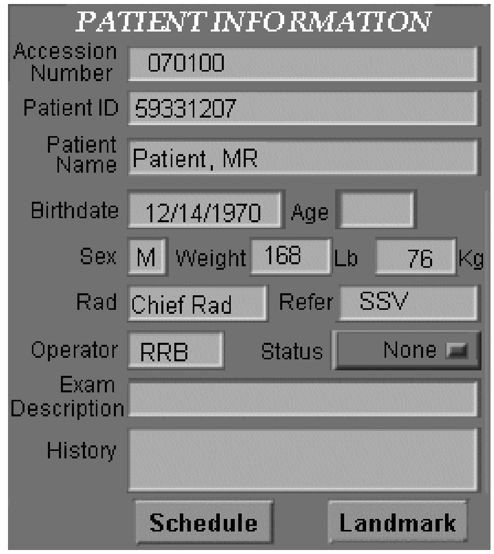
Setting up a FastCard pulse sequence

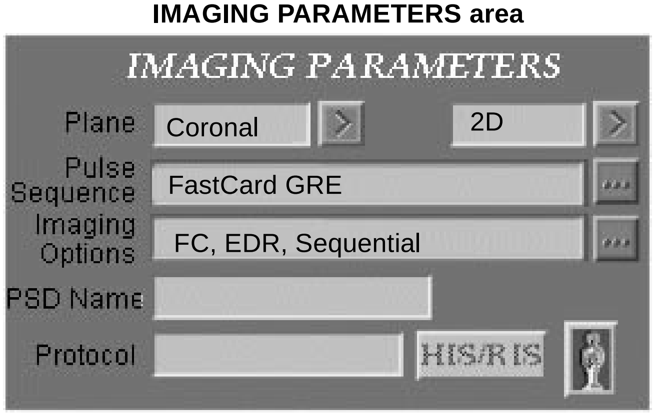
The decision matrix is only for prescribing a FastCard scan. The purpose of the decision matrix to help you understand the trade-offs that occur when you change the values for a particular parameter and to provide a framework with which you may build you own unique protocol.

The selected values are only an example of what could be used for a T2* sequential FastCard acquisition and are not to be considered recommendations by GE Medical Systems. For specific protocols, refer to the protocols on your system.

.

FastCard - What you select	Selection Notes
SCAN DESKTOP screen	
	Select **Scan Desktop** icon. 

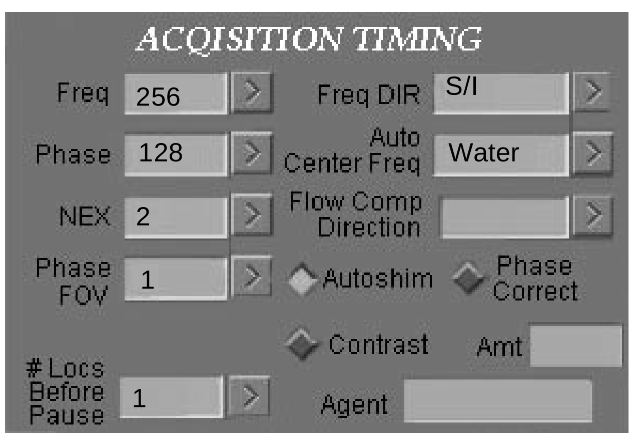
FastCard - What you select		Selection Notes
		Click on **[New Patient]** and fill in the patient information. 
PATIENT POSITION area		
Patient Position	**[Supine]**	**Position and Entry:** A FastCard pulse sequence is compatible with any patient position and entry.
Patient Entry	**[Feet First]**	
Coil	**[Body]**	**Coil:** Select the coil that produces the optimum coverage and SNR.
Series Description		**Series Description:** Enter a suitable series description. If you don not enter a description, the system enters one for you. The series description default is the selected scan mode, PSD, and imaging options.
IMAGING PARAMETERS area		



FastCard - What you select		Selection Notes
Plane	**[Coronal]**	**Plane:** FastCard is compatible with any scan plane except 3-Plane. Select the plane that best meets the clinical need. Multi-planar (non-sequential) FastCard can be used for both short axis and long axis imaging. Sequential FastCard is better suited for short axis imaging because Time of Flight effects are reduced for slow and in-plane flow.
Mode	**[2D]**	**Mode:** Select [2D].
Pulse Seq	**[FastCard GRE]**	**Pulse Seq:** Select [FastCard-GRE] for a T2* contrast. `FastCard-SPGR` can be selected for T1 contribution. Click the **[Accept]** button to register the selection.
Imaging Options	**[FC, EDR, Sequential]**	**Imaging Options:** Select **Sequential** to acquire one slice at a time and multiple cardiac phases. Do not select Sequential for multi-planar FastCard (non-sequential). Multiple cardiac phases is not available in multi-planar. Select imaging options that optimizes SNR, spatial resolution and reduce motion artifacts. Use Flow Comp to increase signal from blood. Click the **[Accept]** button to register the selections.
PSD Name	**N/A**	**PSD Name:** Not applicable for FastCard.
Protocol	**N/A**	
SCAN TIMING area		
# of echoes	**[1]**	**# of echoes:** Only 1 echo is allowed.
TE	**[Min Full]**	**TE:** Increase the TE to produce increased T2* contrast, decreased SNR, signal changes at fat/water interfaces, and increased magnetic susceptibility effects. Minimum is a fractional echo and may compromise SNR.
TR	**N/A**	**TR:** TR is set automatically. In sequential FastCard, TR is determined by other parameters such as RBw. In multi-planar FastCard, TR is essentially the R-R interval.
TI	**N/A**	
Flip Angle	**[20]**	**Flip Angle:** Typical 2D Flip Angle values: 20° to 30°. If you decrease the Flip Angle you increase T2* weighting and decrease SNR.
Echo Train Length	**N/A**	
Bandwidth	**[15.63]**	**Bandwidth:** RBw can only be changed if it was selected from the Imaging Options window. As the RBw decreases, the following occurs: increased SNR, increased chemical shift artifact, increased minimum TE which can potentially decreases # of slices and increased motion artifact. Generally, wider bandwidths are used with Fast sequences to keep minimum TEs and TRs down.
Bandwidth 2	**N/A**	

FastCard - What you select		Selection Notes
SCANNING RANGE area (for 2D Sequential acquisition)		
FOV	**[32]**	**FOV:** Select a FOV that covers the anatomy of interest. Anatomy outside the FOV in the phase direction results in aliasing. Small FOVs produce: increased resolution, decreased SNR, and can increase the minimum TE value.
Slice Thickness	**[10]**	**Slice Thickness:** Thin slices produce: increased resolution and decreased SNR.
Spacing	**[2.0]**	**Spacing:** Interslice cross-talk is eliminated on sequential sequential FastCard. Typical spacing is 0-20% of the slice thickness.
Start, End Locations		**Start, End Locations:** Typically the start and end locations are programmed from the Graphic Rx program.
# Slices	**[9]**	**# Slices:** Sequential scans one slice per acquisition. The number of slices indicates the number of acquisitions prescribed. Non-sequential allows a limited number of slices per acquisition. The number of acquisitions is shown on the Advisory screen. The R-R interval and Trigger Window affect the number of slices per acquisition. As the heart rate increases, the slices per acquisition decreases. Increase Trigger Window and the slices per acquisition decreases.
Cardiac Phases	**N/A**	**Cardiac Phases:** This is not a selectable parameter. The system calculates the maximum number of phases based on the heart rate and VPS. Multi-planar FastCard acquires one cardiac phase.

ACQUISITION TIMING area



Freq	**[256]**	**Freq:** Increasing the frequency matrix produces: increased resolution, and decreased SNR.
Phase	**[128]**	**Phase:** Phase controls scan time and may control resolution.

FastCard - What you select		Selection Notes
NEX	**[2]**	**NEX:** Select a NEX value that produces sufficient SNR. Lower NEX are needed for breath-hold 2D scans. Use higher NEX to decrease motion artifacts for patients unable to hold breath.
Phase FOV	**[1]**	**Phase FOV:** Enter values .75 or .5 to reduce phase steps and thus decrease scan time, decreasing FOV in the phase direction, and decreasing SNR slightly. The phase FOV dimension is displayed next to the phase FOV factor.
Freq DIR	**[S/I]**	**Freq DIR:** The direction displayed is the default frequency direction which is typically the long axis of the image. To swap phase and frequency, select the other direction.
Auto Center Freq	**[Water]**	**Auto Center Freq:** Select the CF peak that is set during prescan.
Flow Comp DIR	**N/A**	
Autoshim	**[On]**	**Autoshim:** Click the Autoshim when using fat SAT or an FOV off center, and on the first series of each exam.
Phase Correct	**N/A**	
# of Acqs/Locs Before Pause	**[1]**	**# of Acqs/Locs Before Pause:** Prescribe an automatic pause in the scan at predetermined points for breath-hold studies.
Additional Parameters SAT Screen		
I	**[80]**	FAT Saturation can be used with sequential FastCard to better visualize coronary arteries. Spatial SAT pulses may decrease signal from blood.
S	**[80]**	
Additional Parameters		To prescribe oblique slices you must select **Oblique** in the Plane pull-down menu.
GRAPHIC RX Screen		

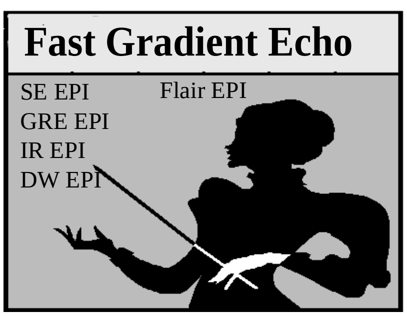
FastCard - What you select		Selection Notes
Click on the image to display the line cursor for Graphic Rx.		The SAT band function can be accessed from the GRAPHIC Rx window and vice versa. If you had graphically prescribed the previous axial series the same prescription can be copied using the **[Copy RX]** button. Consider using an offset to center the anatomy in the middle of the screen so that you can use a PFOV less than 1 and therefore reduce the scan time. In 2D Sequential, view the Advisory panel to note the # of Acqs you are prescribing. The scan time increases as the # of Acquisitions increase. 3D explicit Rx can be done in either L-I-P or R-S-A direction. 3D graphic Rx can only be done in L-I-P direction for orthogonal planes (note that oblique scan planes are not allowed with 3D GRE).
Gating Screen		
Heart Rate	**[Update bpm]**	**Heart Rate:** Click the **[Update bpm]** button to obtain an automatic reading of the current heart rate or, the bpm may be manually entered by observing the monitor.
Trigger Type	**[Auto]**	**Trigger Type:** Auto lets the system choose the best lead for ECG, or it may be manually selected. PG is for peripheral gating.
Trigger Window	**[Auto]**	**Trigger Window:** The system chooses the best value when `Auto` is selected or, it may be manually selected. Values range from 2 – 50%. Increase the Trigger Window, decrease time available to collect data. This is not selectable with sequential FastCard.
Trigger Delay	**[Recom-mended]**	**Trigger Delay:** The only choices are Minimum and Recommended. They are generally the same unless SAT pulses are used.
Views per Segment	**[12]**	**Views per Segment:** Must be 1 or an even number, 2 – 98. Increased VPS results in decreased scan time, decreased # cardiac phases for sequential and increased edge blurring.
User CV Screen		
Perform Arrhythmia Rejection	**[1]**	**Perform Arrhythmia Rejection:** `0` is off, `1` is on. Using Arrhythmia Rejection results in increased scan time if triggers occur outside the Trigger Window, but image quality improves. Too many triggers detected outside the Trigger Window results in an aborted scan.
SCAN OPERATIONS Screen		

FastCard - What you select	Selection Notes
[Save Series] **[Prep to Scan]** **[Auto Prescan]** **[Scan]**	Enter data in all the text boxes and click on **[Save Series]**. The series is saved as RXD.

Chapter 11

Imaging with Echo Planar Pulse Sequences

Where Am I?



Introduction

This chapter explains the pulsing components and timing factors directly related to the Echo Planar (EPI) pulse sequences. This chapter explains the concepts of each, and the step-by-step instructions to help you learn how to:

- Optimize SE Echo Planar images
- Optimize GRE Echo Planar images
- Optimize IR Echo Planar images
- Optimize Flair Echo Planar images
- Optimize Diffusion images
- Select User Control Variables

In addition, this chapter answers the following questions:

1. What is the RF pulsing pattern?
2. How do shots affect echo train?
3. How does echo train affect the image?
4. What affects echo spacing?
5. How do the timing factors control the RF pulsing?
6. How does TR regulate saturation effects?
7. How does TE regulate dephasing effects?
8. What is a null point?
9. How does TI regulate saturation and suppression effects?
10. What are motion probing gradients?
11. How does the B-value affect the image?
12. What are the image characteristics?
13. What are the applications?

About... Echo Planar Sequences

This section presents the concepts necessary to understand Echo Planar pulse sequences. Specifically you need to understand:

- Spin Echo Echo Planar Imaging (SE EPI)
  - Pulsing components and timing factors
  - Echo spacing, echo train length and shots
  - TR and the regulation of saturation effects
  - TE and the regulation of dephasing effects
  - Image characteristics
  - Associated imaging options
  - Applications for SE EPI
- Gradient Echo Planar Imaging (GE EPI)
  - Pulsing components and timing factors
  - Echo spacing, echo train lengths and shots
  - TE and the regulation of dephasing effects
  - TR and FA and the regulation of saturation effects
  - Multi-phase acquisitions
  - Image characteristics
  - Associated imaging options
  - Application for GRE EPI
- Inversion Recovery Echo Planar Imaging (IR EPI)
  - Pulsing components and timing factors
  - Echo spacing, echo train length and shots
  - TE and the regulation of dephasing effects
  - TR and the regulation of saturation effects
  - Null point
  - TI and the regulation of saturation and/or signal suppression
  - Image characteristics
- Flair Echo Planar Imaging (Flair EPI)
  - Pulsing components and timing factors
  - Echo spacing, echo train length and shots
  - TE and the regulation of dephasing effects
  - TR and the regulation of saturation effects
  - Null Point
  - TI and the regulation of saturation and/or signal suppression

- Image characteristics
- Applications for Flair EPI

- Diffusion Echo Planar Imaging (DW EPI)
  - Definition of Diffusion weighting
  - EZDWI Description
  - B-Value
  - Pulsing Components
  - Applications for DW EPI

Echo Planar Imaging (EPI)

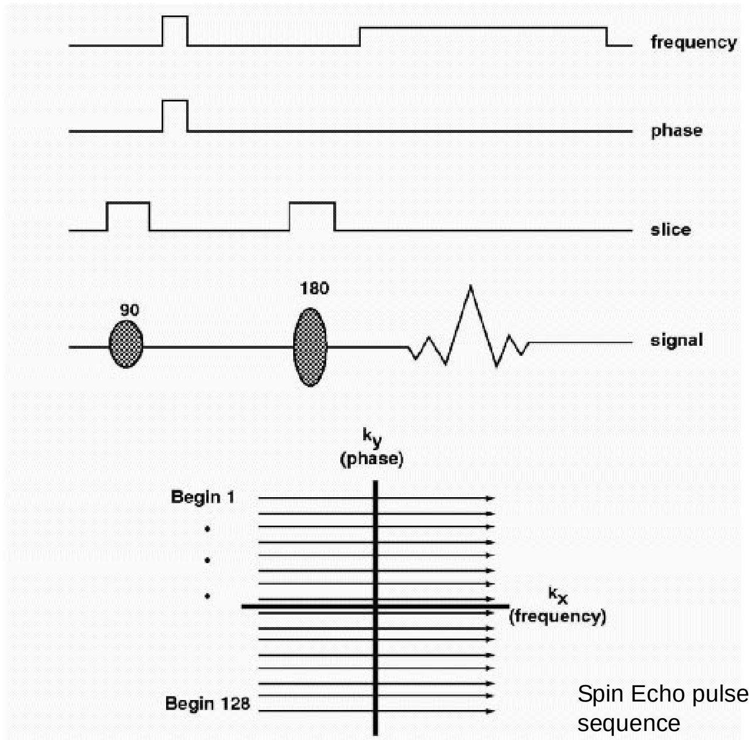
EPI, combined with SE or GRE, is an imaging option primarily used to produce T2 or T2* weighted images. IR-EPI is used for T1 and STIR contrast weighting. In the most simple terms, EPI is like an FSE sequence except that it uses gradients (which take less time to turn on and off) instead of RF pulses to produce echoes. The efficiency of a gradient vs. an RF pulse to produce the echo results in reduced SAR and increased number of slices in comparison to an FSE acquisition.

Just like FSE, EPI uses an echo train to produce numerous echoes within a TR period filling K-space rapidly and thus dramatically reducing scan time.

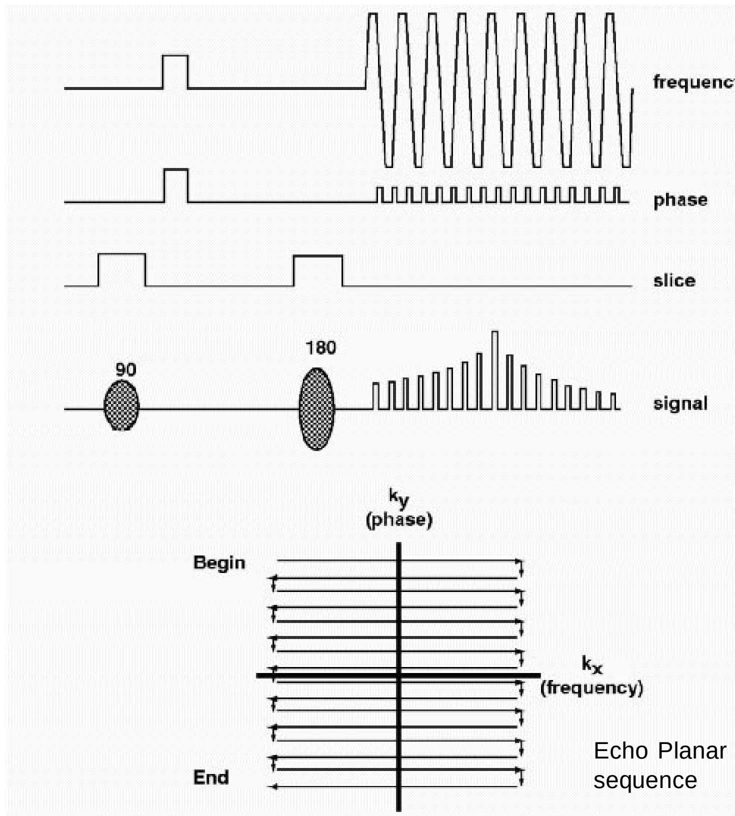
Scan Time

To understand how EPI affects scan time a review of K-space is required. K-space is the domain that contains the MR raw data, which after undergoing a Fourier transform, becomes the image. The following are several keys points about K-space:

- It must be filled by at least 65% to produce an image.
- The manner in which K-space is filled (top to bottom, middle to edges), has an effect on the contrast.
- The position of information within K-space does not correlate to a spatial position within the image.
- The phase gradient’s amplitude determines the strength of the signal “echoed” back. Low phase gradient amplitudes produce strong echoes and fill the middle of K-space, while high phase gradient amplitudes produce weaker echoes with high spatial information and fill the edges of K-space.



Each line of K-space corresponds to one TR interval.



Echo Planar pulse sequence

Within each TR period, multiple lines of K-space are filled.

The number of shots is just a new term and a new Scan Timing area that must be completed for an EPI scan. The # of shots is the number of TR periods that are used to complete the acquisition. EPI protocols that use more than one shot to complete the acquisition are called “multi-shot” and EPI protocols that use only one shot to complete the acquisition are referred to as “single-shot” or “snap-shot”.

Scan time for SE	Scan time for EPI
TR x phase steps x NEX E.g., 2000 x 256 x 2 = 17 mn	TR x # of shots x NEX E.g., 2000 x 1 x 2 = 4 seconds

The following two User CVs (only with Echo speed gradients) affect scan time:

Burst Mode allows the system to override the set gradient duty cycle to gain higher, but temporary, performance is slices per TR. Because the gradients are driven harder at a high duty cycle, there is a required "cool down" period immediately following the acquisition that is equal to or at least twice the scan time. The trade-off for not using Burst Mode is that you do not get the extra slices. A time form one to 30 seconds must be entered as the Burst Scan Time and it must be equal to, or greater, but not longer than the scan time. Therefore, do not enter in the Burst Mode until you know the scan time.

Ramp Sampling allows the system to increase the time when the echo is recorded. Each time the frequency gradient is turned on, there is only a "usable time" when the echo is sampled (often called the "flat top" rather than the rising part of the gradient pulse). The size of the frequency matrix and the "usable time" have a direct effect on the echo spacing. A 256 matrix uses half the "usable time" as a 512 matrix. To achieve short echo spacing (which is desirable for reduced geometric distortion), and high frequency matrix values (for high spatial resolution), Ramp Sampling can be turned on from the User CV screen. Ramp Sampling allows the system to expand the "usable time" it can acquire the echo, by sampling it during both the rise/fall time and the flat top time that the gradient is on. The trade-off for using Ramp Sampling, is that Receive Bandwidth cannot be changed. Typically the system uses a RBw of +/-62.5 or greater. Remember that as RBw increases, SNR decreases. In addition to a high RBw, Ramp Sampling uses the Fast receiver during data collection. The Fast Receiver is not compatible with phased array coils.

NOTE: Ramp Sampling is done automatically with the EZDWI pulse sequence.

Spatial Resolution

An EPI trade-off of using gradients vs. RF to refocus the spins, is that the EPI image becomes very sensitive to off-resonance artifacts (frequency difference between fat and water protons). After the initial RF excitation pulse, a spin that is precessing off-resonance gradually accumulates a phase error. This phase error builds over the course of the echo train and leads to a geometric distortion in the phase encode direction. The longer it takes to sample the echo the more time the water spins have to accumulate phase shifts and the greater the geometric distortion.

Geometric distortion can be reduced by:

- Using the shortest possible echo spacing (keep the RBw as large or wide as possible, FOV large as possible, frequency matrix as small as possible).
- Using multi-shot vs. single shot EPI to reduce ESP -the higher the shots the less the distortion but the longer the scan time.
- Using smaller values for frequency encoding to reduce ESP. Your protocol may have higher phase steps (512) than frequency (256) steps. Remember, EPI scan time is not affected by phase steps.
- Using Ramp Sampling to reduce ESP, particularly when using high frequency matrix values.

Contrast

SE EPI is primarily used to acquire T2-weighted images, GRE EPI is used to acquire T2* weighted images and IR EPI is used to acquire T1 and STIR contrast weighting. FLAIR EPI is used to acquire fluid suppressed images and DW EPI (an optional PSD) is used to acquire images where in the contrast is a function of the spin’s diffusion.

EPI uses multiple oscillating gradient “pulses” within a TR period, rather than RF to create the echo. An SE-EPI protocol produces contrast similar to a standard SE image with the same TR and TE. A GRE-EPI protocol produces similar contrast to a standard GRE with the same flip angle, TR and TE.

All EPI pulse sequences are sensitive to field inhomogeneities (opposed to an FSE which virtually eliminates those effects). Therefore, pathologies that cause disruptions in the local magnetic field have a higher potential for contrast visualization in an EPI image.

Signal-to-noise (SNR)

EPI images typically use very large receive bandwidths so that the echo spacing can be as short as possible and thereby reduce geometric distortion. The trade-off for a large RBw is an increased amount of noise and therefore lower SNR.

The loss of SNR can be gained by either increasing the NEX value or changing scan parameters that affect resolution (matrix, slice thickness, FOV). As the RBw gets larger the minimum FOV increases, which reduces the spatial resolution but gain the SNR that has been lost to the wide RBw. To increase SNR with EPI images, consider decreasing the frequency matrix (enlarges pixel size for more SNR and decreases geometric distortion), while keeping the phase matrix unchanged; for example, a 256-phase matrix with a 128-frequency matrix.

Multi-phase, Multi-repetition

EPI offers great flexibility when applications call for multiple passes and/or phases that need extremely short scan times and high temporal resolution. Possible EPI acquisitions include:

- Multi-pass single-slice
- Multi-pass multi-slice
- Multi-slice single-phase single pass
- Multi-slice single-phase multi-pass

To understand this plethora of imaging options, it would be helpful to apply some meanings with some terms, mainly the difference between a pass and a phase. These two terms are sometimes used interchangeably. Because EPI offers methods for doing both, using a standard meaning for each in this document may alleviate some confusion. For this learning guide, phase and pass are defined as follows:

- A pass is one trip through the slice or slices within a given TR period. For example, if 15 slices can be acquired within a TR of 2000 msecs (and 15 slices have been prescribed) then one pass covers the 15 slices in 2000 msec. Very often the term repetition or rep is used instead of pass.
- A phase is used to describe a particular image that is part of a group of images at the same location. These phases could be cardiac phases or phases of contrast uptake or phases of task activation. Any sequence in which the same slice location is imaged more than once, can be termed a multi-phase sequence. When more than one slice location is being acquired over more than

one pass, meaning a multi-phase multi-pass exam, understanding the difference between pass, or rep, and pass then becomes rather important.

Interleaved vs. Sequential Acquisitions

When all the slice locations go through a single phase for a single pass before moving to the next phase, we refer to this as an interleaved acquisition. If all the phases for one slice location are collected before moving on to the next location, this is referred to as a sequential acquisition.

Sequential

Acquisition 1:	Slice	1	1	1	1
	Phase	1	2	3	4
Acquisition 2:	Slice	2	2	2	2
	Phase	1	2	3	4
Acquisition 3:	Slice	3	3	3	3
	Phase	1	2	3	4

Interleaved

Acquisition 1:	Slice	1	2	3
	Phase	1	1	1
Acquisition 2:	Slice	1	2	3
	Phase	2	2	2
Acquisition 3:	Slice	1	2	3
	Phase	3	3	3
Acquisition 4:	Slice	1	2	3
	Phase	4	4	4

Diagram1 sequential vs. interleaved

For motion studies, where a particular slice location needs to be viewed while moving, a sequential acquisition is often the choice to make. However, when viewing contrast uptake over time through multiple slice locations, a common application in EPI, then an interleaved acquisition is better suited.

Spin Echo EPI and Gradient Echo EPI

In the most simple terms, EPI can be thought of as a FSE sequence with a gradient echo twist. Just like FSE, EPI uses an echo train to produce numerous echoes within a TR period to fill K-space rapidly. However, EPI produces these echoes in a manner very similar to a standard gradient echo sequence. Note that instead of a series of 180 degree RF pulses, EPI produces a series of oscillating gradient reversals. The differences between EPI and a standard GRE are:

- EPI uses more than one gradient echo within a TR.
- EPI uses gradients that have both a positive and negative polarity to produce both “odd” and “even” echoes.

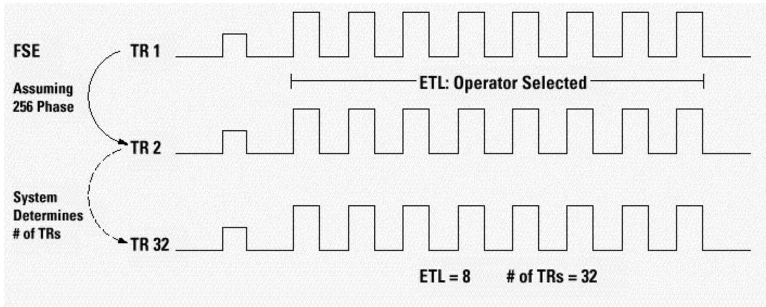


Diagram 2 FSE pulse sequence with 8 ETL.

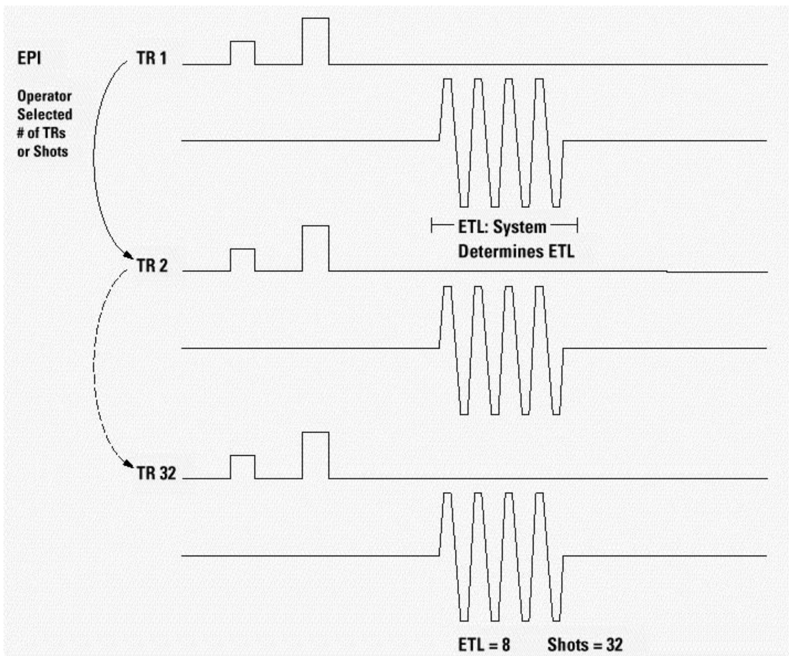


Diagram 3 EPI pulse sequence with 32 shots.

Gradient Echo EPI is typically used to acquire T2* weighted scans. Spin Echo EPI is typically used to acquire T2 weighted scans. It can also be combined with IR Prep (accessed from the Imaging Options menu) to acquire T1-weighted or Short TI IR (STIR) images.

In an IR scan, the system first applies a 180-degree pulse to create magnetization in the negative Z axis. Then, after a brief period called TI, or Inversion Time, it applies a 90-degree pulse. As a result, the longitudinal regrowth magnetization moves to the transverse plane. Another 180-degree pulse rephases the transverse magnetization and results in a spin echo. These scans are acquired by selecting a SE pulse sequence, EPI, and IR Prep to create an IR EPI pulse sequence.

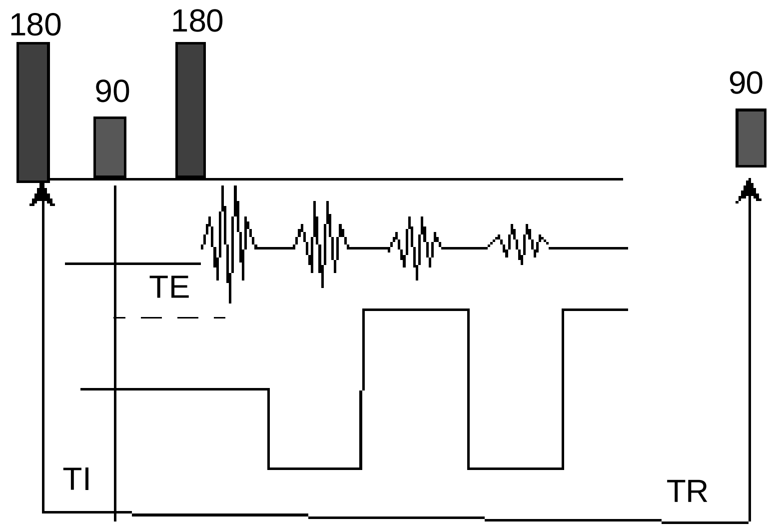
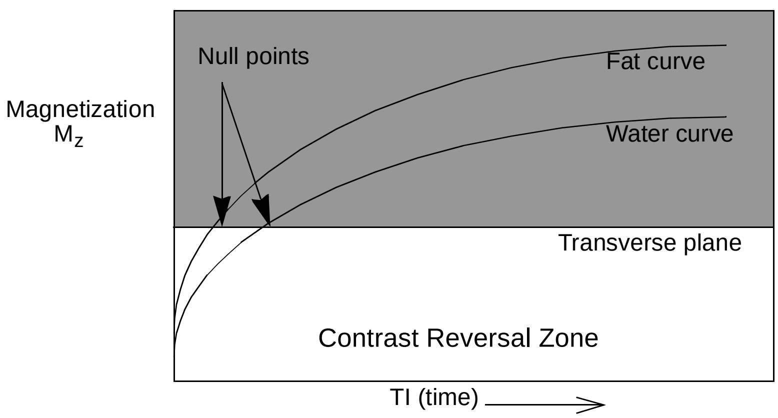


Diagram4 IR EPI pulse sequence

The TI determines the image contrast.



Longitudinal magnetization in Inversion-Recovery pulse sequence, plotted as a function of interpulse interval TI for a short T1 (e. g., fat) and a long T1 (e. g., brain).

Something to Think About...

- EPI is an imaging option which means that it is only available if the option key is installed.
- Even though Short TI Inversion Recovery is thought of as an IR pulse sequence, Spin Echo EPI is the pulse sequence selected on the Imaging Parameters area for an IR-EPI scan.
- It is only valid with 2D.
- EPI images are always fat suppressed due to the off-resonance effects of fat spins. Off-resonance effect

is the frequency difference between protons bound in water vs. fat molecules. The spins accumulate a phase shift during the EPI echo train that results in this loss of signal and chemical shift artifact in the phase direction.

- In EPI acquisitions, the system automatically conducts a reference scan after prescan if the Phase Correct prescan option has been selected.
- Areas near tissue-air interfaces result in water protons accumulating a phase shift or off-resonance affect. These areas of interface produce a geometric image distortion.
- EPI produces more slices per TR as compared to FSE because of the efficiency of gradient generated echoes vs. RF pulse generated echoes, and the reduced SAR.
- EchoSpeed systems have a Fast Receiver as standard equipment. When very large RBws are used (greater than ±62.5 kHz), the Fast Receiver is turned on since the standard receiver cannot keep up with data that is sampled at such fast rates. The Fast Receiver is not compatible with Phased Array coils. No Phase Wrap, POMP, Fast, Respiratory Compensation, Respiratory Triggering, and Classic are Imaging Options that are not compatible with EPI.
- Ramp Sampling uses an “effective” RBw which is displayed on the image and is a function of FOV, Frequency matrix, and # of shots.
- dB/dt refers to the rate of change in magnetic field to time which is expressed in Tesla/seconds. dB/dt and SAR levels for the patients are based on current scientific literature related to safety, and that the level of exposure shall be a medical judgment as to the patients potential risk versus benefit.

CAUTION: **Provide all patients with ear protection prior to any scan to help avoid possible hearing impairment. Acoustic noise levels can exceed 99 dBA in the magnet bore.**

CAUTION: Patients who complain of Peripheral Nerve Stimulation (PNS) during an EPI sequence should have the series stopped and replaced with another pulse sequence. If the PNS occurs with a non-EPI sequence, the patient should be removed from the magnet and the incident reported to GE Medical Systems. Submission forms are in the Scan Assistant, Forms chapter.

CAUTION: Peripheral nerve stimulation is not harmful. The potential for inducing peripheral nerve stimulation is kept within limitations. In the US, the Signa® system is limited from operating above 66% of the PNS threshold by the software (unless the system is operating in research mode). The point at which 50% of a population experiences PNS (peripheral nerve stimulation) is the PNS threshold. PNS has been described as a light "touching" sensation felt on various areas of the skin surface. These areas vary depending upon which gradient axis is in use. Some common areas for the sensation are the bridge of the nose, arms, chest and upper abdomen. Hands clasped together increase the potential for stimulation by approximately 65%. The potential for PNS is low, but it exists for all sequences in all gradient configurations.

The Signa system is capable of operating under several modes: normal, first level controlled operating mode (research mode), and second level controlled operating mode (proprietary license agreement with GE). The dB/dt and SAR levels for a prescribed protocol are displayed on the Scan Operation and Advisory areas.

System Operating Level	dB/dt Limit	Action
Normal Mode	U.S.: 66% of STL IEC: 20T/s (unless **[Accept]** is selected)	If the selected protocol approaches the country's limit, the system requires that scan parameter changes be made to comply with the dB/dt levels. Maintain constant contact with patients during MR exams with dB/dt levels beyond 20T/s. Refer to the Caution statements in the Peripheral Nerve Stimulation section of the Safety chapter as a guideline for patient communication. IEC systems require selecting **[Accept]** before proceeding. This allows a dB/dt as high as 66% of the peripheral nerve stimulation.
First or second level controlled operating mode	Set by IRB or other governing board	At the Imaging Parameters area, either: 1. Type in the T/s. 2. Type in a percentage of peripheral nerve stimulation in the STL key. 3. Select the default value displayed in the STL key. 4. In all cases, if the default level is exceeded, read the warning message and if desired, Click the **[Accept]** button to proceed with the prescription process. IEC systems require selecting **[Accept]** before proceeding, if a T/s value entered is greater than the default value. This allows a dB/dt as high as 66% of the peripheral nerve stimulation. Refer to the Caution statements in the Peripheral Nerve Stimulation section of the Safety document as a guideline for patient communication.

Trade-off EPI Parameter Chart

Parameters	Image Effect				
	Echo Spacing	SNR	Resolution	Scan Time	Geometric Distortion
Increase Gradient Slew Rate	Decrease	—	—	—	Decrease
Increase Receive Bandwidth	Decrease	Decrease	—	—	Decrease
Increase # of Shots	Decrease	Increase	—	Increase	Decrease
Increase Frequency Encoding Steps	Increase	Decrease	Increase	—	Increase
Increase Phase Encoding Steps	—	Decrease	Increase	—	—
Increase Frequency FOV	Decrease	Increase	Decrease	—	Decrease
Increase Phase FOV	—	Increase	Decrease	—	Increase

Parameters	Image Effect				
Increase Ramp Sampling	Decrease	—	—	—	Decrease
Increase Field Strength	—	Increase	—	—	Increase

Associated Imaging Options

In the following table the X's indicate the option available for use with the Echo Planar Imaging pulse sequences.

Imaging Options			
X	None	X	Variable Bandwidth
X	Flow Compensation	X	No Phase Wrap
	POMP	X	Extended Dynamic Range
X	Square Pixel	X	Surface Coil Intensity Correction
	Respiratory Compensation		Classic
	Magnetization Transfer	X	Sequential
X	Cardiac Gating/Triggering		Respiratory Gating/Triggering
	Tailored RF	X	IR Prepared
	DE Prepared	X	Multi-Phase
	Full Echo Train		CCOMP
	ZIP 1024		ZIP 512
	Zip x 2		ZIP x 4
	SmartPrep		Blood Suppression
	Multi Station		Real Time

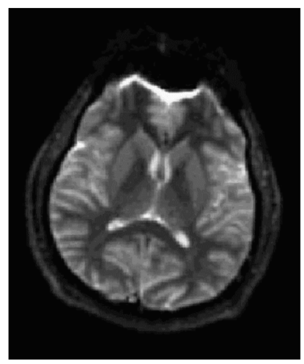
Applications

Spin Echo EPI applications include the following:

- To acquire very fast T2-weighted images when short scan time is imperative; e.g., to minimize breathing motion, or motion from patients that cannot hold still.
- Imaging pathologies that cause disruptions in the local magnetic field because they have a higher potential for contrast visualization with EPI sequences.

- Cardiac imaging for single-slice multi-phase cardiac image without using gating A single shot acquisition images at a single location over a period of a few seconds.
- Single or multi-slice multi-phase using cardiac gating are taken within a single breath-hold.

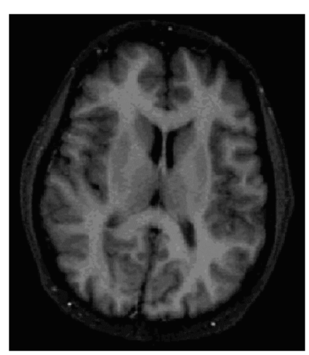
Short TI Inversion Recovery is an EPI pulse sequence that, in addition to nulling fat, provides unique image contrast. In addition, a spectral fat suppression technique that is unique to all GE EPI acquisitions, is applied. It differs from the Fast IR (FMPIR) in that it uses an EPI data acquisition method which introduces more magnetic susceptibility effects into the image. It is typically used in both head and extremity imaging.



Single Shot TR: 4500 TE: 31 TI: 165 128x128 Ramp Sampled

The images are annotated IR/EPI with a TI time annotated on the image.

T1 w Inversion Recovery: SE EPI with IR Prep can be used to acquire very fast T1 w images. It uses a long TR (2000 ms), a TI to produce T1 contrast (600 – 800 ms) and a short TE. These images have a fat suppression appearance due to the spectral fat suppression technique that is unique to all GE EPI acquisitions.



8 shots TR: 3500 TE: 35 TI: 800 256x256

Gradient Echo EPI

Gradient Echo EPI applications include the following:

- Task activation uses GRE EPI with Multi-Phase (an Additional Parameter).
- Imaging of the brain to produce cerebral-blood volume maps to aid in diagnosis of recurrent tumor vs. edema in post therapy patients.

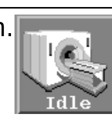
CAUTION: **Provide all patients with ear protection prior to any scan to help avoid possible hearing impairment.** Acoustic noise levels can exceed 99 dBA in the magnet bore.

Setting up a Echo Planar Imaging pulse sequence

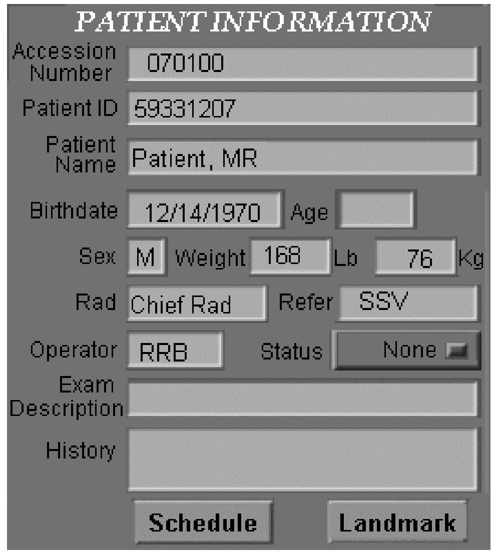
The decision matrix is only for prescribing an EPI, IR-EPI, or a Gradient Echo EPI scan. The purpose of the decision matrix to help you understand the trade-offs that occur when you change the values for a particular parameter and to provide a framework with which you may build you own unique protocol.

The selected values are only an example of what could be used for a T2 weighted acquisition and is not to be considered a recommendation by GE Medical Systems. For specific protocols, refer to the protocols on your system.

.

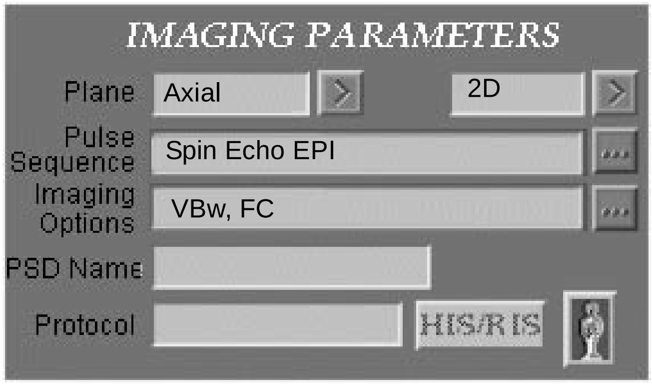
EPI - What you select	Selection Notes
SCAN DESKTOP screen	
	Select **Scan Desktop** icon. 

EPI - What you select		Selection Notes
		Click on **[New Patient]** and fill in the patient information.



PATIENT POSITION area		
Patient Position	**[Supine]**	**Position and Entry:** An EPI pulse sequence is compatible with any patient position and orientation. Not compatible with phased array coils. **NOTE:** Hands clasped together may increase the potential for PNS.
Patient Entry	**[Head First]**	
Coil	**[Head]**	**Coil:** Select the coil that produces the optimum coverage and SNR. If Ramp Sampling is turned on, phased array coils are not compatible. EchoSpeed systems using a protocol with a RBw > 62.5 kHz automatically turns on the Fast Receiver which is not compatible with Phased Array coils.
Series Description		**Series Description:** Enter a suitable series description. If you don not enter a description, the system enters one for you. The series description default is the selected scan mode, PSD, and imaging options.

EPI - What you select		Selection Notes
	IMAGING PARAMETERS area	



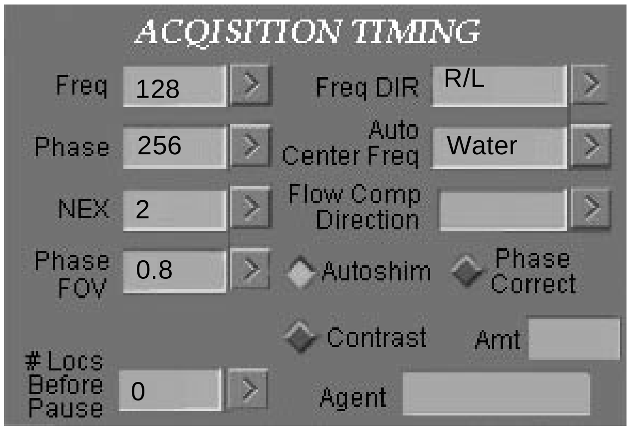
Plane	**[Axial]**	**Plane:** EPI is compatible with any scan plane except 3 plane; select the plane that best meets the clinical need.
Mode	**[2D]**	**Mode:** Select 2D.
Pulse Seq	**[Spin Echo EPI]**	**Pulse Seq:** Select Spin Echo EPI for T2-weighted contrast (with some T2* effects) and Gradient Echo EPI for T2*-weighted contrast, and Spin Echo EPI with IR Prepared for T1 or STIR contrast. Click the **[Accept]** button to register the selection.
Imaging Options	**[VBw, FC]**	**Imaging Options:** Select imaging options that optimizes SNR and spatial resolution, # of slices and reduce motion artifacts. Select `IR Prepared` for either an IR, T1-weighted or short TI IR (STIR) contrast. Click the **[Accept]** button to register the selections.
PSD Name	**N/A**	
Protocol	**N/A**	
	Additional Parameters User CV screen	
Ramp Sampling	**[0]**	**Ramp Sampling:** Click `1` to turn on Ramp Sampling or `0` to turn it off. Ramp Sampling is selected when the shortest possible echo spacing is desired. Typically it is used for single shot acquisitions with high frequency values, and to decrease geometric distortion. Phased array coils are not compatible with Ramp Sampling. Note that when the Ramp Sampling is turned on, the Receive Bandwidth is automatically set.

EPI - What you select		Selection Notes
Burst Scan Time	**[0]**	**Burst Scan Time:** Burst Scan Time can scan with shots > 1 and use Burst Scan Time. Burst Scan Time is selected with single shot acquisitions. Select 0 to turn it off, or select a Burst Scan Time that is longer than the acquisition time (maximum value = 30 sec.). **NOTE:** Bust Mode is only available with SE and GRE EPI acquisitions if the system operates with a 8645 GRAM gradient amplifier. Burst Mode no longer appears on the User CV screen with systems operating with a SGD or ACGD gradient amplifier.
SCAN TIMING area		
# of echoes	**[1]**	**# of echoes:** Number of echoes, is not a selectable parameter, it is automatically 1.
# of shots	**[8]**	**# of shots:** As the number of shots increases, the susceptibility artifacts decrease, however the scan time increases.
TE	**[80]**	**TE and TR for SE EPI:** Select parameters for T2-weighted contrast, typically TR> 2000 ms and TE 80 – 120 ms. For multi-shot EPI several “set-up” pulses are applied before the system collects data to insure proper amounts of longitudinal magnetization. The “set-up” shots keep the contrast consistent, from one TR period to the next. **TE, TR and flip angle for GRE EPI:** Select parameters for T2*-weighted contrast, typically TR 400 – 700, TE < 35 ms, and flip angle 20 – 30 degrees. If a TE less than a Minimum Full is selected, the system collects the minimum lines of K-space (65% of K-space) plus a required number of overscans. These images are labeled with an effective TE. The benefit of only partially filling K-space is more slices. **TR, TE, TI for IR EPI:** Select parameters for T1-weighted contrast, typically TR 2000, TE min, TI 800 for 1.5T and TI 700 for 1.0T. Select parameters for short TI IR weighting, typically TR 2000, TE 40, TI 170 for 1.5T and TI 150 for 1.0T.
TR	**[2500]**	
TI	**[170]**	
Flip Angle	**[20]**	
Echo Train Length	**N/A**	

EPI - What you select		Selection Notes
Bandwidth	**[32]**	**Bandwidth:** As the RBw increases, SNR decreases, chemical shift artifact decreases, minimum TE decreases (which means the echo space decreases). As echo space decreases, geometric distortion decreases. Typically a 32 kHz RBw is used with 16 or more shots, 64 kHz RBw (maximum RBw for non EchoSpeed systems), is used with 4 – 8 shots, and for EchoSpeed systems only, RBw > 64 kHz depends on balancing ESP and resolution demands. Remember that RBw> 62.5 kHz is not compatible with Phased Array coils. Single shot EPI uses the largest RBw possible. Note that when the Ramp Sampling is turned on, the Receive Bandwidth is automatically set.
Bandwidth 2	**N/A**	
SCANNING RANGE area		
FOV	**[25]**	**FOV:** Select a FOV that covers the anatomy of interest. Anatomy outside the FOV in the phase direction results in aliasing. Large FOVs produce decreased resolution, increased SNR, and decreased echo space. The shortest possible ESP is desirable for a single shot acquisition. Therefore, as the # of shots decreases, consider increasing the FOV.
Slice Thickness	**[5]**	**Slice Thickness:** Thin slices produce: increased resolution and decreased SNR.
Spacing	**[2.5]**	**Spacing:** Enter a spacing that reduces cross-talk between slices (typically 20% of the slice thickness). If the scan is a dual acquisition with no concantenated SAT pulse, 0 spacing is allowed.
Start, End Locations		**Start, End Locations:** Typically the start and end locations are programmed from the Graphic Rx program.
# Slices	**[16]**	**# Slices:** The maximum number of slices available is determined by the TR, TE, TI, SAR, and gradient stress.

EPI - What you select		Selection Notes

ACQUISITION TIMING area



Freq	**[128]**	**Freq:** Frequency value choices range from 32 – 512 in steps of 32. As the Frequency matrix increases, the ESP increases. Typically on a single shot keep the frequency matrix as low as possible to keep the ESP as short as possible. Finding the right balance between ESP and resolution is critical. Typically a 256 frequency matrix is used with 8 shots or more and RBw 32 – 64 kHz. For 512 frequency matrix, increase the shots and RBw.
Phase	**[256]**	**Phase:** As phase matrix increases, the resolution increases, and the # of slices decreases, but the scan time does not change (scan time = shots x TR). An EPI protocol is the only instance where phase may be larger than the frequency value.
NEX	**[2]**	**NEX:** Increase the NEX and the SNR and scan time increase.
Phase FOV	**[0.8]**	**Phase FOV:** The PFOV variable ranges from 0.5 – 1 in steps of 0.1. Select a volume that doesn't result in anatomy outside the phase FOV. As PFOV decreases, geometric distortion decreases.
Freq DIR	**[R/L]**	**Freq DIR:** In the head coil, axial, axial oblique, coronal and coronal oblique planes automatically have the phase and frequency swapped in comparison to non-EPI scans. This is to lessen the presentation of geometric distortion and to reduce the potential for peripheral nerve stimulation.
Auto Center Freq	**[Water]**	**Auto Center Freq:** Select `Water` since EPI is always fat suppressed. Current CF can be used if the previous series used the correct center frequency and Autoshim is not in use.
Flow Comp DIR	**N/A**	
Autoshim	**[On]**	**Autoshim:** Select Autoshim on the first EPI scan in each plane.

EPI - What you select		Selection Notes
Phase Correct	**[On]**	**Phase Correct:** Always select Phase Correct with EPI scans so that the system can run a “reference” scan prior to data acquisition. If a 1 NEX acquisition is programmed, the reference scan can take as long as the EPI scan, but it is imperative to run phase correct in order to have optimum image quality. The reference scan automatically occurs after a successful prescan. It makes calculations and corrections for placing the echo underneath the frequency gradient.
# of Acqs/Locs Before Pause	**[N/A]**	
Additional Parameters **SAT Screen**		
S	**[80]**	**SAT:** Select spatial SAT pulses perpendicular to the flow to suppress signal from fast flowing spins. A single shot acquisition typically doesn’t require spatial SAT pulses. Do not select a chemical saturation technique. EPI sequences are automatically fat suppressed so there is no need to apply FAT SAT.
I	**[80]**	
GRAPHIC RX Screen		
Click on the image to display the line cursor for Graphic Rx.		To prescribe oblique slices **Oblique** must be selected in the Plane pull-down menu. The SAT band function can be accessed from the Graphic Rx window and vice versa. If you had graphically prescribed the previous axial series the same prescription can be copied using the **[Copy RX]** button. Consider using an offset to center the anatomy in the middle of the screen so that you can use a PFOV less than 1 and therefore reduce the scan time. View the Advisory panel to note the # of Acqs you are prescribing. The scan time increases as the # of Acquisitions increase.
SCAN OPERATIONS Screen		
	[Save Series] **[Prep to Scan]** **[Auto Prescan]** **[Scan]**	Enter data in all the text boxes and click on **[Save Series]**. The series is saved as RXD. After prescan, the reference scan can be activated and consists of a 1 or 2 shot sequence. When the Reference scan is completed, click **[Scan]**. If performing a breath-hold study, click **[Prep for Scan]**.

Flair EPI

FLAIR-EPI is a pulse sequence designed to minimize the signal from CSF on a T2 w EPI sequence.

FLAIR (Fluid Attenuated Inversion Recovery) uses a long TR (~ 10,000 msec), long TI (~ 2300 msec) and a long TE (100 – 200 msec). It differs from the Fast FLAIR technique in that it uses an EPI data acquisition method which introduces more magnetic susceptibility effects into the image.

The images are annotated `IR/EPI` with a TI time annotated on the image.

A Flair-EPI User CV screen is accessed from the Additional Parameters area.

Something to Think About...

- Flair EPI and gating are not compatible.

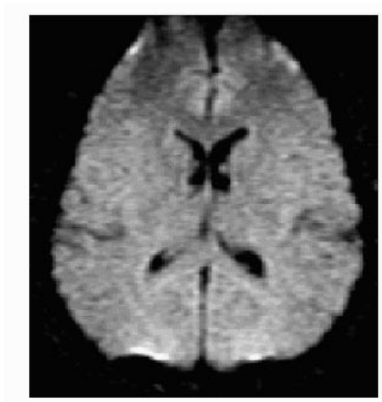
Associated Imaging Options

In the following table the X's indicate the option available for use with the Flair Echo Planar Imaging pulse sequences.

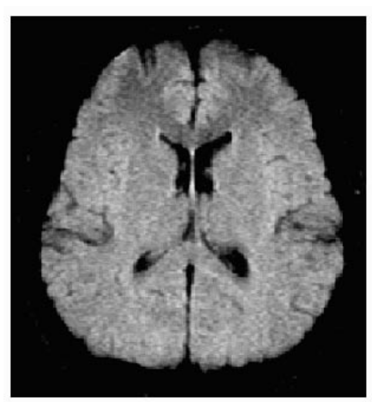
Imaging Options			
X	None	**X**	Variable Bandwidth
X	Flow Compensation		No Phase Wrap
	POMP	**X**	Extended Dynamic Range
X	Square Pixel	**X**	Surface Coil Intensity Correction
	Respiratory Compensation		Classic
	Magnetization Transfer	**X**	Sequential
	Cardiac Gating/Triggering		Respiratory Gating/Triggering
	Tailored RF		IR Prepared
	DE Prepared		Multi-Phase
	Full Echo Train		CCOMP
	ZIP 1024		ZIP 512
	Zip x 2		ZIP x 4
	SmartPrep		Blood Suppression
	Multi Station		Real Time

Applications

- Head imaging.



SS -FLAIR-EPI: 16 slices /00: 30 secs.



Multi Shot -FLAIR-EPI: 16 slices /1: 25 min.

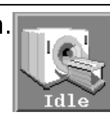
CAUTION: **Provide all patients with ear protection prior to any scan to help avoid possible hearing impairment.** Acoustic noise levels can exceed 99 dBA in the magnet bore.

Setting up a Flair Echo Planar pulse sequence

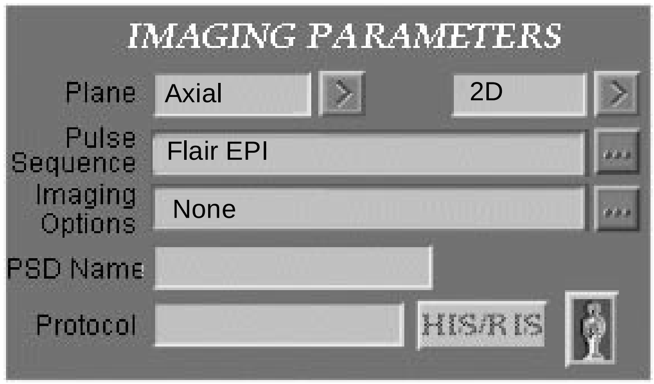
The decision matrix is only for prescribing a Flair EPI scan. The purpose of the decision matrix to help you understand the trade-offs that occur when you change the values for a particular parameter and to provide a framework with which you may build you own unique protocol.

The selected values are only an example of what could be used are not to be considered a recommendation by GE Medical Systems. For specific protocols, refer to the protocols on your system.

.

Flair EPI - What you select	Selection Notes
SCAN DESKTOP screen	
	Click the **Scan Desktop** icon.  Click on **[New Patient]** and fill in the patient information. 
PATIENT POSITION area	
Patient Position **[Supine]**	**Position and Entry:** Flair EPI is used in neuro scanning, so the patient position and coil selections reflect a head scan.
Patient Entry **[Head First]**	
Coil **[Head]**	**Coil:** Select the head coil.
Series Description	**Series Description:** Enter a suitable series description. If you don not enter a description, the system enters one for you. The series description default is the selected scan mode, PSD, and imaging options.

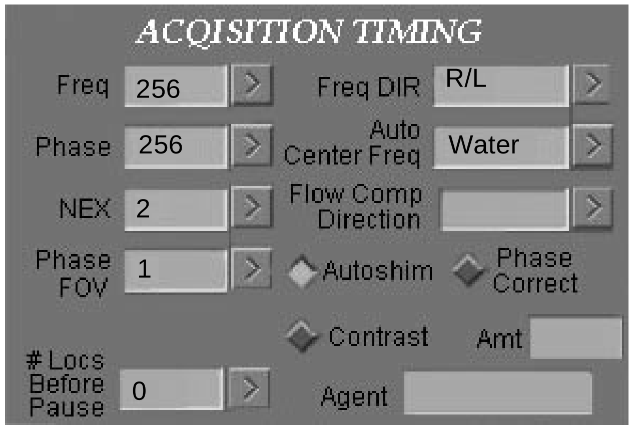
Flair EPI - What you select		Selection Notes
IMAGING PARAMETERS area		



Plane	**[Axial]**	**Plane:** Flair EPI is compatible with any scan plane except 3 plane; select the plane that best meets the clinical need.
Mode	**[2D]**	**Mode:** Select [2D].
Pulse Seq	**[Flair EPI]**	**Pulse Seq:** Select [Flair EPI]. Select [Accept] to register the selection.
Imaging Options	**None**	**Imaging Options:** Select imaging options that optimizes SNR and spatial resolution, # of slices and reduce motion artifacts. Click **[Accept]** to register the selections.
PSD Name	**N/A**	
Protocol	**N/A**	
Additional Parameters User CV screen		
Ramp Sampling	**[0]**	**Ramp Sampling:** Select `1` to turn on Ramp Sampling or `0` to turn it off. Ramp Sampling is selected when the shortest possible echo spacing is desired. Typically it is used for single shot acquisitions.
Burst Scan Time	**[0]**	**Burst Scan Time:** Burst Scan Time is selected with contrast injected acquisitions. Select `0` to turn it off, or select a Burst Scan Time that is 1 – 2 seconds longer than the acquisition time (maximum value = 120 sec.). **NOTE:** Bust Mode is only available with SE and GRE EPI acquisitions if the system operates with a 8645 GRAM gradient amplifier. Burst Mode no longer appears on the User CV screen with systems operating with a SGD or ACGD gradient amplifier.
FLAIR	**[1]**	Select `1` to turn FLAIR on.
SCAN TIMING area		
# of echoes	**[1]**	**# of echoes:** Number of echoes, is not a selectable parameter, it is automatically 1.

Flair EPI - What you select		Selection Notes
# of shots	**[8]**	**# of shots:** As the number of shots increases, the susceptibility artifacts decrease, however the scan time increases.
TE	**[80]**	**TE:** Select a moderate TE (80 – 200).
TR	**[10,000]**	**TR:** Select a long TR (8000 – 10,000 ms) to minimize T1 effects and to accommodate the number of slices.
TI	**[2200]**	**TI:** For FLAIR scans select a TI (2200 – 2500 ms for 1.5T and 2000 ms for 1.0T) to suppress CSF.
Flip Angle	**[20]**	
Echo Train Length	**N/A**	
Bandwidth	**[62.5]**	**Bandwidth:** As the RBw increases, the ESP decreases (which is desirable), which means the Minimum TE decreases, also the SNR decreases. Select a RBw that is a compromise between SNR and short ESP requirements.
Bandwidth 2	**N/A**	
SCANNING RANGE area		
FOV	**[24]**	**FOV:** As FOV increases, ESP decreases. The shortest possible ESP is desirable for a single shot acquisition.
Slice Thickness	**[5]**	**Slice Thickness:** Thin slices produce: increased resolution and decreased SNR.
Spacing	**[2.5]**	**Spacing:** Select a spacing that reduces cross-talk between slices (typically 20% of the slice thickness). If the scan is a dual acquisition with no concantenated SAT pulse, 0 spacing is allowed.
Start, End Locations		**Start, End Locations:** Typically the start and end locations are programmed from the Graphic Rx program.
# Slices	**[16]**	**# Slices:** The maximum number of slices available is determined by the TR, TE, TI, SAR, and gradient stress.FLAIR must have 4 or more slices prescribed.

Flair EPI - What you select		Selection Notes
ACQUISITION TIMING area		



Freq	**[256]**	**Freq:** Frequency value choices range from 64– 512 in steps of 32. As the Frequency matrix increases, the ESP increases. Typically on a single shot keep the frequency matrix as low as possible to keep the ESP as short as possible.
Phase	**[256]**	**Phase:** Phase values available are between 32 – 512 in steps of 32. As phase matrix increases, the resolution increases, and the # of slices decreases, but the scan time does not change (scan time = shots x TR). An EPI protocol is the only instance where phase may be larger than the frequency value.
NEX	**[2]**	**NEX:** Select a NEX value that produces sufficient SNR.
Phase FOV	**[1]**	**Phase FOV:** The PFOV variable ranges from 0.5 – 1 in steps of 0.1. Select a volume that doesn't result in anatomy outside the phase FOV. As PFOV decreases, geometric distortion decreases.
Freq DIR	**Swapped**	**Freq DIR:** In the head coil, axial, axial oblique, coronal and coronal oblique planes automatically have the phase and frequency swapped in comparison to non-EPI scans. This is to lessen the presentation of geometric distortion and to reduce the potential for peripheral nerve stimulation.
Auto Center Freq	**[Water]**	**Auto Center Freq:** Select `Water` since EPI is always fat suppressed. Current CF can be used if the previous series used the correct center frequency and Autoshim is not in use.
Flow Comp DIR	**N/A**	
Autoshim	**[On]**	
Phase Correct	**[On]**	
# of Acqs/Locs Before Pause	**[N/A]**	

Flair EPI - What you select		Selection Notes
Additional Parameters **SAT Screen**		
S	**[80]**	**SAT:** Select spatial SAT pulses perpendicular to the flow to suppress signal from fast flowing spins. A single shot acquisition typically doesn't require spatial SAT pulses. Do not select a chemical saturation technique. EPI sequences are automatically fat suppressed so there is no need to apply FAT SAT.
I	**[80]**	
GRAPHIC RX Screen		
Click on the image to display the line cursor for Graphic Rx.		To prescribe oblique slices **Oblique** must be selected in the Plane pull-down menu. The SAT band function can be accessed from the Graphic Rx window and vice versa. If you had graphically prescribed the previous axial series the same prescription can be copied using the **[Copy RX]** button. Consider using an offset to center the anatomy in the middle of the screen so that you can use a PFOV less than 1 and therefore reduce the scan time. View the Advisory panel to note the # of Acqs you are prescribing. The scan time increases as the # of Acquisitions increase.
SCAN OPERATIONS Screen		
	[Save Series] **[Prep to Scan]** **[Auto Prescan]** **[Scan]**	Enter data in all the text boxes and click on **[Save Series]**. The series is saved as RXD. After prescan, the reference scan can be activated and consists of a 1 or 2 shot sequence. When the Reference scan is completed, click **[Scan]**. If performing a breath-hold study, click **[Prep for Scan]**.

Diffusion EPI

Diffusion-Weighted Echo Planar Imaging (DW-EPI) is a single shot EPI pulse sequence designed to create images that differentiate tissues with restricted diffusion from tissues with normal diffusion.

EZDWI is a purchasable option for Signa Horizon LX Base or Signa MR/*i* Base systems at either 1.0T or 1.5T.

Selecting DW-EPI results in two new screens. One is accessed from the User CV screen, and the other is accessed by selecting the DWI Additional Parameters icon.

The following are User CVs that appear with DW-EPI:

- User CV: EPI Flair
- Burst Scan Time
  - Burst Scan Time is not available with DW-EPI, even though it appears on the User Control Variables screen.
- Ramp Sampling

Imaging Options menu:

- ZIP256
  - ZIP256 is automatically applied to all DWI images (both the baseline and diffusion images). ZIP (Zerofill Interpolation Processing) is a reconstruction technique. The images are reconstructed to a 256x256 matrix using this process, thereby enhancing the apparent image resolution.

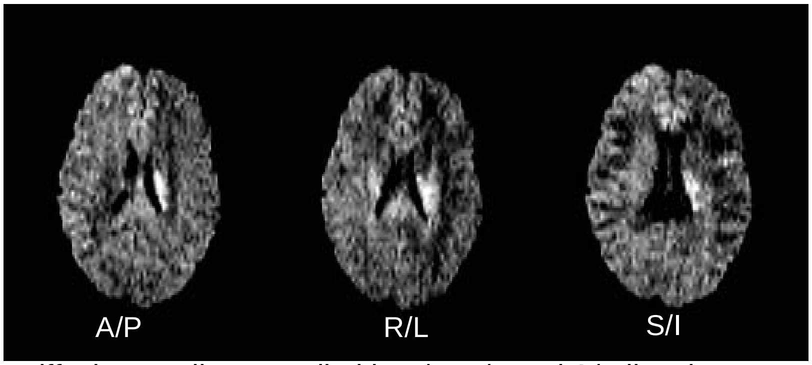
Additional Parameters: Diffusion Options screen

- Diffusion images are annotated DW-EPI, with the diffusion direction and the B-Value, for example: 1000 s/mm 2 All.

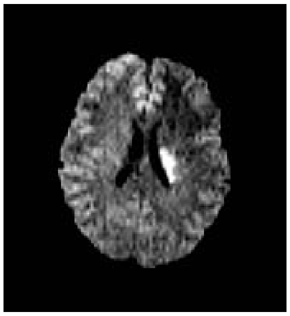
Diffusion EPI collects 2 sets of image, T2 weighted image or FLAIR series and the diffusion series.

T2 FLAIR Diffusion

DW EPI is a single shot SE EPI sequence that uses a motion probing or diffusion gradient in up to 3 directions (A/P, R/L, S/I or all) to dephase moving nuclei. The images are then mathematically combined into one isotropic diffusion image.

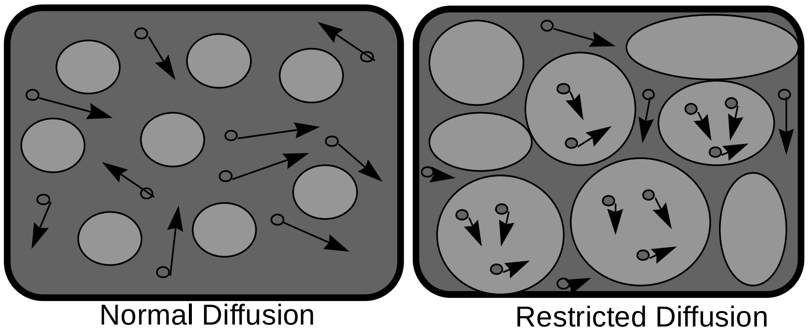


Diffusion gradients applied in A/P, R/L and S/I directions.



Combined isotropic diffusion image.

The extra-cellular water in normal brain tissue diffuses freely, resulting in a dark signal. The extra-cellular water in dead brain tissue does not diffuse, resulting in a bright signal.



In a DW-EPI sequence, the prescribed B-Value can be achieved with different combinations of gradient amplitude and duration. The gradient duration directly affects the minimum TE for a DW-EPI sequence. As gradient amplitude increases, the duration needed to obtain the prescribed B-Value can be decreased.

Diffusion gradients used to be at a fixed duration while the amplitude was varied to obtain the selectable B-Value. A fixed gradient duration results in a fixed TE value. The TE value in this case is approximately 100ms. Two potential problems exist with the method:

- The TE is approximately the same value regardless of the B-Value. At high B-Values, SNR is reduced. The SNR reduction, coupled with the lower SNR associated with long TEs (approximately 100ms), decreases total SNR in the images.
- The maximum B-Value that can be achieved is 1000s/mm^2 on MR/i and LX systems. Higher B-Values may help eliminate T2 shine-through, improve visualization of white matter tracks, and may be useful in differentiation of sub acute versus chronic infarcts.

To overcome these potential problems and offer more options in B-Value selections, High B-Value DW-EPI has been developed. High B-Value DW-EPI calculates the minimum gradient duration needed to achieve the prescribed B-Value. DW-EPI calculates the minimum gradient duration needed to achieve the prescribed B-Value while utilizing the maximum gradient amplitude allowed for a system’s gradient configuration. The benefits of this method are:

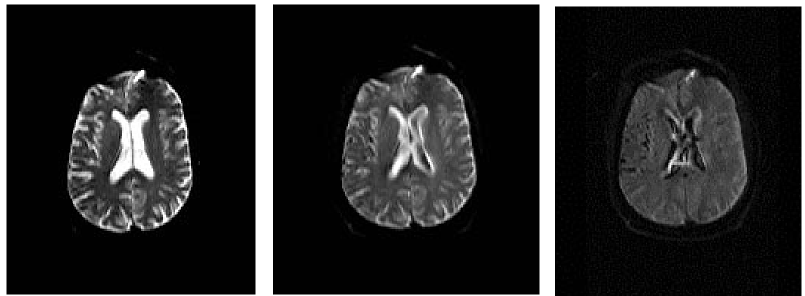
- Decreasing gradient duration decreases the TE for B-Values of 1000 or less on MR/i and LX systems.
- B-Values greater than 1000 can be defined on MR/i and LX systems.

NOTE: B-Values up to 7000 can be achieved. This value is dependant upon system gradients.

NOTE: Maximum B-Value for EZDWI is 1000 and the minimum is 1.

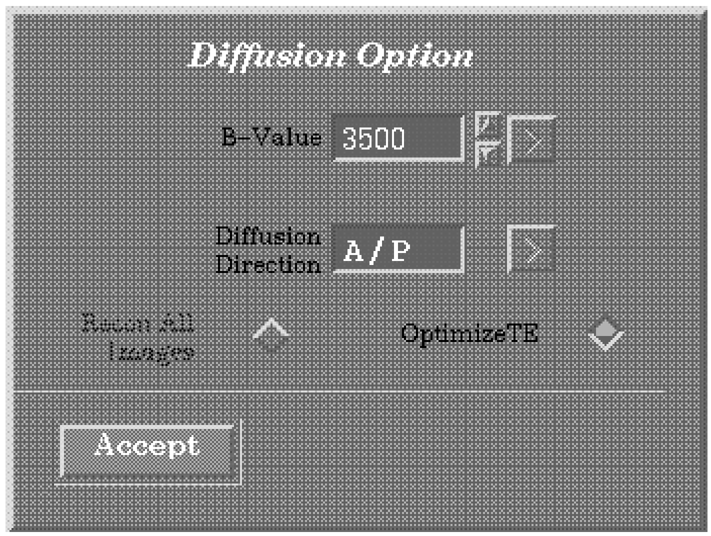
In the additional parameters area, click the DWI screen.

Both methods of applying the diffusion gradients are available for use. Selections made at the Diffusion screen define which method is implemented. ***Optimize TE needs to be selected to get the higher B-Values.*** If you want the same images as before ASP, you would want Optimize TE off.



B=5 B=500 B=1000

Diffusion Images with varying B-Values



B-Value	The menu offers only a few selections. The desired B-Value can be entered manually. The maximum depends on the state of Optimize TE. When enabled, Optimize TE permits higher values, when off, B-value options are restricted to lower values. It is recommended that a 1000 is used.
Diffusion Direction	The direction of the diffusion gradients is defined here: All, L/R, A/P, or S/I for orthogonal planes; All or Slice for oblique planes. The diffusion images reflect the motion of water molecules in the selected diffusion direction.
Recon All Images	Systems with a research agreement are able to reconstruct the directional diffusion images, (L/R, A/P, or S/I) when All is the diffusion direction.
Optimize TE	ON is the default. When Optimize TE is on, maximum gradient amplitudes are employed while the minimum possible TE, based on the B-Value, is used. Higher B-values are also available. When turned off, B-Values are limited and gradient duration is fixed, resulting in a TE of approximately 100ms.

The gradient configuration of the system determines the maximum B-Value. The following chart can be used to determine the maximum for a system with or without Optimize TE enabled.

System	***TE***	***Maximum B-Value***
MR/i and LX SmartSpeed systems		
Optimize TE OFF	Approximately 100ms	1,000s/mm^2
Optimize TE ON	Minimum TE is used and is based on the prescribed B-Value.	2,500s/mm^2
MR/i and LX HiSpeedPlus systems		
Optimize TE OFF	Approximately 100ms	2,200s/mm^2
Optimize TE ON	Minimum TE is used and is based on the prescribed B-Value.	4,000s/mm^2
MR/i and LX EchoSpeedPlus systems		
Optimize TE OFF	Approximately 100ms	2,200s/mm^2
Optimize TE ON	Minimum TE is used and is based on the prescribed B-Value.	7,000s/mm^2

Multiple NEX Image Averaging

Another benefit to High B-Value DW-EPI is Multiple NEX Image Averaging. One to sixteen NEX can be prescribed for a DW-EPI sequence. High B-Value imaging can lead to a significant suppression of water signal and loss of SNR. Multiple NEX can be used to improve SNR in diffusion-weighted images. Of course, as the number of NEX increases, scan time increases accordingly. This increase in scan time may be offset by the benefit of improving SNR.

Something to Think About...

- The peak gradient amplitude is limited by the constraints of the gradient subsystem; therefore, there is a limit to the minimum TE and the maximum B-Values that can be achieved for a given MRI system.
- Using multiple NEX imaging increases the need for bulk acquisition memory (BAM). If the system cannot allocate enough BAM for the series, a message is posted. The following parameters can be decreased to decrease the amount of BAM needed: frequency matrix, phase matrix, number of slices, or number of NEX.
- If the selected B-Value cannot be achieved, an error message is posted.
- The assessment of the diffusion of the anatomy is dependent on the number of Diffusion Directions selected. If All is selected, then anatomy in all directions can be assessed for diffusion. If a single direction is selected, then only the anatomy in that particular direction within the slice can be diffusion assessed.
- If the All Diffusion Direction is selected, a combined image is created by recon from the diffusion image data. If All is not selected, there is no combination image created.
- The EZDWI pulse sequence is only available for Signa Horizon LX and Signa MR/*i* Base systems.
- EZDWI is allowed only in the axial plane, Utilizing the Head Coil.
- With EZDWI the frequency direction cannot be altered from the default direction of R/L
- The Recon All Images key is only available when operating the system in research mode that is in accordance with your country’s regulations. If the Recon

All Images key is not selected, only the combined diffusion images are reconstructed rather than an image from each of the directions. This assumes that the All key was selected.

Compatible with DWI-EPI	Not Compatible with DWI-EPI
EDR	Classic
Gating	NPW
VBW (32kHz, 64kHz)	POMP
FLAIR	Resp Comp
Single Shot (required)	3D Acquisitions
Min TE (required)	Gradient Echo
1 NEX (required)	Multi-Shot
Ramp Sampling	CINE
	Flow Comp

Associated Imaging Options

In the following table the X's indicate the option available for use with the Diffusion Echo Planar Imaging pulse sequences.

Imaging Options			
X	None	X	Variable Bandwidth
X	Flow Compensation		No Phase Wrap
	POMP	X	Extended Dynamic Range
X	Square Pixel	X	Surface Coil Intensity Correction
	Respiratory Compensation		Classic
	Magnetization Transfer	X	Sequential
X	Cardiac Gating/Triggering		Respiratory Gating/Triggering
	Tailored RF		IR Prepared
	DE Prepared		Multi-Phase
	Full Echo Train		CCOMP
	ZIP 1024		ZIP 512
	Zip x 2		ZIP x 4
	SmartPrep		Blood Suppression
	Multi Station		Real Time

NOTE: Surface Coil Intensity Correction coil compatibility should be checked with Imaging Options chapter.

STL is a research option that is found in the Imaging Parameters area of the Scan Deskstop. An STL or T/s key appears and displays the default value for the Stimulated Threshold Limit or the dB/dt expressed as Tesla/second. The default value has been set by the IRB (Investigational Review Board) or other governing board. Either accept the default value or type in a new value that is no greater than the maximum value approved by the governing board.

EPI can prompt STL messages depending on the situation.

- For non-research IEC, non-EPI scans using a HiSpeed or EchoSpeed gradient system:
  - Accept >20T/s On /Off. Selecting `On` means 20T/s might be exceeded and it produces the following message:

    `“Attention, possible patient peripheral nerve stimulation OK”`
  - Select **[OK]** to proceed. Off allows the default value set by the site’s governing board to be used.
- For research IEC or FDA EPI scans using a HiSpeed or EchoSpeed gradient system:
  - The STL% or T/s is displayed which can be changed by entering a value between the default and maximum value allowed. If the value exceeds the default value the following message appears:

    `”Do you accept responsibility for operation up to STL% of peripheral nerve stimulation threshold limit?”`
  - If the site does not have an STL% display but rather a T/s display, the message is:

    `“Do you accept responsibility for operation up to T/s?”`
  - Click **[Accept]** to proceed with protocol prescription, or click **[Reject]** and enter a value less than or equal to the default value the governing board has approved. Note that the system never allows a protocol to exceed the maximum level set by the governing board.

- ° If a value that exceeds the governing board's maximum value is entered, the following message appears:

  ```
  "Valid range is 1 to xx STL%" or "Valid range is 1 to xx T/s OK"
  ```

- ° The xx STL% or xx T/s is the maximum value allowed by the governing board. Click **[OK]** to proceed.

Applications

Use DW EPI for examining the tissues in the brain. At low B-Values (<1000 for LX and MR/i) with Optimize TE enabled, lower TEs are achieved. This provides increased SNR as compared to images obtained at longer TE values, provided the B-Values remain the same. Multiple NEX image averaging can be used to improve SNR, especially when using high B-Value.

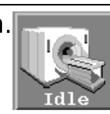
CAUTION: Provide all patients with ear protection prior to any scan to help avoid possible hearing impairment. Acoustic noise levels can exceed 99 dBA in the magnet bore.

Setting up a Diffusion Echo Planar pulse sequence

The decision matrix is only for prescribing a Diffusion weighted EPI scan. The purpose of the decision matrix to help you understand the trade-offs that occur when you change the values for a particular parameter and to provide a framework with which you may build you own unique protocol.

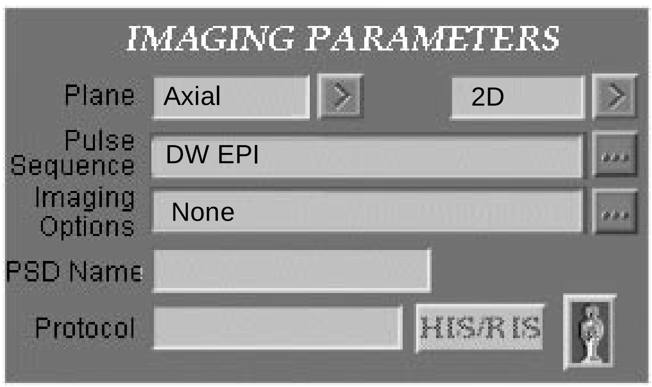
The selected values are only an example of what could be used are not to be considered a recommendation by GE Medical Systems. For specific protocols, refer to the protocols on your system.

.

EZDWI/DW EPI - What you select	Selection Notes
SCAN DESKTOP screen	
	Click the **Scan Desktop** icon.  Click on **[New Patient]** and fill in the patient information. 
PATIENT POSITION area	

EZDWI/DW EPI - What you select		Selection Notes
Patient Position	**[Supine]**	**Position and Entry:** An EPI pulse sequence is compatible with any patient position and orientation and every coil. Note that hands clasped together may increase the potential for Peripheral Nerve Stimulation.
Patient Entry	**[Head First]**	
Coil	**[Head]**	**Coil:** Select the head coil. EZDWI is compatible only with the Head Coil.
Series Description		**Series Description:** Enter a suitable series description. If you don not enter a description, the system enters one for you. The series description default is the selected scan mode, PSD, and imaging options.

IMAGING PARAMETERS area



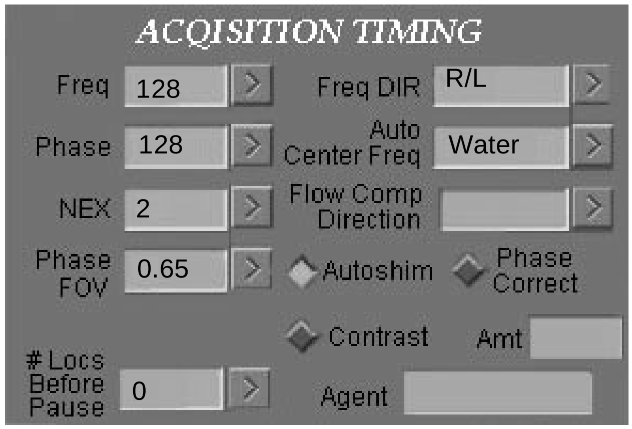
Plane	**[Axial]**	**Plane:** DW EPI is compatible with any scan plane except 3 plane; select the plane that best meets the clinical need. EZDWI can be acquired only in the axial plane.
Mode	**[2D]**	**Mode:** Select [2D].
Pulse Seq	**[DW EPI]**	**Pulse Seq:** Select [DW EPI]. Select [Accept] to register the selection.
Imaging Options	**None**	**Imaging Options:** Select imaging options that optimizes SNR and spatial resolution, # of slices and reduce motion artifacts. Select [Accept] to register the selections.
PSD Name	**N/A** **ezdwi**	For systems with EZDWI software you must type [ezdwi] in text box.
Protocol	**N/A**	

Additional Parameters User CV screen

EZDWI/DW EPI - What you select		Selection Notes
Ramp Sampling	**[0]**	**Ramp Sampling:** Select `1` to turn on Ramp Sampling or `0` to turn it off. Ramp Sampling is selected when the shortest possible echo spacing is desired. Typically it is used for single shot acquisitions with high frequency values, and to decrease geometric distortion. Phased array coils are not compatible with Ramp Sampling.
FLAIR	**[1]**	Select `1` to turn FLAIR on.
		SCAN TIMING area
# of echoes	**[1]**	**# of echoes:** Number of echoes, is not a selectable parameter, it is automatically 1.
# of shots	**[1]**	**# of shots:** 1 must be selected. As the number of shots increases, the susceptibility artifacts decrease, however the scan time increases.
TE	**[Min]**	**TE:** Select `Minimum` TE. It is the only option available.
TR	**[10,000]**	**TR:** Select a long TR (8000 – 10,000 ms) to minimize T1 effects and to accommodate the number of slices. TR must be 4 times longer than the Inversion Time.
TI	**[2300]**	**TI:** For FLAIR scans only, select a TI to suppress CSF (2300 – 2500 ms).
Flip Angle	**N/A**	
Echo Train Length	**N/A**	
Bandwidth	**[64]**	**Bandwidth:** RBw can only be changed if it was selected from the Imaging Options window. As the RBw increases, SNR decreases, chemical shift artifact decreases, and minimum TE decreases (which means the echo space decreases). As echo space decreases, geometric distortion decreases. For EZDWI software bandwidth is fixed at +/- 125 kHz.
Bandwidth 2	**N/A**	
		SCANNING RANGE area
FOV	**[30]**	**FOV:** As FOV increases and RBw increases, ESP decreases. The shortest possible ESP is desirable for a single shot acquisition. For EZDWI software the FOV is fixed at 36 cm.
Slice Thickness	**[5]**	**Slice Thickness:** Thin slices produce: increased resolution and decreased SNR.
Spacing	**[1.0]**	**Spacing:** Select a spacing that reduces cross-talk.
Start, End Locations		**Start, End Locations:** Typically the start and end locations are programmed from the Graphic Rx program.
# Slices	**[16]**	**# Slices:** The maximum number of slices available is determined by the TR, TE, TI, SAR, and gradient stress.

EZDWI/DW EPI - What you select		Selection Notes

ACQUISITION TIMING area



Freq	**[128]**	**Freq:** Frequency value choices range from 32 – 512 in steps of 32. As the Frequency matrix increases, the ESP increases. Typically on a single shot keep the frequency matrix as low as possible to keep the ESP as short as possible. Finding the right balance between ESP and resolution is critical. For EZDWI software the available options are 96 and 128.
Phase	**[128]**	**Phase:** As phase matrix increases, the resolution increases, and the # of slices decreases, but the scan time does not change (scan time = shots x TR). An EPI protocol is the only instance where phase may be larger than the frequency value. For EZDWI software the phase is fixed at 128.
NEX	**[1]**	**NEX:** Select a NEX value that produces sufficient SNR.
Phase FOV	**[0.65]**	**Phase FOV:** The PFOV variable ranges from 0.5 – 1 in steps of 0.1. Select a volume that doesn't result in anatomy outside the phase FOV. As PFOV decreases, geometric distortion decreases. For EZDWI software the PFOV is fixed at 0.6
Freq DIR	**Swapped**	**Freq DIR:** In the head coil, axial, axial oblique, coronal and coronal oblique planes automatically have the phase and frequency swapped in comparison to non-EPI scans. This is to lessen the presentation of geometric distortion and to reduce the potential for peripheral nerve stimulation. For EZDWI software the frequency is applied and fixed for R/L direction.

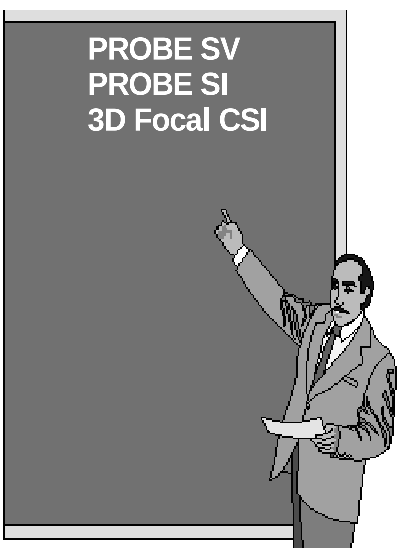
EZDWI/DW EPI - What you select		Selection Notes
Auto Center Freq	**[Water]**	**Auto Center Freq:** Select `Water` since EPI is always fat suppressed. Current CF can be used if the previous series used the correct center frequency and Autoshim is not in use.
Flow Comp DIR	**N/A**	
Autoshim	**[On]**	Click **[Autoshim]** for the first EPI scan in each plane.
Phase Correct	**[On]**	Click **[Phase Correct]** with EPI scans so that the system can run a “reference” scan prior to data acquisition. If a 1 NEX acquisition is programmed, the reference scan can take as long as the EPI scan, but it is imperative to run phase correct in order to have optimum image quality. The reference scan automatically occurs after a successful prescan. It makes calculations and corrections for placing the echo underneath the frequency gradient.
# of Acqs/Locs Before Pause	**[N/A]**	
	Additional Parameters SAT Screen	
SAT	**None**	**SAT:** Spatial SAT pulses are not needed when doing single shot EPI due to the fast acquisition time. Do not select a chemical saturation technique. EPI sequences are automatically fat suppressed so there is no need to apply FAT SAT.
	GRAPHIC RX Screen	
Click on the image to display the line cursor for Graphic Rx.		To prescribe oblique slices **Oblique** must be selected in the Plane pull-down menu. The SAT band function can be accessed from the Graphic Rx window and vice versa. If you had graphically prescribed the previous axial series the same prescription can be copied using the **[Copy RX]** button. Consider using an offset to center the anatomy in the middle of the screen so that you can use a PFOV less than 1 and therefore reduce the scan time. View the Advisory panel to note the # of Acqs you are prescribing. The scan time increases as the # of Acquisitions increase.
	SCAN OPERATIONS Screen	
	[Save Series] **[Prep to Scan]** **[Auto Prescan]** **[Reference Scan]** **[Scan]**	Enter data in all the text boxes and click on **[Save Series]**. The series is saved as RXD. After prescan, the reference scan can be activated and consists of a 1 or 2 shot sequence. When the Reference scan is completed, select **[Scan]**.

Volume 2

Chapter 12

Imaging with Spectroscopy Pulse Sequences

Where Am I?



Introduction

This chapter explains the pulsing components and timing factors directly related to the Spectroscopy pulse sequences. This chapter explains the concepts of each, and the step-by-step instructions to help you learn how to:

- Optimize PROBE SV images
- Optimize PROBE SI images
- Select optimal parameters

In addition, this chapter answers the following questions:

1. What causes chemical shift?
2. What are the major chemical components of the H1 spectrum in the brain?
3. What pulse sequence is used in PROBE-SI and how do parameters affect the spectra?
4. How are multiple spectra collected?
5. What are metabolite maps?
6. What are the applications?

About... Spectroscopy Pulse Sequences

This section presents the concepts necessary to understand Spectroscopy pulse sequences. Specifically you need to understand:

- Safety Indications
- Spectroscopy Overview
- Chemical Shift
- Brain Spectrum
- Very Selective Spatial Saturation
- Mode of Operation
- Spectroscopy Single Voxel
  - Graphic ROI Prescription
  - Scan Mode Selection
  - Auto Prescan Description
  - Spectrum Display and Storage
- Spectroscopy Multi-Voxel Probe SI
- 3D Focal CSI

Safety

The safety precautions needed for PROBE/SV spectroscopy are identical to those required for any other Signa® exam. Review the Safety chapter in the Signa Select Learning Guide to make sure that the MR environment is as safe as possible for all patients.

The PROBE/SV option is a diagnostic device that provides, in a non-invasive manner, estimates of the concentrations of molecules containing hydrogen present in the brain. These NMR data, in the form of spectra, reflect the NMR properties of proton density, spin-lattice relaxation time (T1), spin-spin relaxation time (T2), and chemical shift. When interpreted by a trained medical practitioner, these spectral data provide information that can be useful in making a diagnosis.

Spectroscopy Overview

Magnetic Resonance Spectroscopy (MRS) is a device that provides, in a non-invasive manner, the signal intensities of molecules containing hydrogen present in a specified region of interest in the body. In-vivo hydrogen spectroscopy is in its infancy. It may be some time before it provides the level of diagnostic confidence offered by conventional techniques. Until then, spectroscopy examinations should not be used as the primary basis for diagnosis.

Chemical Shift Imaging (CSI) is an effective and efficient method of simultaneously characterizing the spatial distribution and spectral frequency content of signal producing species in a magnetic resonance (MR) examination. Voxel localization is used to limit data acquisition to a particular volume of interest (VOI) and to exclude unwanted signals. In voxel localized CSI, spatial distribution is encoded using magnetic field gradients incremented on successive acquisitions to produce spatially dependent phase changes. Such phase encoding can be applied on three orthogonal axes to dimensionally characterize the excited volume in three dimensional (3D) space. The Field Of View (FOV) over which the signal is encoded may be independent of the bounds of the excited volume.

The frequency content of each spatial location is evaluated by detecting the time dependence of the signal, the Free Induction Decay (FID), in the absence of magnetic field gradients. Fourier transformation along the phase encoded axes separates the data into spatially separated FIDs. Fourier transformation of the FIDs yields the spatially localized frequency plots, or spectra.

The Single-voxel Proton Brain Exam, or PROBE/SV, is an image-guided, clinical spectroscopy package. It acquires a volume-localized, water-suppressed spectrum from a single voxel or VOI. Automated acquisition setup, including the adjustment of homogeneity through the voxel and water suppression, is standard on the PROBE/SV pulse sequences.

While the PROBE/SV package is primarily designed for the acquisition of spectra from the brain, it may be used in any anatomy containing little or no fat.

Features of the PROBE/SV package include:

- Scan prescription
- User selection of either PROBE-S or PROBE-P spectral acquisition methods
- Image-guided Graphic Prescription of the voxel or VOI

- Optional voxel imaging acquisition mode
- All standard Auto Prescan capabilities plus the automatic adjustment of water suppression and homogeneity
- A processed spectrum displayed on the scanner mini-viewer on the screen and stored in the patient data base, where it can be viewed with the SDC Browser
- Quantitative measurements of spectral peaks associated with water, creatine, choline, NA, and myo-Inositol are provided.

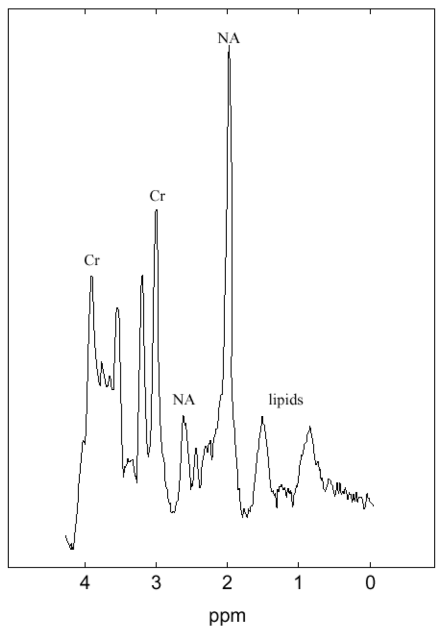
Compared to 2D chemical shift imaging, automated voxel localized three-dimensional (3D) chemical shift imaging provides more efficient coverage of the brain tissue. The feature is optimized for use in the brain where lipid signals are restricted to the edges of the skull and can be avoided by volume positioning and outer volume suppression (OVS) rather than in-volume signal suppression. This feature builds upon the current technology for acquiring single voxel and two-dimensional (slice oriented) CSI data by enabling encoding of the third dimension in a user-friendly manner.

Chemical Shift

Spectroscopy is made possible by chemical shift. Chemical shift is the change in precessional frequency caused by the local magnetic environment. The local magnetic environment is a function of the molecular or electron environment in which the proton nucleus resides. This electron environment either shields or deshields the nucleus. With the nucleus shielded the local magnetic field is diminished and the precessional frequency of the nucleus decreases. With the nucleus deshielded the local magnetic field is augmented and the precessional frequency of the nucleus increases.

Since the change or shift in precessional frequency is caused by the chemical environment it is called chemical shift. Hydrogen nuclei are bonded to Carbon nuclei in fat in long chains. The Carbon nuclei are weakly electronegative and the long chains of molecules form an electron cloud that shields the Hydrogen nuclei. The resulting chemical shift is in the 1.0 to 1.5 ppm (part per million) range. Hydrogen nuclei are ionically bonded to Oxygen nuclei in water. The Oxygen nuclei are strongly electronegative and "pull away" the protective electrons deshielding the Hydrogen nuclei. The resulting chemical shift is in the 4.5 ppm range. The Hydrogen nuclei bonded to Carbon in benzene rings experience a large chemical shift, 6 to 8 ppm due to the circulation of delocalized electrons around the aromatic ring.

Brain Spectrum



The different peaks make up the different chemical elements in the spectrum. The position of each peak is determined by the chemical composition and resulting frequency shift. The peaks are also indicative of normal or abnormal brain function.

Chemical Compound	Chemical Shift (ppm)	Comments
N-acetylaspartate (NAA)	2.0	NAA is thought to be a neuro marker. This peak may also reflect contributions from other compounds containing N-acetyl residues.
Creatine/phosphocreatine (Cr/PCr)	3.0, 3.9	Supplier of phosphate to convert ADP to ATP. There are two peaks one at 3.0 the other 3.9 ppm.
Choline (Cho)	3.2	This peak most likely represents total choline brain stores, including the neurotransmitter acetylcholine, phosphocholine and, perhaps, membrane phosphatidylcholine.

Chemical Compound	Chemical Shift (ppm)	Comments
Myo-inositol (ml)	3.6	May be a storage form of the hormonal messenger inositol diphosphate.
Glutamate (Glu) Glutamine (Gln) Note: Glu + Gln = Glx	2.1-2.5	An excitatory neurotransmitter and regulator. These two chemical compounds tend to resonate very closely together and can usually not be separated. The two combined are then labeled Glx.
Lipids (Lip)	0.9-1.4	An indicator of cell breakdown.
Lactate (Lac)	1.3	An end product of anaerobic glycolysis.
Tetramethylsilane (TMS)	0	Reflects silane.

Some of the cerebral metabolites that are thought to contribute to the peaks in the brain spectrum.

Very Selective Spatial Saturation

As spectroscopy imaging becomes more prevalent and targeted at challenging areas of the anatomy, effective spatial saturation of unwanted signals becomes more critical. Very Selective Spatial Saturation (VSS) provides an effective means to saturate signals within a chosen plane. The saturated plane is characterized by flat transmission and stop bands, and very narrow transition bands. This allows you to apply saturation bands very close to the VOI without affecting signals within the VOI because of unwanted overlap with the saturation transition band. VSS pulses also have a very high effective bandwidth, and are therefore very appropriate for use in regions of high inhomogeneity, or in cases where chemical shift is important. Sharply defined bandwidths are necessary to cut out unwanted signals near or within volumes of interest without unduly impacting the signals of interest. Slice selective Very Selective Saturation RF pulses are designed to provide improved spatial saturation performance with no increase in the time required for the pulse sequence. VSS pulses can be used with Probe-P single voxel, probe SI, and 3D Focal CSI.

In the default mode, VSS provides the use of six fixed-position saturation bands bordering and surrounding the MRS-mode prescribed Volume of Interest (VOI).

The default VOI edge sat bands can be turned on and off by a user control variable (User CV) which appears on the User CV screen when default sat bands are available. The User CV allows independent on-off control of the sat bands placed at

Right/Left (R/L), Anterior/Posterior (A/P), and Superior/Inferior (S/I) edges of the VOI.

Additionally, up to four explicitly prescribed SAT bands can be placed on the same localizer image used to prescribe the PROBE-P voxel. The four explicit sat bands can be graphically prescribed using the Saturation Prescription screen on a localizer image. Choose the same axis plane that was used to place your VOI scan prescription. The saturation bands may be changed in thickness and angle and may be placed anywhere on the image by dragging or by explicitly entering the coordinate. The prescription process gives you visible feedback of the sat band positioning and thickness. The true thickness is displayed numerically in millimeters. These bands help refine the VOI. FOV edge sat bands can also be chosen on the Saturation Prescription screen, but no explicit position is given. The thickness can be changed by typing it in the thickness text box.

Mode of Operation

Probe-P Single Voxel (Probe/SV), probe SI, and 3D Focal CSI can all be accessed from the PROBE-P pulse sequence. For example, when you choose PROBE-P from the PSD menu, the mode of operation is based on the selections of frequency and phase matrices, and the locations per slab.

If the phase matrix, frequency matrix, and Locs per Slab are all set to 1, acquire single voxel data. If the phase and frequency matrices are greater than 1 (the options are there to select the same resolutions that exist for the current 2D product) and Locs per Slab is set to 1, acquire single slice, multi-voxel data (same as the probe SI product). When all three (frequency matrix, phase matrix, and Locs per Slab) are greater than 1, you will get the 3D behavior which returns data in the appearance of a multi-slice version of probe SI. The data is analyzable in a very similar (but multi-slice) fashion as probe SI.

Mode of Operation	***Parameter***	***Selection***
PROBE/SV	Locs per Slab	1
	Phase Matrix	1
	Frequency Matrix	1
probeSI	Locs per Slab	1
	Phase Matrix	>1
	Frequency Matrix	>1
3D Focal CSI	Locs per Slab	≥8 *
	Phase Matrix	≥8 *
	Frequency Matrix	≥8 *

** Only even numbers from eight to 16 are valid.*

The distance between the slices is controlled by the Spacing text box. Select the parameters for the Field of View (FOV), Voxel Thickness, Phase matrix, Frequency matrix and the Locs per Slab before selecting the Spacing. The Phase FOV is not a selectable option, the system chooses this for you.

Matrix	***Phase FOV***
8 x 8, 16 x 16	1
8 x 10, 8 x 12, 8 x 14, 8 x 16	.5
10 x 8, 12 x 8, 14 x 8, 16 x 8	.5
All other matrices	1

The matrix sizes in the above table correspond to Frequency x Phase.

The following are approximate scan times using the given parameters.

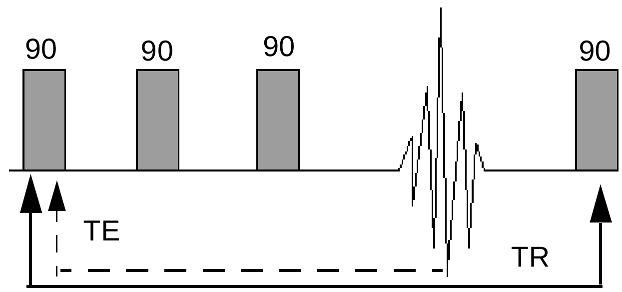
TR	***Locs per slab***	***Frequency***	***Phase***	***Nex***	***Approximate Scan Time***
1000	8	8	8	1	8:32 min
1000	8	10	10	1	13:20 min
1000	8	16	16	1	34:08 min
1000	16	8	8	1	17:08 min

Spectroscopy Single Voxel (PROBE SV)

Select either of two volume-localized pulse sequences:

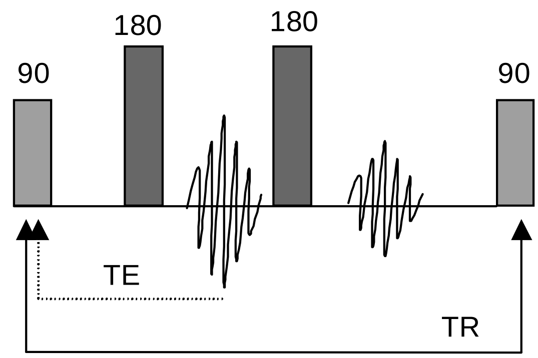
- PROBE-S, or
- PROBE-P

PROBE-S is a version of the STEAM (STimulated Echo Acquisition Mode) pulse sequence. Three 90-degree, slice selective RF pulses are used to generate a stimulated echo from a localized volume The STEAM sequence is less sensitive to T_2 relaxation effects since no T_2 relaxation occurs between the second and third RF pulses.



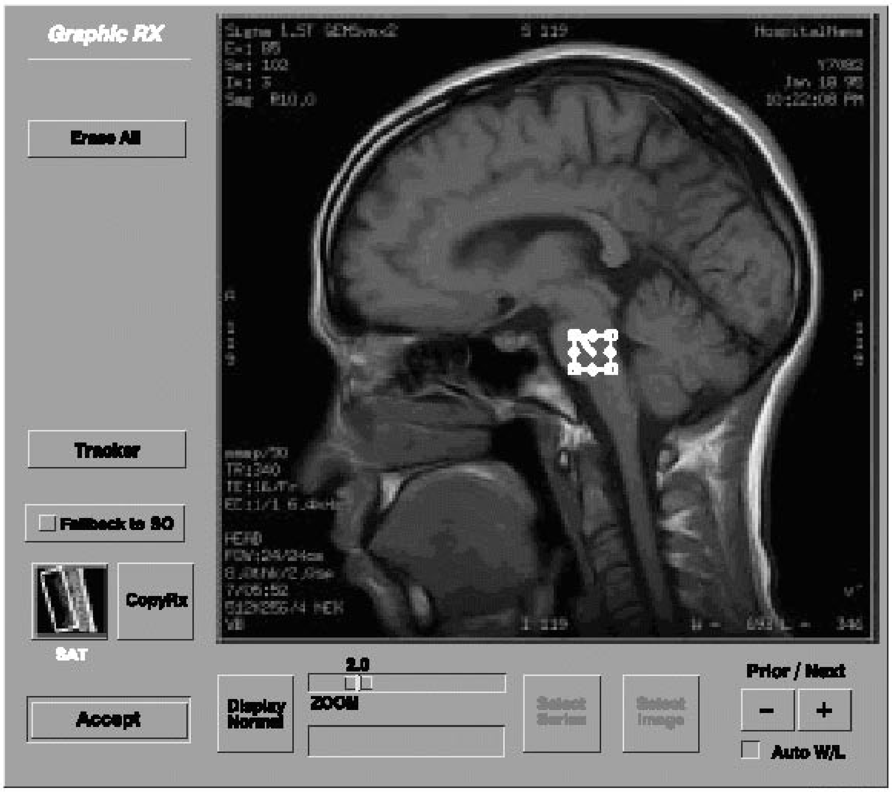
STEAM diagram

PROBE-P is a version of the PRESS (Point RESolved Spectroscopy) pulse sequence. It is a double spin echo sequence that uses one 90-degree and two 180-degree, slice selective RF pulses to generate a spin echo from a localized volume. The minimum echo time is increased relative to the PROBE-S sequence. The spin echo has twice the signal-to-noise ratio of the stimulated echo acquired with the PROBE-S sequence with identical acquisition parameters. It is sensitive to T_2 relaxation throughout the excitation.



PRESS diagram

Graphic ROI Prescription



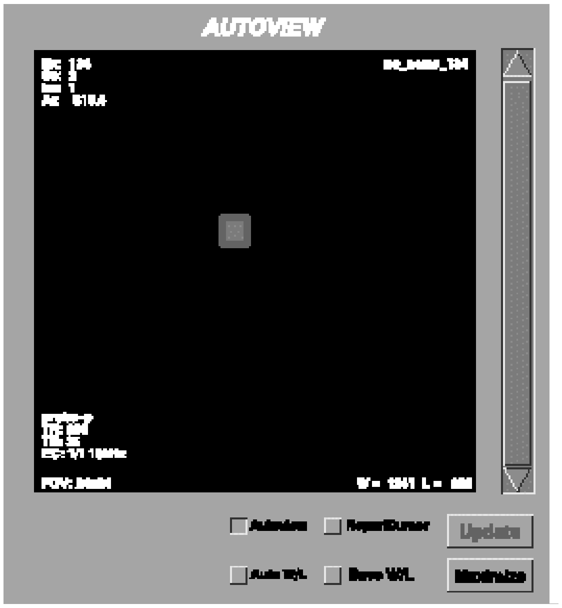
Graphic volume localization is a feature of the PROBE/SV package. PROBE-S and PROBE-P pulse sequences define the volume with three intersecting orthogonal slices. Placement of the volume is controlled with the Graphic Prescription tools by using one or more series of localizer images to guide the sizing and placement of the voxel or the volume of interest (VOI).

Scan Mode Selection

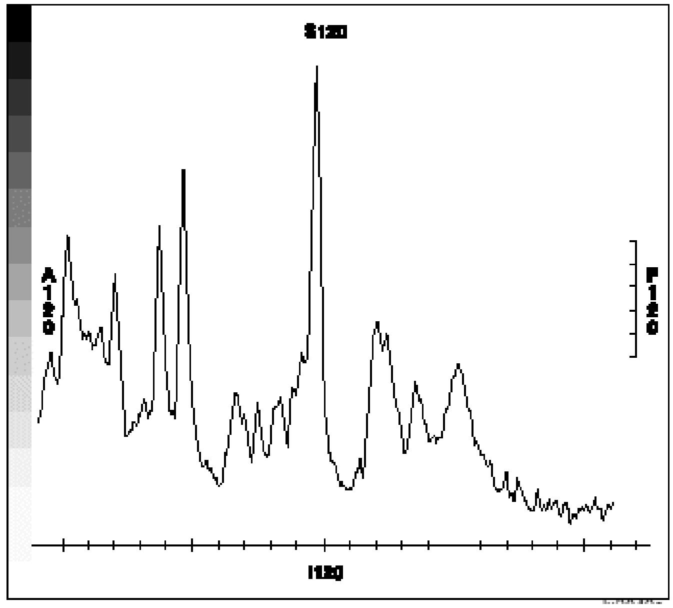
A User Control Variable screen appears with Probe/SV.

Function	Description
Scan Mode	Selects the voxel imaging mode (0) or spectrum acquisition mode (1).
Total number of scans	Determines the total number of water-suppressed excitations to acquire.

Both PROBE/SV pulse sequences have two user-selected modes of operation: a voxel imaging mode and a spectrum acquisition mode. The voxel imaging mode (scan mode = 0) acquires an image of the prescribed voxel. The image can be used to confirm the location of the voxel, to examine the shape and profile of the voxel, and to verify the absence of any fat contamination of the voxel. Useful voxels are placed close to the scalp.



A sample Scan Mode
(Scan Mode = 0)



A sample Spectrum Acquisition Mode
(Scan Mode = 1)

The total number of scans or averages can be thought of as the number of RF pulses delivered to the volume. The total number of scans divided by the NEX value determines the number of frames. To see a spectrum, the number of frames must be an even number.

Auto Prescan Description

The behavior of Auto Prescan depends on the scan mode selected. In the voxel imaging mode (scan mode = 0), Auto Prescan automatically adjusts the receive gains (R1 and R2), the transmit gain (TG), the center frequency (AX, DX), and a 3-plane autoshim for the prescribed volume of interest. In the spectrum acquisition mode (scan mode = 1), the receive gains, transmit gain, and center frequency are automatically adjusted, a 3-plane autoshim is executed for the prescribed volume of interest, and in addition, the flip angle of the third water suppression pulse is automatically adjusted for optimal water suppression. The presence of these features in Auto Prescan eliminates the time-consuming manual adjustment of homogeneity and the water suppression parameters.

Data Acquisition and Processing

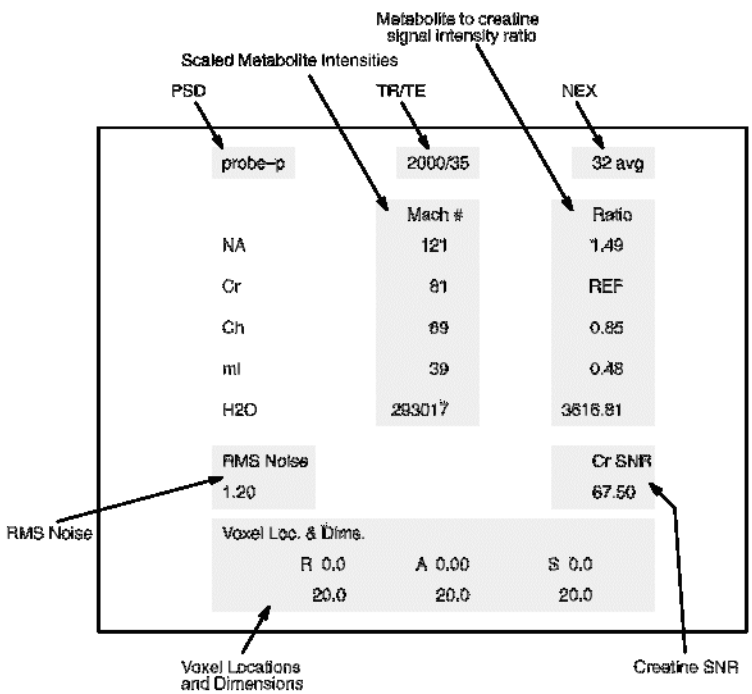
The raw spectroscopy data are processed to provide a single, phased spectrum that is displayed on the image screen and is stored in the patient data base.

Spectrum Display and Storage

PROBE/SV spectra are stored in the standard image format as 512x512 images in a separate series as part of the patient study. In the auto display mode, the spectra are displayed upon completion of data reconstruction. All image analysis features are available for use with the spectra. The PROBE/SV spectra cover a spectral window from 4.40 ppm (parts-per-million) to -0.60 ppm (relative to water at 4.75 ppm).

When the image from the Display Browser is selected, text is displayed in the upper right-hand corner of the screen over the PROBE/SV spectrum.

The PROBE/SV image display includes the name of the pulse sequence, acquisition parameters, voxel size and location, metabolite signal intensities, and metabolite to reference metabolite ratios.



Screen Notation	Description
Probe-P	Name of PSD used to acquire spectrum
2000/35	Repetition time (TR)/Echo Time (TE)
32 avg	Number of Excitations (NEX)
Mach #	Scaled metabolite intensities
Ratio	Metabolite to creatine signal intensity ratios
RMS Noise	RMS noise level
Cr SNR	Signal-to-Noise ratio (SNR) for creatine
Voxel Loc. & Dims	Voxel location and dimensions
R,A, S	Voxel locations

Machine #

The machine numbers (the column labeled, Mach. #) are scaled signal intensities calculated for spectral resonances associated with four major brain chemicals and water:

- N-acetyl residues (NA)
- creatine (Cr)
- choline (Ch)
- myo-Inositol (ml)
- water (H_20)

The signal intensities are scaled to be invariant with respect to the Signa system receive gains (R1 and R2). They are also invariant with respect to use of Extended Dynamic Range.

Ratio

The Ratio column lists the ratio of the signal intensity of a particular metabolite (and water) to the signal intensity of the reference metabolite, (the default metabolite is creatine). The item in the Ratio column used for the reference is always labelled REF.

Variations of Quant Table Information

The metabolite and water signals appear in a normal PROBE/SV spectrum at fixed resonance frequencies. If no signal is found in the appropriate frequency region, “Void” appears in the Mach. # and Ratio columns.

Similarly, if a signal does not meet the minimum Signal-to-Noise ratio (SNR) requirement of a 5-to-1 ratio, “Not Det or ???????” appears in each column and “Void” appears under the Ratio column.

NOTE: PROBE/SV data acquired on the LX system and then networked to a Genesis console (plasma screens) cannot be viewed. Quantified data is annotated as question marks (?) when displayed on the Genesis console. View and film PROBE/SV images and spectrum only from an LX console.

Prescribing a PROBE/SV Acquisition

A PROBE/SV exam begins with the acquisition of one or more localizer image scans, and continues through the imaging screens. Graphic ROI Prescription is recommended to guide the sizing and placement of the voxel.

Center Frequency (CF) differences and static shim offsets generates a predictable offset, or shift, of any two MR images. The CF and shim requirements for the small restricted volumes used in PROBE/SV can be quite different from the CF and shim values for the standard MR sequences generally used for PROBE/SV localizer series. In addition, the FOV center of the localizer is often not the area of interest for the PROBE/SV volume, and it is the FOV center that is used to determine the CF and shim values for the localizer series.

These differences can occasionally lead to volume prescription (Rx) errors when specifying the desired PROBE/SV volume. The resulting voxel volume is not in the prescribed location. This is especially true in volumes located far from isocenter and areas of large susceptibility changes, e.g., near the air-tissue interfaces such as the sinuses, at the base of the skull and areas of recent surgery.

To help offset these CF and shim differences, it may be helpful to run two Voxel Image Mode acquisitions prior to the Spectrum Acquisition Mode scan. Use the first voxel image to confirm the location of the volume. If an error is observed, adjust the volume location and acquire a second Voxel Image Mode acquisition. The second voxel image then has the correct CF and shim values for the subsequent spectrum acquisition.

Procedure

A voxel shift can occur when the voxel volume cursor is positioned over anatomy that is heterogeneous. To verify the location of the prescribed voxel volume relative to the anatomy use the following procedure:

1. Acquire a localizer scan.
2. Place the cursor on the localizer and press the left mouse button to deposit the voxel volume. Pick up the voxel volume and position it over the anatomy of interest.
3. Click **[Report Cursor]** from the Graphic Rx screen. Place the cursor over the center of the voxel volume and note the R/L, A/P and S/I mm locations.
4. Acquire an image in the voxel image mode (scan mode = 0).
5. Display the voxel image and click **[Report Cursor]** from the Auto View window. Place the cursor over the center of the voxel image and note the R/L, A/P and S/I mm locations.
6. Compare the cursor locations of the voxel volume and the voxel image. If the locations are significantly different, adjust the location of the voxel volume so that it matches the original location of the voxel volume.
7. Acquire a second voxel image, and from that image prescribe a spectrum (scan mode = 1).

This procedure is only for prescribing a spectroscopy scan from a localizer and not for reading the spectrum. A prerequisite for this data collection is the acquisition of one or more localizer images. For some PROBE/SV exams, more than one localizer scan plane may be advisable so the anatomy that is in the PROBE/SV voxel volume can be previewed. Remember that the PROBE/SV spectrum is generated from the intersection of three planes defined by the Graphic ROI. Carefully consider the interscan spacing of the localizer image — it should be relatively small.

When first using PROBE/SV, it may be advisable to:

- Film the localizer with the ROI in place.
- Acquire and film a voxel image.
- Acquire and film the spectrum information.

Something to Think About...

- Choice of TE, TR, voxel size, total number of scans and NEX affects the appearance of the spectra and SNR.
- For most applications PROBE-P is the preferred sequence because of its two-fold Signal-to-Noise advantage over PROBE-S.
- The PROBE-S sequence is most commonly prescribed with an echo time (TE) of 20 – 30 ms.

- For a study where the primary interest is choline, creatine, N-acetylaspartate and lactate, use PROBE-P with a long echo time (TE = 144) for inverted lactate peaks, or TE = 288 ms for fully refocused lactate peaks. For studies in which short T2 components are to be seen such as glutamine/glutamate and myo-Inositol, use PROBE-P with a short echo time (e.g., TE = 35 ms).
- Typical TRs, in spectrum acquisitions, can range from 1500 – 6000 milliseconds.
- Experience has shown that the following parameter selection delivers good signal-to-noise and a reasonable scan time: PROBE-P with TE = 35 ms, TR = 1500 ms, Voxel Size = 20 x 20 x 20 mm, total number of scans = 64 and NEX = 8 giving a total acquisition time of just 2 minutes, 6 seconds.
- The SNR of a spectrum increases with the square root of the number of excitations acquired from the voxel. To double the SNR, four times as many excitations must be acquired.
- A total of 64 excitations for PROBE-P and 128 excitations for PROBE-S should provide sufficient signal in a nominal 20 mm by 20 mm by 20 mm volume of interest in a human brain.
- The PROBE/SV data reconstruction process requires the acquisition of an even number of frames of data.
- The number of frames of data = (total number of scans entered on the CVs screen) /NEX (selected on the Acquisition Timing area).
- Prescribe a value that is not a multiple of 16 if the total number of frames of data is even.
- Two image mode acquisitions are recommended for volumes located far from isocenter and areas of large susceptibility changes, e.g., near the air-tissue interfaces such as the sinuses, at the base of the skull and areas of recent surgery. The second voxel image can be used to prescribe the spectrum mode volume to decrease the effects of voxel shift.

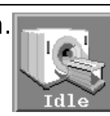
CAUTION: **Provide all patients with ear protection prior to any scan to help avoid possible hearing impairment.** Acoustic noise levels can exceed 99 dBA in the magnet bore.

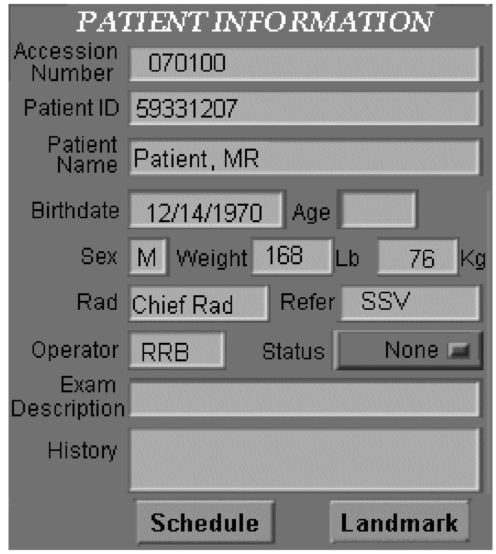
Setting up a PROBE/SV pulse sequence

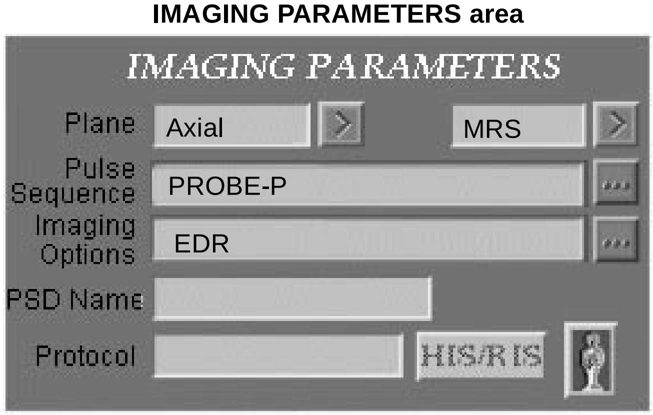
The decision matrix is only for prescribing a PROBE/SV scan. The purpose of the decision matrix to help you understand the trade-offs that occur when you change the values for a particular parameter and to provide a framework with which you may build you own unique protocol.

The selected values are only an example of what could be used for a PROBE/SV acquisition and are not to be considered recommendations by GE Medical Systems. For specific protocols, refer to the protocols on your system.

.

PROBE/SV - What you select	Selection Notes
SCAN DESKTOP screen	
	Select **Scan Desktop** icon. 

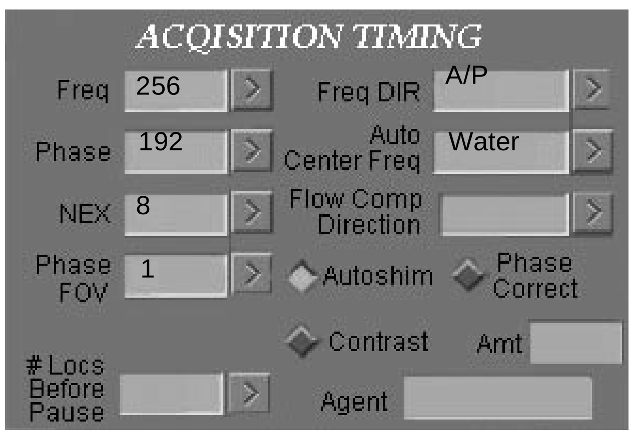
PROBE/SV - What you select		Selection Notes
		Click on **[New Patient]** and fill in the patient information. 
PATIENT POSITION area		
Patient Position	**[Supine]**	**Position and Entry:** PROBE/SV is most frequently used in neuro scanning, so the patient position and entry selections reflect that.
Patient Entry	**[Head First]**	
Coil	**[Head]**	**Coil:** Select the coil that produces the optimum coverage and SNR.
Series Description		**Series Description:** Enter a suitable series description. If you don not enter a description, the system enters one for you. The series description default is the selected scan mode, PSD, and imaging options.
IMAGING PARAMETERS area		



PROBE/SV - What you select		Selection Notes
Plane	**[Axial]**	**Plane:** PROBE/SV works with any scan plane except 3-Plane. Select a plane that matches the localizer scan. This is different from the normal prescription process. Typically, an axial from a sagittal or coronal is prescribed. With PROBE/SV, an axial from an axial localizer must be prescribed. If a sagittal or coronal that is already offset in the S/I direction is used, the system offsets the voxel based on an isocenter point of origin, not the actual location. The only way around this is to return to the landmark and prescribe from there.
Mode	**[MRS]**	**Mode:** Select [MRS].
Pulse Seq	**[PROBE-P]**	**Pulse Seq:** Select [PROBE-P] for a PRESS acquisition with is typically used with long TE (> 35 ms). Select [PROBE-S] for a STEAM acquisition which is typically used with a short TE (< 35 ms).
Imaging Options	**[EDR]**	**Imaging Options:** Use Extended Dynamic Range on all PROBE/SV scans. Click **[Accept]** to register the selections.
PSD Name	**N/A**	**PSD Name:** Not applicable for PROBE/SV.
Protocol	**N/A**	
SCAN TIMING area		
# of echoes	**[1]**	**# of echoes:** Only 1 echo is allowed.
TE	**[35]**	**TE:** If the scan mode = 0, (voxel image) select the shortest values for TR and TE. If the scan mode = 1 (spectrum), select the TE based on the pulse sequence: PROBE-S or PROBE-P. PROBE-S is typically used with a short TE (20 – 30 ms). Use PROBE-P TE (35 ms) with short T2 chemical species such as glutamate, glutamine, and glucose. PROBE-P is typically used with long TE (not less than 35 ms) for long T2 chemical species such as creatine, choline, and N-acetylaspartate.
TR	**[2000]**	**TR:** If the scan mode = 0, (voxel image) select the shortest values for TR and TE. TR: If the scan mode = 1, select a TR > 1200 ms. (typically 1500 – 2000 ms). The TR should ideally be 3 times as long as the T1 of the metabolite being imaged and long enough for good water suppression. If interested in quantitative data and the chemical species being imaged has a long T1, the longer the TR the better. As TR increases, scan time increases.
TI	**N/A**	
Flip Angle	**N/A**	
Echo Train Length	**N/A**	
Bandwidth	**N/A**	**Bandwidth:** The Receiver Bandwidth is automatically selected for PROBE/SV scans and cannot be programmed.

PROBE/SV - What you select		Selection Notes
Bandwidth 2	**N/A**	
	SCANNING RANGE area	
FOV	**[24]**	**FOV:** The minimum available FOV is displayed next to the text box. This is also the default FOV if the voxel is graphically prescribed without entering a value. It is recommended that a FOV as large as the localizer image's FOV be used.
Slice Thickness	**N/A**	**Slice Thickness:** Slice Thickness is not selectable.
Start, End Locations		**Start, End Locations:** A voxel volume can be explicitly prescribed by entering the patient coordinates. Enter three values, in millimeters, for the extent of the voxel along the S/I, A/P, and R/L directions. When entering the voxel center parameters, enter RAS locations as positive values and LPI locations as negative values. When prescribing the voxel explicitly, the voxel thickness must be at least 3 mm in the direction of the scan plane.

ACQUISITION TIMING area



Freq	**[256]**	**Freq:** The frequency values selected have no effect on the scan time or resolution.
Phase	**[192]**	**Phase:** The phase values selected have no effect on the scan time or resolution.

PROBE/SV - What you select		Selection Notes
NEX	**[8]**	**NEX:** The NEX value controls the number of phase cycles. In general, enter 8 which reduces motion and susceptibility artifacts more than 2 or 4 NEX. Phase cycling is the repetition of a pulse sequence and signal acquisition such that all acquisition parameters except the phase of the RF pulse (and, possibly, the receiver) remain unchanged from repetition to repetition. Only the RF phase is changed, or cycled, as the repetitions occur. Phase cycling suppresses, or eliminates, undesirable signals while taking advantage of the effects of signal averaging. In an example, using the two-phase cycling scheme, a pair of excitations is obtained by inverting the phase of the RF pulse of the second acquisition relative to the first, causing an inversion of the desired signal. The second acquisition is then subtracted from the first. The result is that the first signal and the inverted second signal are added together while RF errors independent of the phase of the RF are canceled by the subtraction.
Freq DIR	**[A/P]**	**Freq DIR:** Select the default value.
Auto Center Freq	**[Water]**	**Auto Center Freq:** Select [Water].
Flow Comp DIR	**N/A**	
Autoshim	**[On]**	**Autoshim:** Select Autoshim to make the volume of interest as homogeneous as possible.
Phase Correct	**N/A**	
GRAPHIC RX Screen		

<table>
<tr><th colspan="2">PROBE/SV - What you select</th><th>Selection Notes</th></tr>
<tr><td colspan="2"></td><td>Enter the in-plane thickness/location in the scan-location boxes located on the Scanning Range area. If a value is not entered before graphically prescribing the voxel volume, the voxel thickness in the slice direction defaults to the slice thickness of the localizer image.

Size and move the cursor over the anatomy of interest and [Accept].

Grab the adjustment handle to re-size or move the voxel volume. Click and drag the mouse to deposit the voxel volume at the new location.

Click [Erase] to eliminate the voxel volume from the screen and start over.

A typical voxel volume is 20 mm x 20 mm x 20 mm. Best results are obtained if the voxel is placed in a region that is easy to shim (i.e., not close to the sinuses or near the base of the brain).

The chemical composition of the brain varies from region to region; pay close attention to where the voxel is positioned.

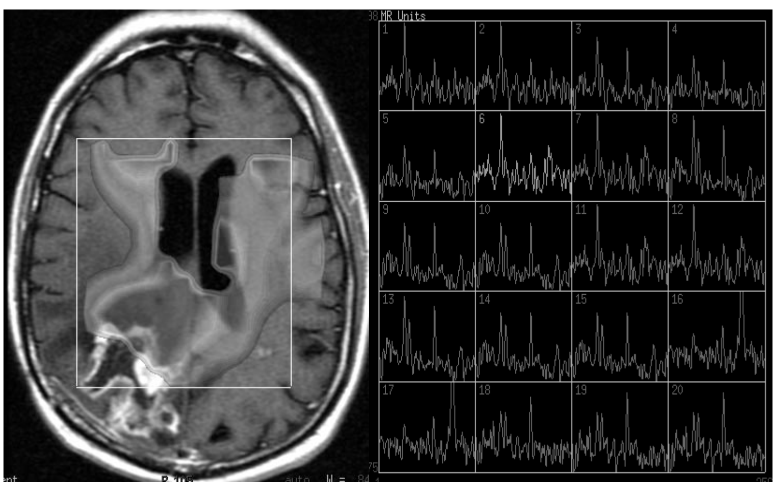
Consider placing the voxel in the same relative position for patient-to-patient or time course comparisons.</td></tr>
<tr><td colspan="3">PROBE/SV CVs Screen</td></tr>
<tr><td>Scan Mode</td><td>[1]</td><td>Scan Mode: Enter a scan mode of 0 for the voxel imaging mode or 1 for the spectroscopy acquisition mode.</td></tr>
<tr><td>Total # of scans</td><td>[64] PROBE-P
[128] PROBE-S</td><td>Total # of scans: the number of scans must be a multiple of the selected NEX. The total number of scans or averages can be thought of as the number of RF pulses delivered to the volume. Increase the total # of scans or averages and the SNR increases (by the square root) and the scan time increases (directly) when in the spectrum acquisition mode.</td></tr>
<tr><td colspan="3">SCAN OPERATIONS area</td></tr>
</table>

PROBE/SV - What you select	Selection Notes
[Save Series] **[Prep to Scan]** **[Auto Prescan]** **[Scan]**	Click [Save Series], [Prepare to Scan], [Auto Prescan]. Auto prescan completes the following: • Sets the TG, RG, CF. • Gradient field offsets for increased homogeneity. • Flip angle of third water suppression pulse is adjusted. If Auto Prescan is successful, that is, if the FWHM is less than or equal to 4 Hz, then Click [Scan]. If it is greater than 4 Hz then repeat Auto Prescan 1 – 2 times or try repositioning the voxel volume to a more homogeneous anatomy and repeat Auto Prescan. If the FWHM is still greater than 4 Hz the scan may result in an unusable spectrum — the peaks are likely be broader than normal. Auto Prescan can fail if the voxel volume is comprised of too varied anatomy. If auto prescan fails, it is most likely due to the placement of the voxel volume. Try repositioning the voxel volume to a more homogeneous anatomy and Click [Auto Prescan] again.

Spectroscopy Multi-Voxel (Probe-SI)

Probe-SI is a purchasable option available if you have the PROBE/SV package.

ProbeSI is an image-guided, clinical spectroscopy software that permits the acquisition of chemical shift images from a volume prescribed during the Graphic Rx procedure. A 512x512 image comprised of an array of two-hundred fifty-six, 32x32 chemical shift images, is displayed in the Auto View window. This image can be displayed and filmed from the Display Browser. The spectra and metabolic images are displayed in FuncTool.



PROBE-P and probeSI are versions of the PRESS (Point RESolved Spectroscopy) pulse sequence.

ProbeSI employs the same Chemical Shift Imaging strategy as single voxel spectroscopy. Long echo time (either 144 or 288 ms) spectra can be acquired from a number of voxels within a PRESS volume. Typical examination times range from 3 to 15 minutes.

The spectra and metabolic images are displayed in FuncTool where the system can quantify the signal intensities of water, N-Acetyl residues (NA), Creatine (Cr), Choline (Cho), and myo-Inositol (mI). In addition the SNR relative to Creatine is calculated along with certain metabolite ratios including NA-to-Cr, Cho-to-Cr, and mI-to-Cr.

NOTE: See Functool chapter for more information on how the metabolic images are displayed.

Something to Think About...

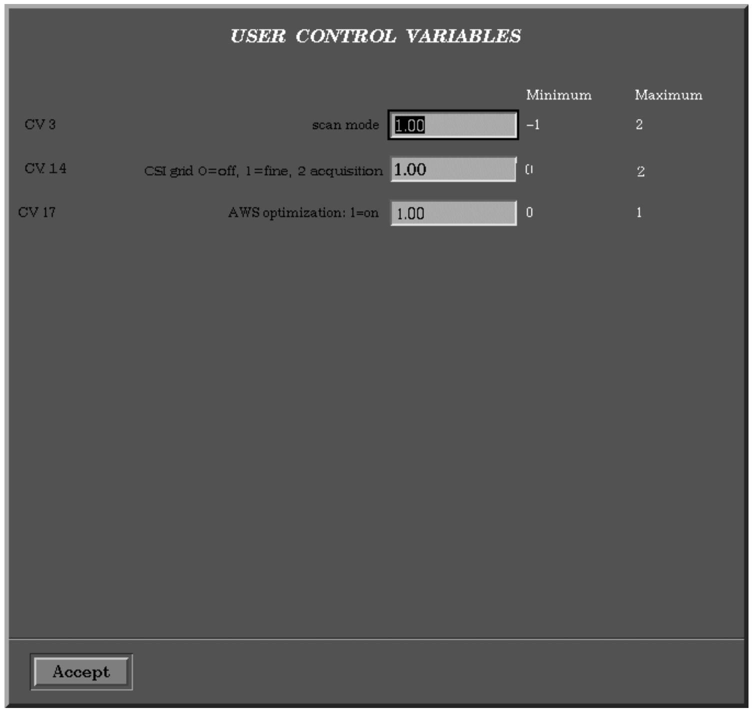
- Choice of TE, TR, the prescribed volume, the Phase, and NEX affects the SNR and spectral resolution.
- Acquisition time increases as TR, NEX, and Phase increase. For a one second TR and NEX = 1, scan times are the following:
- 2:28 for a 12 phase selection
- 4:20 for a 16 phase selection
- 9:40 for a 24 phase selection
- A typical slice thickness for a probeSI volume is 10 to 15 mm.
- The probeSI volume should be located completely within the brain. In particular, the corners and the edges of the prescribed ROI should not touch the scalp; this also applies to the anatomy above and below the ROI. The volume should not include any of the scalp.

PROBE SI User CV

There are three PROBE SI User CVs:

- Scan Mode
- CSI grid

- AWS optimization



Scan Mode "`0`" results in an image of the Graphic Rx ROI. Scan Mode "`1`" results in the acquisition of chemical shift images form the prescribed FOV. The spectra are displayed with the FuncTool program.

CSI grid has three options 0 - 2. Selecting "`0`" results in this feature being off, and no grid is displayed. Selecting "`1`" displays a 32x32 grid that represents the final reconstructed matrix size. Option "`2`" displays a grid size determined by the phase value programmed from the Acquisition Timing area. FOV/phase value = size of individual voxel within the Graphic Rx ROI. Phase value choices include 12, 16, or 24. Use this grid option to visualize the placement of voxels in relationship to the anatomy. For example, smaller grids result in a larger voxel which may not be best when each voxel is comprised of quite varied tissue. It is difficult for the system to achieve optimum shim values for larger voxels. As the voxel volume increases the spectral resolution decreases.

AWS Optimization = "`0`" uses predefined water suppression parameters during scan. This eliminates the water suppression program in prescan and thus reduces prescan time. Enter AWS Optimization = "`1`" if your experience indicates that water is better suppressed with the Auto Prescan optimization process.

Something to Think About...

- Much shorter TRs can be used when Scan Mode is set to `0`. Therefore, to select a shorter TR in the scan prescription, first click the User CV, and set the Scan Mode to `0`, before prescribing the shorter TR.
- If the spectrum demonstrates too much water, enter `1` for AWS.

CAUTION: **Provide all patients with ear protection prior to any scan to help avoid possible hearing impairment.** Acoustic noise levels can exceed 99 dBA in the magnet bore.

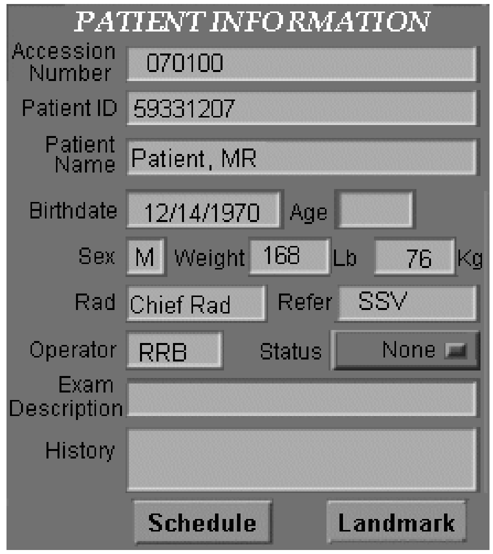
Setting up a PROBE/SI pulse sequence

This procedure is only for prescribing a spectroscopy scan from a localizer and not for displaying the spectra. A prerequisite for this data collection is the acquisition of one or more localizer images. For some probeSI exams, more than one localizer scan plane may be needed in order to preview the anatomy that is in the probeSI volume. Remember that the probeSI volume is generated from the intersection of three planes defined by the Graphic ROI. Carefully consider the interscan spacing of the localizer image — it should be relatively small.

The selected values are only an example of what could be used for a PROBE/SI acquisition and are not to be considered recommendations by GE Medical Systems.

.

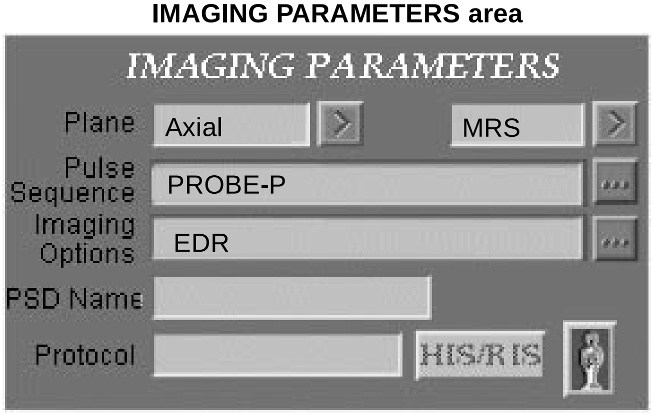
PROBE/SI - What you select	Selection Notes
SCAN DESKTOP screen	
	Select **Scan Desktop** icon. 

PROBE/SI - What you select		Selection Notes
		Click on **[New Patient]** and fill in the patient information. 

PATIENT POSITION area

Patient Position	**[Supine]**	**Position and Entry:** PROBE/SI is most frequently used in neuro scanning, so the patient position and entry selections reflect that.
Patient Entry	**[Head First]**	
Coil	**[Head]**	**Coil:** Select the coil that produces the optimum coverage and SNR.
Series Description		**Series Description:** Enter a suitable series description. If you don not enter a description, the system enters one for you. The series description default is the selected scan mode, PSD, and imaging options.

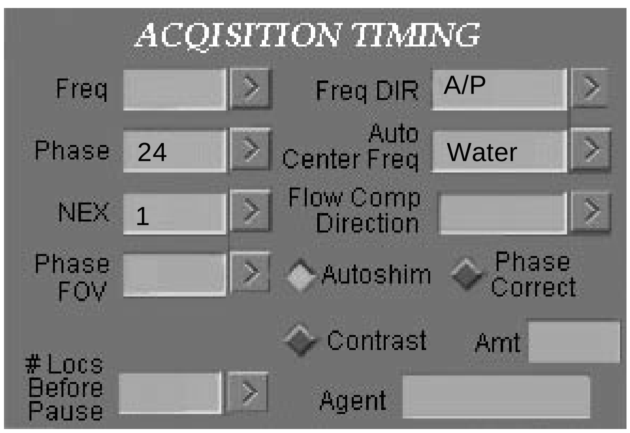
IMAGING PARAMETERS area



PROBE/SI - What you select		Selection Notes
Plane	**[Axial]**	**Plane:** PROBE/SI is compatible with any orthogonal scan plane except 3-Plane; select a plane that matches the localizer scan. **This is different from the normal prescription process.** Typically, an axial is prescribed from a sagittal or coronal. With probeSI, an axial must be prescribed from an axial localizer.
Mode	**[MRS]**	**Mode:** Select [MRS].
Pulse Seq	**[PROBE-P]**	**Pulse Seq:** Select [PROBE-P].
Imaging Options	**[EDR]**	**Imaging Options:** Use Extended Dynamic Range on all PROBE scans. Click **[Accept]** to register the selections.
PSD Name	**probeSI**	**PSD Name:** Enter the name “probeSI” to activate the multi-voxel acquisition. It is case sensitive.
Protocol	**N/A**	
SCAN TIMING area		
# of echoes	**[1]**	**# of echoes:** Only 1 echo is allowed.
TE	**[144]**	**TE:** If the scan mode = 1 (spectrum), select a recommended TE of 144 or 288. As in all other MR scans, the longer the TE, the less the SNR. A TE of 144 ms inverts the lactate peak; the lactate peak is not inverted with a TE of 288 ms. If the scan mode = 0 (voxel image), select the shortest values for TE.
TR	**[1000]**	**TR:** If the scan mode = 1, select a typical TR of 1000 ms. A longer TR results in increased SNR at the expense of increased scan time. If the scan mode = 0, (voxel image) select the shortest allowed values for TR.
TI	**N/A**	
Flip Angle	**N/A**	
Echo Train Length	**N/A**	
Bandwidth	**N/A**	**Bandwidth:** The Receiver Bandwidth is automatically selected for PROBE/SI scans and cannot be programmed.
Bandwidth 2	**N/A**	
SCANNING RANGE area		
FOV	**[24]**	**FOV:** The minimum available FOV is displayed next to the text box. This is also the default FOV if the voxel is graphically prescribed without entering a value. It is recommended that a FOV as large as the localizer image’s FOV be used.
Slice Thickness	**N/A**	**Slice Thickness:** Slice Thickness is not selectable. The slice thickness is determined by the start and end location entries.

PROBE/SI - What you select	Selection Notes
Start, End Locations	**Start, End Locations:** The slice thickness is determined by the start and end location entries. The system defaults to the slice thickness of the localizer - typically change this to a slice thickness of 10-15 mm. **1.** Scroll through the localizer images to find the slice that best represents the center of the desired 10-15 mm thick spectroscopy slice. **2.** Position the ROI and Click **[Accept]**. **3.** Type in the start/end location entries using a 10-15 mm span that is centered on the image location you selected in step 1.

ACQUISITION TIMING area



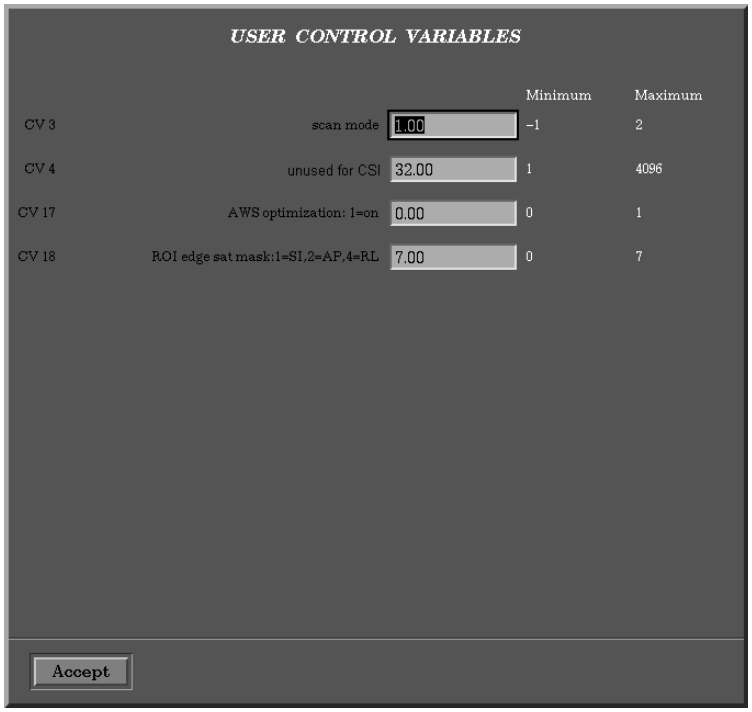
Freq	**N/A**	
Phase	**[24]**	**Phase:** ProbeSI matrix choices are 12, 16, and 24. These phase choices correspond to 12x12, 16x16, and 24x24 matrices. The value is entered in the phase text box. As the phase value increases, the spectral resolution increases and the scan time increases. Therefore, only select 12 to sacrifice spectral resolution for scan speed. The FOV divided by the phase value determines the CSI grid cell size.
NEX	**[1]**	**NEX:** As the NEX value increases, the SNR increases and the scan time increases.
Freq DIR	**[A/P]**	**Freq DIR:** Select the default value.
Auto Center Freq	**[Water]**	**Auto Center Freq:** Select [Water].
Flow Comp DIR	**N/A**	

PROBE/SI - What you select		Selection Notes
Autoshim	**[On]**	**Autoshim:** Select Autoshim to make the volume of interest as homogeneous as possible.
Phase Correct	**N/A**	
	GRAPHIC RX Screen	
		To view a grid overlay, select the User CV screen and chose1or 2. Click on the image to display the voxel for Graphic Rx. Size and move the voxel over the anatomy of interest and click **Accept**. Click on the adjustment handle to re-size or move the voxel volume. Click and drag the mouse to deposit the voxel volume at a new location. The voxel size and position are determined by the anatomy and pathology to be viewed. Best results are obtained if the voxel is placed in a region that is easy to shim (i. e., not close to the sinuses, or near the base of the brain, or near the scalp). Click **[Accept]** to accept the cursor position and exit Graphic Rx. Click **[Erase]** to eliminate the voxel volume from the screen and start over.
	User CV Screen	
Scan Mode	**[1]**	**Scan Mode:** Select a scan mode of 0 for the voxel imaging mode or 1 for the spectroscopy acquisition mode.
CSI Grid	**[1]**	**CSI Grid:** Select a grid option: 0 for off, 1 for fine (reconstructed matrix of 32x32), and 2 for acquisition matrix (grid cell determined by FOV/phase value).
AWS Optimization	**[0]**	**AWS Optimization:** Enter 0 for AWS to use predefined water suppression parameters during scan. This eliminates the water suppression program in prescan and thus reduces pres-can time. Enter 1 for AWS if your experience indicates the water is better suppressed in comparison with AWS = 0.
	SCAN OPERATIONS area	
	[Save Series] **[Prep to Scan]** **[Auto Prescan]** **[Scan]**	Click **Save Series**. Click **Prepare to Scan** Click **Auto Prescan**. Auto prescan completes the following: • sets the TG, RG, and CF; • determines the gradient field offsets for increased homogeneity; • determines the flip angle of third water suppression pulse when AWS = 1. Click **Scan**.

3D Focal CSI

3D Focal CSI has four options presented under the User CV menu. They are:

- scan Mode,
- total number of scans,
- AWS optimimization, and
- ROI edge sat mask.



Scan Modes allows for four choices, two imaging modes (-1 and 0) and two spectroscopy modes (1 and 2).

- Scan Mode = -1 scans and displays an image of the slice centered within the voxel with narrow Sat bands placed at the edges of the prescribed voxel. This image clearly shows the location of the voxel in reference to the entire slice and can be used to confirm the location of the voxel. Reduce the TR and TE to reduce the scan time.
- Scan Mode = 0 scans and displays an image of the voxel. This displays only the signal from the prescribed volume. Reduce the TR and TE to reduce the scan time.
- Scan Mode = 1 reconstructs the chemical shift images centered on the localizer images within the 3D volume. The spectra will be at the exact locations as the localizer images. When using the CSI display tool, the overlay

localizer images are the **exact** matches to the metabolic images. This is the default mode.

- ° Scan Mode = 2 acquires chemical shift images with the prescribed number of phase encoding steps, center spacing, and locs per slab. When displayed, the overlay localizer image is the **closest** match to the metabolic image.

Something to Think About...

- If match is not exact a message appears in the Functool command window stating "Not a perfect match."
- If User CV 15 steady state appears on the User CVs window, select one and continue to scan. Notify the service engineer the system needs calibration.

NOTE: Total number of Scans is not used it is displayed as Unused for CSI.

CSI Grid allows a grid to be displayed over an image, three choices are available for this option.

- ° CSI Grid = `0` grid allows for no grid display
- ° CSI Grid = `1` fine grid allows for a reconstructed matrix 32 x 32 grid, which represents zero-fill.
- ° CSI Grid = `2` grid displays a grid that is determined by the acquisition matrix. FOV/phase matrix.

AWS Optimization is Automatic Water Suppression. This option only presents two choices off = `0` and on = `1`. The default and recommended value is `0`. The prescan time is decreased with AWS off. Only turn this option on if you know from past experience that the default water suppression is not acceptable or if you wish to us the optimization portion of the Auto Prescan process.

ROI edge sat mask enables the placement of Very Selective SAT bands around the VOI. Select one of the following:

Selection	***Sat Band Placement***
0	Off (no SAT bands)
1	Superior (S) and Inferior (I)
2	Anterior (A) and Posterior (P)
3	S/I and A/P
4	Right (R) and Left (L)
5	R/L and S/I
6	R/L and A/P

Selection	***Sat Band Placement***
7	R/L and A/P and S/I

Something to Think About...

- Minimize the time between the localizer scan and the spectroscopy acquisition to decrease chances of patient movement and to ensure accurate position.
- Because of sequence dependencies, it is best to prescribe a 3D CSI examination by selecting (in this order) **Locs per slab**, **frequency matrix**, and **phase matrix** before selecting any other values on the scan desktop. Similarly, you should choose the voxel thickness value before entering the Graphic Rx window.
- Up to four saturation bands can be selected for a scan prescription when the default saturation bands are in use. When more than four are selected, there is not enough time available for all the requested saturation bands. When this condition is detected by the system, the default saturation bands are deleted in deference to the explicitly prescribed sat bands. The S/I bands are deleted first, followed by the A/P bands, and then the R/L default saturation bands.
- If you copy and paste a PROBE/SV sequence and adapt to scan a 3D Focal CSI sequence, note when selecting the Locs per slab an advisory window appears with the frequency matrix selection. Selecting [Accept] places this value into the frequency matrix text box. Remember to change the Locs per slab to the desired value.
- Homogeneity is more critical than water suppression to obtain a successful CSI acquisition. The linewidth should not be greater than 15. If the linewidth is greater that 15 try one or more of the following:
  - Make the voxel smaller.
  - Move the voxel to avoid regions of large susceptibility change.
  - Move the voxel to avoid anatomy known to cause linewidth problems.
  - Move the voxel to avoid disease regions (hemorrhage) that are known to cause linewidth problems.

- The suppression level (Supp Lvl) percentage, shown on the Advisory Panel, should be between 95-99%. If the value is less than 95% run prescan again, if the value is still low you may need to reposition your voxel over more homogeneous anatomy.
- Upon scan completion, a number Chemical Shift storage images appear in the AutoView window. Each one of these CSI storage slices contains a collection of frequency specific data centered at the stated slice location.

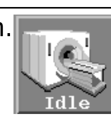
CAUTION: **Provide all patients with ear protection prior to any scan to help avoid possible hearing impairment.** Acoustic noise levels can exceed 99 dBA in the magnet bore.

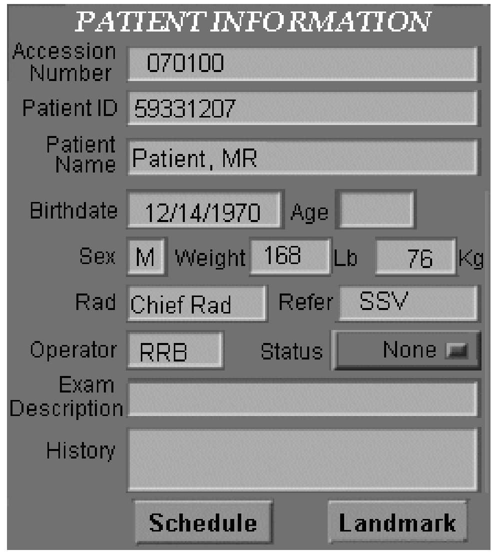
Setting up a 3D Focal CSI pulse sequence

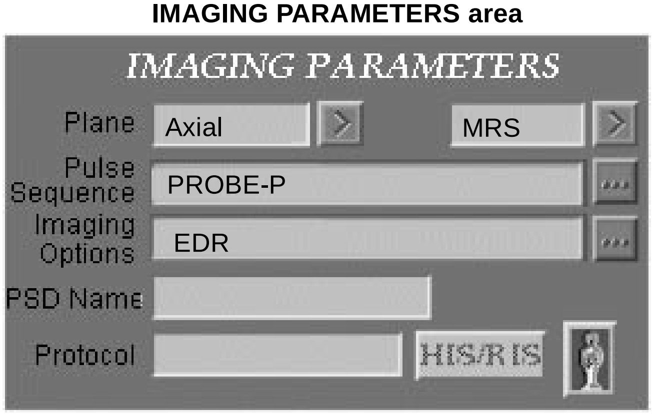
This procedure is only for prescribing a spectroscopy scan from a localizer and not for displaying the spectra. A prerequisite for this data collection is the acquisition of one or more localizer images. Carefully consider the interscan spacing of the localizer image — it should be relatively small.

The selected values are only an example of what could be used for a 3D Focal CSI acquisition and are not to be considered recommendations by GE Medical Systems.

.

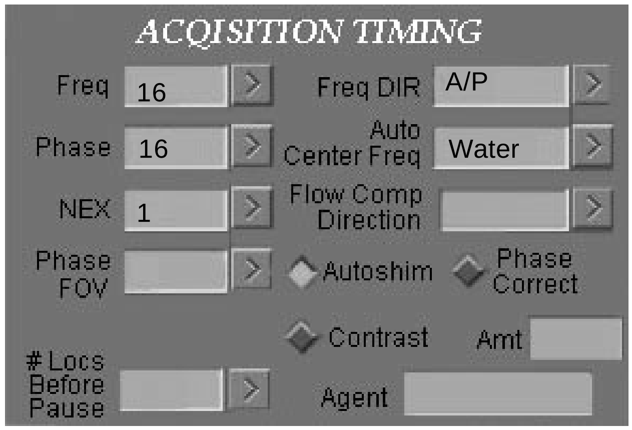
3D Focal CSI - What you select	Selection Notes
SCAN DESKTOP screen	
	Select **Scan Desktop** icon. 

3D Focal CSI - What you select	Selection Notes
	Click on **[New Patient]** and fill in the patient information. 
PATIENT POSITION area	
Patient Position **[Supine]**	**Position and Entry:** 3D Focal CSI is most frequently used in neuro scanning, so the patient position and entry selections reflect that.
Patient Entry **[Head First]**	
Coil **[Head]**	**Coil:** Select the coil that produces the optimum coverage and SNR.
Series Description	**Series Description:** Enter a suitable series description. If you don not enter a description, the system enters one for you. The series description default is the selected scan mode, PSD, and imaging options.
IMAGING PARAMETERS area	



3D Focal CSI - What you select		Selection Notes
Plane	**[Axial]**	**Plane:** 3D Focal CSI is compatible with any scan plane including oblique and 3-Plane localizers; select the same plane as the localizer scan plane. This is different from the normal prescription process. Typically, an axial is prescribed from a sagittal or coronal. With probe, an axial must be prescribed from an axial localizer.
Mode	**[MRS]**	**Mode:** Select [MRS].
Pulse Seq	**[PROBE-P]**	**Pulse Seq:** Select [PROBE-P].
Imaging Options	**[EDR]**	**Imaging Options:** Use Extended Dynamic Range on all PROBE scans. Click **[Accept]** to register the selections.
SCAN TIMING area		
# of echoes	**[1]**	**# of echoes:** Only 1 echo is allowed.
TE	**[144]**	**TE:** In the spectroscopy acquisition modes (1 or 2), select a recommended TE of 144, or 288. As in all other MR scans, the longer the TE, the less the SNR. With a TE 144ms the lactate peak is exactly inverted; at TE 288ms the lactate peak is not inverted.
TR	**[1000]**	**TR:** If the scan mode = 1, select a typical TR of 1000 ms. A longer TR results in increased SNR at the expense of increased scan time. If the scan mode = 0, (voxel image) select the shortest allowed values for TR.
TI	**N/A**	
Flip Angle	**N/A**	
Echo Train Length	**N/A**	
Bandwidth	**N/A**	**Bandwidth:** The Receiver Bandwidth is automatically selected for probe scans and cannot be programmed.
Bandwidth 2	**N/A**	
SCANNING RANGE area		
FOV	**[24]**	**FOV:** Choose the same FOV as the localizer image.
Voxel Thickness	**[50]**	**Voxel Thickness:** Choose a voxel thickness large enough to cover the anatomy or pathology. The lower limit is 3mm and the upper limit is 100mm.
Locs per Slab	**[8-16]**	**Locs per Slab:** Choose the number of locations per slab. For 3D Focal CSI, acceptable values are even numbers from 8 to 16.
Spacing	**Desired Choice**	**Spacing:** Selecting the Locs per slab before Spacing allows for more Spacing choices

3D Focal CSI - What you select		Selection Notes
ACQUISITION TIMING area		



Freq	**[8-16]**	**Frequency**: Choose the frequency matrix. Acceptable values are even numbers 8-16. As the frequency value increases, the spatial resolution increases and the scan time increases. The FOV divided by the frequency value determines the CSI grid cell size in the frequency dimension.
Phase	**[8-16]**	**Phase:** Choose the phase matrix. Acceptable values are even numbers 8-16. As the phase value increases, the spatial resolution increases and the scan time increases. The FOV divided by the phase value determines the CSI grid cell size in the phase dimension.
NEX	**[1]**	**NEX:** As the NEX value increases, the SNR increases and the scan time increases.
Freq DIR	**[A/P]**	**Freq DIR:** Select the default value.
Auto Center Freq	**[Water]**	**Auto Center Freq:** Select [Water].
Flow Comp DIR	**N/A**	
Autoshim	**[On]**	**Autoshim:** Select Autoshim to make the volume of interest as homogeneous as possible.
Phase Correct	**N/A**	
GRAPHIC RX Screen		

3D Focal CSI - What you select		Selection Notes
		Click on the image to display the voxel for Graphic Rx. Click on the adjustment handle to re-size. Drag the voxel ROI to deposit at desired location. Position the voxel for the anatomy and pathology. Click **[Accept]**. Click **[+]** and **[-]**. To page through the localizer images to check the position of the voxel. The center of the voxel will be the center image of the localizer series, which is the first image that appears when you enter Graphic Rx. Click **[Reset Center]**. (If Necessary.) To change the center of the voxel prescription to the desired image location. If you Reset Center a message appears on the left side of the Graphic Rx window. Click **[Erase]** to eliminate the voxel volume from the screen and start over.
User CV Screen		
Scan Mode	**[1]**	**Scan Mode:** Select a scan mode of -1 to acquire an image of the slice centered within the voxel with sat bands at edges, 0 for the voxel imaging mode, 1 to reconstruct the CSI images on the exact centers of the localizer images (this is the default mode), or 2 to acquire and reconstruct the CSI images as prescribed.
Total number of scans	**Default**	**Total number of scans:** Unused for CSI.
Steady State	**[0]**	**Steady State:** Continue to scan, contact service engineer to calibrate system.
CSI Grid	**[1]**	**CSI Grid:** Enter a grid option: 0 for off, 1 for fine (reconstructed matrix of 32x32), and 2 for acquisition matrix (grid cell determined by FOV/phase value).
AWS Optimization	**[0]**	**AWS Optimization:** Enter 0 for AWS to use predefined water suppression parameters during scan. This eliminates the water suppression program in prescan and thus reduces prescan time. Enter 1 for AWS if your experience indicates the water is better suppressed in comparison with AWS = 0.
SCAN OPERATIONS area		

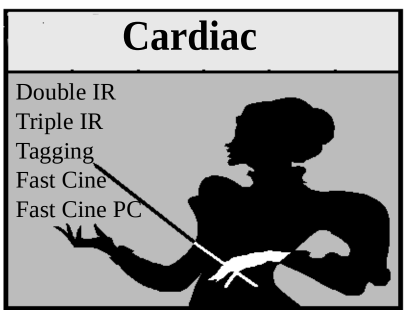
3D Focal CSI - What you select	Selection Notes
[Save Series] **[Prep to Scan]** **[Auto Prescan]** **[Scan]**	Click **Save Series**. Click **Prepare to Scan** Click **Auto Prescan**. Auto prescan completes the following: • sets the TG, RG, and CF; • determines the gradient field offsets for increased homogeneity; • determines the flip angle of third water suppression pulse when AWS = 1. Click **Scan**.

Volume 2

Chapter 13

Imaging with Cardiac Pulse Sequences

Where Am I?



Introduction

This chapter explains the pulsing components and timing factors directly related to the Cardiac pulse sequences. This chapter explains the concepts of each, and the step-by-step instructions to help you learn how to:

- Optimize FSE-XL with Blood Suppression images
- Optimize FSE-XL IR with Blood Suppression images
- Optimize Fast Cine and Fast Cine PC images
- Optimize Tagging images

In addition, this chapter answers the following questions:

1. What are the pulsing components and timing factors for Double and Triple IR sequences?

2. What is the meant by tagging?

3. When would you use Fast Cine vs Fast Cine PC pulse sequence?

About... Cardiac Pulse Sequences

This section presents the concepts necessary to understand the Cardiac pulse sequences. Specifically you need to understand:

- Cardiac Introduction
- FSE-XL with Blood Suppression (Double IR)
  - Associated imaging options
  - Applications for Double IR
- FSE-XL IR with Blood Suppression (Triple IR)
  - Associated imaging options
  - Applications for Triple IR
- Fast Cine and Fast Cine PC
  - Associated imaging options
  - Applications for Fast Cine and Fast Cine PC
- Manual Arrhythmia Monitoring
  - Trigger Type
  - Arrhythmia Rejection Window
  - Number of Phases to Reconstruct
  - Views per Segment
- Respiratory Gating with FastCine/FastCine PC
- Tagging
  - Associated imaging options
  - Applications for Tagging

Cardiac Introduction

The 8.3 Cardiac Pulse Sequence package is a purchase option that does not require purchase of additional hardware for the Signa® MR/i or Signa® LX system (except Base SR20 systems). The following cardiac features are provided with the package:

- Blood Suppressed FSE-XL and FSE-XL-IR (Fast Spin Echo-XL and Fast Spin Echo-XL with Inversion Recovery);
- FASTCINE and FASTCINE-PC pulse sequences; and
- Cardiac Tagging for FASTCINE-GRE and FastCard-GRE.

This package is available for use with the Signa MR/*i* or Signa Horizon LX MRI system (except Base SR20 systems).

Use of the Cardiac Pulse Sequences on Signa MR/*i* and Signa LX systems requires a thorough understanding of the safety information provided in volume 1 chapter 1 of this guide.

Review the procedures and safety precautions periodically.

FSE-XL with Blood Suppression

FSE-XL with Blood Suppression (also known as Double-IR FSE) uses a double inversion recovery (IR) preparation pulse. After the ECG trigger is detected, a non-slice-selective IR pulse inverts all spins in the body, including blood. A second, slice-selective IR pulse is immediately applied, re-inverting spins in the image slice. At this point, magnetization within the slice is essentially unchanged, as compared to the state of the spins prior to the initial whole body IR pulse.

A delay time, seen as [BSP TI] on the Scan Timing area, is programmed. This delay time is equal to the time required to allow inverted blood spins to reach the null point, about 650ms with a 60 bpm heart rate, at both1.5T and 1.0T. The BSP TI time occurs during the systolic portion of the cardiac cycle, resulting in a "wash-in" and "wash-out" of blood; the nulled blood flows into the imaging slice, while the blood in the slice during the slice re-inversion IR pulse exits. After the BSP TI time, the FSE-XL sequence is initiated and image data is acquired as in any FSE-XL acquisition.

The [Auto] BSP TI selection is calculated to obtain maximum blood suppression. The calculation is based on the patient's heart rate. If the calculated value is too high for selected scan parameters, a message is posted stating that the BSP TI must be decreased. You can alter the following scan parameters as shown, to allow the calculated BSP TI to be accepted: increase the [Receive Bandwidth], decrease the [ETL], and/or decrease the [Trigger Window].

Something to Think About...

- You must select the pulse sequence and type in "`fse-xl`" before selecting [Blood Suppression] or the system posts a compatibility error message.
- On the Cardiac Gating/Triggering screen, 2xRR is the default for [# of RR Intervals]. Note that there are additional parameters, which must be selected on this

screen for cardiac gating/triggering. See the gating and triggering chapter for more detail.

- The recommended TE value for Blood Suppression is 40ms. It has been observed that setting the TE to 40ms is likely to reduce flow-related artifact, thus optimizing image quality. The recommended Blood Suppression TE value is the same on both 1.5T and 1.0T.
- Phase Correction is recommended. Phase Correction is now performed following prescan and does not add to the total scan time.

Associated Imaging Options

In the following table the X's indicate the option available for use with the FSE-XL with Blood Suppression (Double IR) pulse sequences.

Imaging Options			
X	None	**X**	Variable Bandwidth
X	Flow Compensation	**X**	No Phase Wrap
	POMP	**X**	Extended Dynamic Range
	Square Pixel		Surface Coil Intensity Correction
	Respiratory Compensation		Classic
	Magnetization Transfer	**X**	Sequential
X	Cardiac Gating/Triggering		Respiratory Gating/Triggering
	Tailored RF		IR Prepared
	DE Prepared		Multi-Phase
	Full Echo Train		CCOMP
	ZIP 1024		ZIP 512
	Zip x 2		ZIP x 4
	SmartPrep	**X**	Blood Suppression
	Multi Station		Real Time

Applications

Visualization of cardiac anatomy and myocardial wall masses. Also helps to visualize valve leaflets.

FSE-XL IR with Blood Suppression

FSE-XL-IR with Blood Suppression (also known as Triple-IR FSE) uses the same double-IR pulse as FSE-XL with Blood Suppression, plus a third IR pulse which is used to null fat signal in the slice. In addition to the BSP TI time, an Inversion Time (Inv Time) is entered at the Scan Timing area. The Inversion Time is for application of the fat-nulling IR pulse. This pulse is applied before data acquisition is initiated. The Inversion Time for nulling fat at 1.5T is approximately 150ms, and at 1.0T is approximately 130ms. This is the same TI time used in other short TI inversion recovery sequences when fat nulling is desired.

To enable Blood Suppressed FSE-XL-IR (Triple-IR FSE):

- Select FSE-IR on the Pulse Sequence area;
- Type and enter **`fse-xl`** `(or` **`FSE-XL`**`)` at the PSD Name text box; must be done before selecting Imaging Options.
- Select Blood Suppression as the Imaging Option. Cardiac Gating/Triggering and Sequential are automatically selected.
- On the Gating area, 2xRR is the default for [# of RR Intervals]. Note that there are additional parameters, which must be selected on this area for cardiac gating/triggering. See the gating and triggering chapter for more details.
- Rate and 2xRR intervals, and [Auto] are entered automatically for the BSP TI time. The system automatically calculates the BSP TI time based on the heart
- [Auto] is automatically entered for the Inv Time and results in a value of 150ms. **Attention 1.0T users**: DO NOT USE [AUTO], must manually enter 130ms, using [Auto] at 1.0T gives you Inv time of 150ms.
- The recommended TE value for Blood Suppression is 40ms. It has been observed that setting the TE to 40ms is likely to reduce flow-related artifact, thus optimizing image quality. The recommended Blood Suppression TE value is the same on both 1.5T and 1.0T.
- Phase Correction is recommended. Phase Correction is now performed following prescan and does not add to the total scan time.

Something to Think About...

- [Sequential] cannot be turned off for Blood Suppression. Interleaved acquisitions, those acquiring multiple slices per TR, are not possible due to the initial non-selective IR preparation pulse.
- BSP TI defaults to [Auto] although a value can be entered manually. The [Auto] BSP TI selection is calculated to obtain maximum blood suppression. The calculation is based on the patient's heart rate. If the calculated value is too high for selected scan parameters, a message is posted stating that the BSP TI must be decreased. You can alter the following scan parameters, as shown, to allow the calculated BSP TI to be accepted: increase the [Receive Bandwidth], decrease the [ETL], and/or decrease the [Trigger Window].
- Use of contrast material such as gadolinium decreases the T1 of blood and so may require a decreased BSP TI. The [Auto] calculation assumes no contrast material is present.
- When entering the Trigger Window or Trigger Delay, a message stating that available imaging time is insufficient for the selected parameters may be posted. At this point the system prompts you to change the Trigger Window or Trigger Delay. If a change in these parameters does not allow you to proceed with prescription, it may be necessary to increase the RBw or decrease the ETL.
- The combination of 2xRR and the TI time of blood results in data acquisition taking place during the quiescent period of diastole. Note that with a 60 bpm heart rate at both 1.5T and 1.0T, the TI of blood is about 650ms.
- Peripheral gating is allowed, however, application of the IR pulses at specific points of the cardiac cycle is crucial to obtain optimal blood suppression; therefore, ECG gating is recommended.
- Chemical SAT (fat and water suppression) pulses cannot be selected with FSE-XL-IR Blood Suppression sequences.
- FSE-XL/FSE-XL-IR with Blood Suppression is not compatible with [Respiratory Gating/Triggering]. These sequences are meant to be acquired in breath-held fashion.

- The actual BSP TI time is not posted in the Scan Timing area or the resulting images, however, the Series Text Page shows the BSP TI. Access the Series Text Page from a Viewer. The BSP TI is labeled as the Blood Null Time and is posted in msec (micro-seconds).

Associated Imaging Options

In the following table the X's indicate the option available for use with the FSE-XL IR with Blood Suppression (Triple IR) pulse sequences.

Imaging Options			
X	None	X	Variable Bandwidth
X	Flow Compensation	X	No Phase Wrap
	POMP	X	Extended Dynamic Range
	Square Pixel		Surface Coil Intensity Correction
	Respiratory Compensation		Classic
	Magnetization Transfer	X	Sequential
X	Cardiac Gating/Triggering		Respiratory Gating/Triggering
	Tailored RF		IR Prepared
	DE Prepared		Multi-Phase
	Full Echo Train		CCOMP
	ZIP 1024		ZIP 512
	Zip x 2		ZIP x 4
	SmartPrep	X	Blood Suppression
	Multi Station		Real Time

Applications

Visualization of cardiac anatomy and myocardial wall masses.
Also helps to visualize valve leaflets.

(A) (B) (C)

(A) Short axis cardiac FSE-XL image acquired without blood suppression
(B) FSE-XL with Blood Suppression. Note the resulting "black blood."
(C) FSE-XL IR with Blood Suppression. Note the "black blood," fat suppression, and modified STIR contrast.

CAUTION: **Provide all patients with ear protection prior to any scan to help avoid possible hearing impairment.** Acoustic noise levels can exceed 99 dBA in the magnet bore.

Setting up a FSE-XL with Blood Suppression pulse sequence

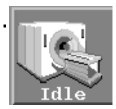
The decision matrix is only for prescribing a FSE-XL with Blood Suppression scan. The purpose of the decision matrix to help you understand the trade-offs that occur when you change the values for a particular parameter and to provide a framework with which you may build you own unique protocol.

The selected values are only an example of what could be used for a FSE-XL with Blood Suppression acquisition and

is not to be considered a recommendation by GE Medical Systems. For specific protocols, refer to the protocols on your system.

.

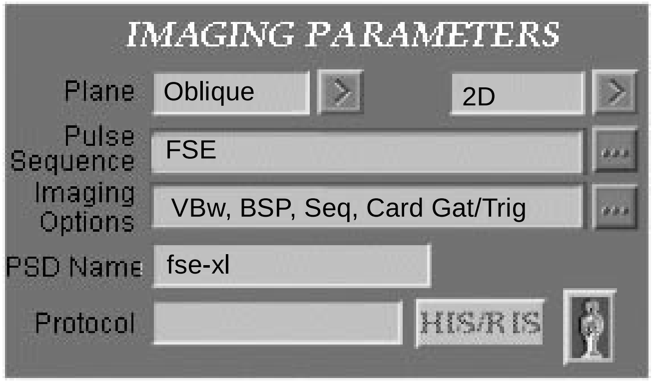
Double IR- What you select		Selection Notes
SCAN DESKTOP screen		

Select **Scan Desktop** icon.


Click on **[New Patient]** and fill in the patient information.

Double IR- What you select		Selection Notes
PATIENT POSITION area		
Patient Position	**[Supine]**	**Position and Entry:** Blood Suppression acquisitions have been designed for cardiac imaging. The patient position and entry should reflect a cardiac exam.
Patient Entry	**[Feet First]**	
Coil	**[Cardiac] [Torso Phased Array on 1.0T]**	**Coil:** Select the coil that produces the optimum coverage and SNR.
Series Description		**Series Description:** Enter a suitable series description. If you don not enter a description, the system enters one for you. The series description default is the selected scan mode, PSD, and imaging options.

Double IR- What you select		Selection Notes
IMAGING PARAMETERS area		

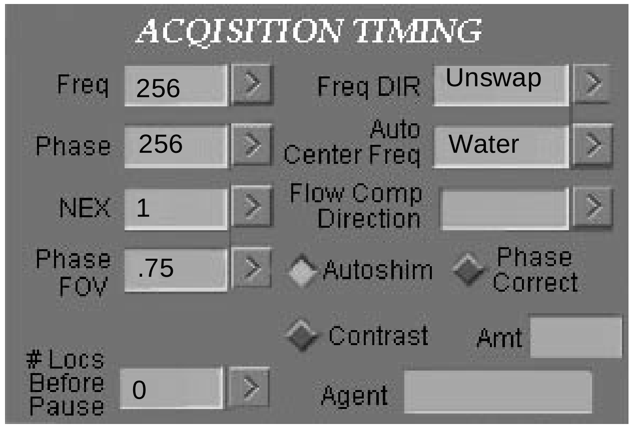


Plane	**[Oblique]**	**Plane:** FSE-XL with Blood Suppression is compatible with any scan plane (except 3-plane); select the plane that best meets the clinical need. [Oblique] must be selected if an angled scan plane is desired.
Mode	**[2D]**	**Mode:** FSE-XL is only compatible with 2D.
Pulse Seq	**[FSE]**	**Pulse Seq:** Select FSE for Double- IR Blood Suppression. Select FSE-IR for Triple-IR Blood Suppression that suppresses fat.
Imaging Options	**[VBw, BSP, Seq, Card Gat/Trig]**	**Imaging Options:** Select Blood Suppression. **Note that you must enter the type-in PSD Name before selecting Blood Suppression.** [Cardiac Gating/Triggering] and [Sequential] are automatically activated when Blood Suppression is selected first. Select [VBw] to achieve higher receive bandwidths (RBw). As the RBw increases, SNR decreases and echo space decreases. Click on the [Accept] button to register the selections.
PSD Name	**fse-xl**	**PSD Name:** You must type and enter **“fse-xl”** or **“FSE-XL”** in the PSD filename text box.
Protocol	**N/A**	
SCAN TIMING area		
# of echoes	**[1]**	**# of echoes:** One or two echoes are allowed. One echo is generally done with Blood Suppression.
TE	**[40]**	**TE:** The minimum TE available is the echo space. Set the TE for the desired image contrast: low TEs for higher SNR and PD-weighted images, long TEs for T2 weighting. Note that it has been observed that TE values of 40ms or greater are likely to reduce the appearance of flow-related artifacts. (use 40ms TE on both 1.5T and 1.0T systems).
TR	**N/A**	**TR:** TR is not available with gated scans. The heart rate and the default R-R Interval of 2xRR determine the TR.

Double IR- What you select		Selection Notes
TI	**N/A**	**Inv Time: Inversion Time is available if the pulse sequence is FSE-IR.** [Auto] is the default and provides a 150ms Inv. Time. **Attention 1.0T Users**: DO NOT USE [AUTO], manually enter Inv Time of 130ms.
BSP TI	**[Auto]**	**BSP TI:** [Auto] defaults on. The [Auto] selection prompts the system to calculate the most accurate value based on the patient's heart rate. Note that the use of contrast material, such as gadolinium, decreases the T1 of blood and so may require a decreased BSP TI. The [Auto] calculation assumes no contrast material is present.
Flip Angle	**N/A**	
Echo Train Length	**1.5T [32]** **1.0T [24]**	**ETL:** An increase in ETL decreases scan time, increase edge blurring, increase signal from fat, and decrease the maximum available BSP TI.
Bandwidth	**1.5T [62.5]** **1.0T [32]**	**Bandwidth:** RBw can only be changed if [VB] was selected from the Imaging Options menu. As Receive Bandwidth increases, the ESP decreases (which is desirable), and the maximum BSP TI increases. Blood Suppression acquisitions generally use maximum bandwidths to keep the echo space small and thereby decrease the effects of blurring with the long ETLs. Compensate for the loss in SNR that occurs with these wide RBws by increasing the slice thickness or FOV.
Bandwidth 2	**N/A**	
SCANNING RANGE area		
FOV	**[36-48]**	**FOV:** Select a FOV that covers the anatomy of interest. Anatomy outside the FOV in the phase direction results in aliasing. Small FOVs produce: increased resolution, decreased SNR, and can increase the minimum TE value.
Slice Thickness	**[8-10]**	**Slice Thickness:** Thicker slices are generally used due to the large area of coverage.
Spacing	**[0]**	**Spacing:** 0 (zero) to 1.5mm is generally used. One slice is acquired per acquisition, therefore, cross-talk is not a problem. Adjust the spacing as needed to cover the anatomy.
Start, End Locations		**Start, End Locations:** Locations are graphically prescribed to obtain the proper angle for the desired anatomy.
# Slices	**as needed to cover the anatomy of interest**	**# Slices:** The number of slice locations is adjusted as needed for coverage of the desired anatomy.

Double IR- What you select		Selection Notes

ACQUISITION TIMING area



Freq	**[256]**	**Freq:** Increasing the frequency matrix produces: increased echo spacing, increased resolution, and decreased SNR. Valid frequency matrix values are: 128, 160, 192, and 256, and from 256 to 512 in incremental steps of 64. Use of a low frequency matrix combined with ZIP 512 helps maintain resolution while decreasing the echo space.
Phase	**[256]**	**Phase:** Increasing the Phase matrix produces: increased scan time, increased resolution, and may decrease edge blurring. Valid values are from 128 to 512 in increments of 32. The phase matrix cannot be larger than the frequency matrix.
NEX	**[1]**	**NEX:** Select a NEX value conducive to breath-hold scan times.
Phase FOV	**[.75]** **[1] when using Torso Phased Array Coil**	**Phase FOV:** Select a Phase FOV value less than 1 to reduce the phase steps and thus decrease scan time, decrease the FOV in the phase direction, and decrease SNR slightly. The Phase FOV dimension is displayed next to the Phase FOV factor in the pull-down menu. At 1.0T or when using Torso Phased Array Coil use a phase FOV of 1 to avoid wrap-around artifact.
Freq DIR	**[Unswap]**	**Freq DIR:** The direction displayed is the default frequency direction which is typically the long axis of the image. To swap phase and frequency, select the other direction.
Auto Center Freq	**[Water]**	**Auto Center Freq:** Select the CF peak that is set during prescan.
Flow Comp DIR	**N/A**	**Flow Comp Direction:** FC is not needed in blood suppressed FSE-XL.
Autoshim	**[On]**	**Autoshim:** Turn Autoshim on to improve homogeneity.

Double IR- What you select		Selection Notes
Phase Correct	**[On]**	**Phase Correct:** Phase Correction is recommended for all FSE sequences, including Blood Suppressed FSE-XL. The phase correction is performed following prescan and does not add to scan time.
# of Acqs/Locs Before Pause	**adjust as needed for breath-holding**	**# of Acqs/Locs Before Pause:** If more than one location is prescribed (as is generally the case), select a pause to allow for breath-hold instructions.
	Additional Parameters SAT Screen	
SAT	**None**	**SAT:** Chemical SAT pulses (Fat/Water Suppression) are not available for FSE-XL-IR with Blood Suppression (Triple-IR Blood Suppression). Chem SAT can be used for FSE-XL with Blood Suppression (Double-IR Blood Suppression), however, FSE-XL-IR is generally used to suppress fat in Blood Suppressed sequences. Spatial SAT pulses are not needed.
	Additional Parameters Card/Resp screen	
Trigger Type	**[ECG-II]**	**Trigger Type:** Select the lead that provides the best signal. Peripheral Gating is allowed but not recommended.
# of RR Interval	**[2xRR]**	**# of RR Interval:** 2xRR is automatically selected.
Trigger Window	**[20]**	**Trigger Window:** Increase the TW for patients with irregular heart rates. It may be necessary to increase the RBw or decrease the ETL to obtain the proper BSP TI when the heart rate is high (over 100 bpm) and the TW is wide. A message is posted when this is necessary.
Trigger Delay	**[Min]**	**Trigger Delay:** The only choices are Minimum and Recommended. The values are generally the same.
Heart Rate	**[Update Rate]**	**Heart Rate:** Click [update Rate] to obtain the current heart rate. Update the heart rate prior to beginning the scan.
	GRAPHIC RX Screen	
Click on the image to display the line cursor for Graphic Rx.		To prescribe oblique slices, you must select [Oblique] at the Plane pull-down menu. As the number of slices is increased, total scan time increases; each location is one acquisition. Click [Accept] to exit the Graphic Rx.
	SCAN OPERATIONS area	

Double IR- What you select	Selection Notes
[Save Series] **[Prep to Scan]** **[Auto Prescan]** **[Scan]**	Enter data in all the text boxes and click on **[Save Series]**. The series is saved as RXD. Click **[Prepare to Scan]** to download the series. The series is be labeled ACT in the RX Manager. Click **[Prep Scan]**. Auto Prescan is performed and the system will be ready to start scanning immediately when **[Scan]** is selected. Instruct the patient to hold his/her breath and click **[Scan]** to start data acquisition. If a pause has been programmed, the system acquires the data for the defined location(s), stop scanning automatically, and the [Start Scan] button on the keyboard is lit. When ready to obtain the next slice location(s), breathe the patient and press the [Start Scan] button.

FastCine and FastCine PC

FASTCINE and FASTCINE PC are sequences that use a combination of FastCard and Cine features to enable data acquisition throughout the entire cardiac cycle.

In FastCard acquisitions, trigger (R-wave) detection initiates data acquisition. The window in which to look for the trigger (the Arrhythmia Rejection Window) is placed at end diastole, and as a result, images from that point of the cardiac cycle cannot be acquired. Note that RF is continuously applied, at the selected TR, throughout the cardiac cycle.

FASTCINE and FASTCINE PC do not use trigger detection to initiate data acquisition. Data is acquired throughout the cardiac cycle just as in a conventional Cine acquisition. The RR interval is monitored and the information is used to retrospectively sort the data before reconstruction. Images are reconstructed using Cine interpolation, which compensates for differences within the cardiac cycle. This is called retrospective gating.

In addition to retrospective gating, FASTCINE and FASTCINE PC use Fast GRE/SPGR techniques to obtain scan times which are much shorter than conventional Cine: short TEs and TRs, increased receive bandwidths and segmented K-space. Recall that segmented K-space techniques allow collection of multiple phase encoding views in one cardiac cycle (RR interval).

The following features can be used with the specified FASTCINE and FASTCINE-PC sequences:

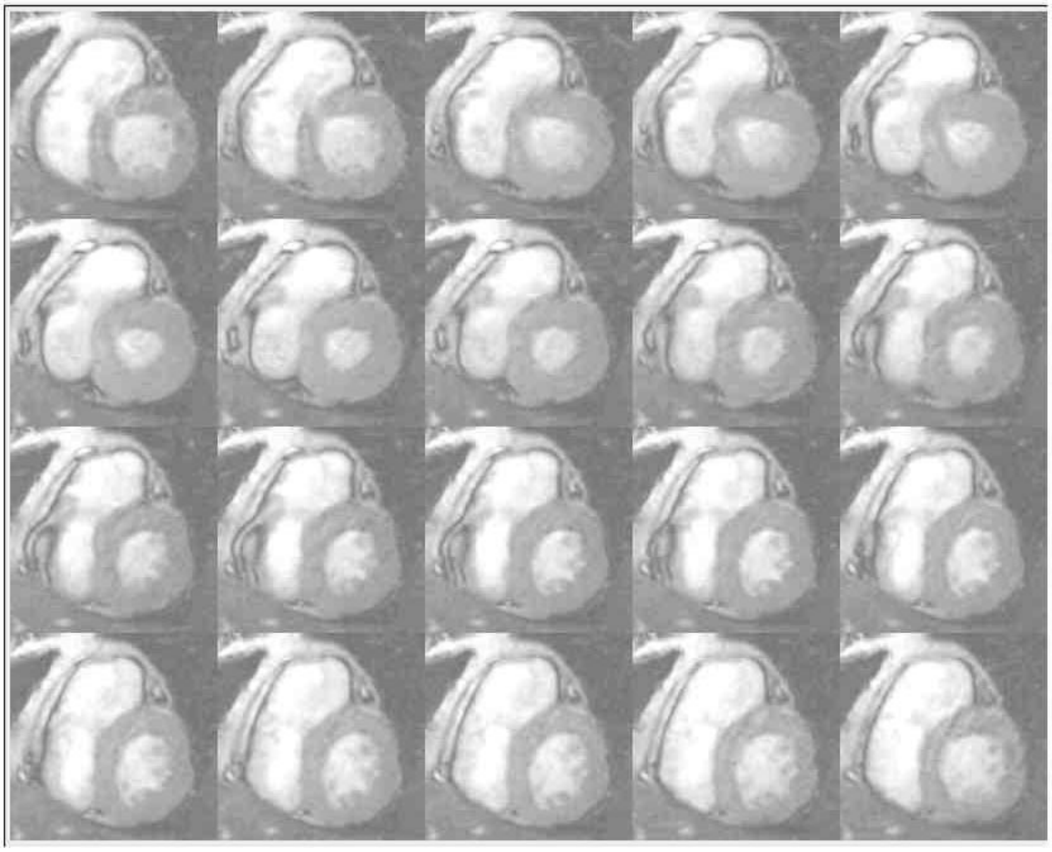
- FASTCINE and FASTCINE-PC are compatible with Respiratory Gating;
- FASTCINE and FASTCINE-PC can be used with Chemical SAT techniques (Fat and Water Suppression); and
- Cardiac Tagging can be used in conjunction with FASTCINE-GRE.

FASTCINE is initiated by:

- Selecting 2D Mode with a FastCard-GRE or FastCard-SPGR pulse sequence;
- Selecting Cardiac Gating/Triggering and Sequential default [On] at the Imaging Options menu, and
- Entering a number value for # of Cardiac Phases to Reconstruct on the combined Card/Resp screen. If Auto is selected here, the sequence becomes a FastCard sequence, not FASTCINE.

FASTCINE PC is initiated by:

- Selecting 2D Mode with the Fast 2D Phase Contrast pulse sequence;
- Selecting Cardiac Gating/Triggering and Sequential default [On] at the Imaging Options menu;
- Entering a number value for # of Phases to Reconstruct on the combined Card/Resp screen; and
- Entering Phase Contrast parameters at the Vascular screen.



FASTCINE results in smoother Cine images (as opposed to conventional Cine), even at high heart rates, due to the use of very short TR and TE values.

FASTCINE and FASTCINE PC also require you to select parameters from the combined Card/Resp screen.

Trigger Type

Select ECG or Peripheral. ECG is recommended for the most accurate trigger detection for cardiac imaging. With peripheral gating, there is a delay from the actual trigger to when it is detected in the extremity.

In ECG Gating/Triggering, observe the waveforms from each lead (ECG I, II and III). Select the lead that provides the best signal. Should signal from the selected lead diminish or be lost during data acquisition, a new lead can be selected from the Card/Resp screen.

Arrhythmia Rejection Window

Define the window size, as a percentage of the RR interval, outside of which the system rejects data if a trigger is detected. In FASTCINE and FASTCINE PC, the rejection window encompasses time before and after the expected trigger; therefore, data is discarded when both early and late triggers are detected.

Widening the window is recommended for patients with irregular heart rates. If too many rejections occur, the acquisition aborts (when Manual Arrhythmia Monitoring is off). *See "Manual Arrhythmia Monitoring" later in this section.*

of Phases to Reconstruct

Define the number of phases you want to see at each slice location. The default is 20 phases, but the range is from 2 to 512 phases, with the maximum value dependent upon the number of slices prescribed and the number of Views per Segment. As the number of slices increases, the maximum number of phases decreases. The maximum number of cardiac phases is shown to the right of this field.

Note that selecting [Auto] results in a conventional FastCard GRE/SPGR acquisition. A number entered into the text box results in a FASTCINE acquisition. When the pulse sequence is a Non-Sequential FastCard-GRE/ SPGR, [Auto] is defaulted [On], and cannot be turned off. For FASTCINE, you must select [Sequential].

Views per Segment (VPS)

This defines the number of K-space lines that are filled per RR interval. This defaults to 8 VPS. As the VPS increases, scan time decreases, temporal resolution decreases, and the maximum number of phases allowed decreases.

Manual Arrhythmia Monitoring

The FASTCINE and FASTCINE-PC User CV screen provides the ability to turn off arrhythmia monitoring for these sequences. This can be useful when scanning patients with erratic heart rates.

FASTCINE and FASTCINE PC sequences automatically monitor the occurrence of triggers (R-waves) during data acquisition. If too many triggers are detected outside of the

Arrhythmia Rejection Window, the scan aborts. Up to 8 arrhythmias (triggers outside the window) are allowed for scans shorter than 25 seconds, and up to 20 are allowed for scans longer than 25 seconds.

You have the option to turn off this automatic monitoring to avoid scan aborts. This is done at the User CV screen.

Leave this value at the default, "**0**," to allow the system to automatically monitor arrhythmias. Enter "**1**" to enable Manual Arrhythmia Monitoring. When Manual Arrhythmia Monitoring is enabled, it is recommended that you monitor the occurrence of arrhythmias yourself (or manually). Note that Manual Arrhythmia Monitoring prevents a scan from aborting. It does not turn off Arrhythmia Rejection. Therefore, if triggers are detected outside the rejection window, the data obtained during that cycle is discarded and must be obtained again. This increases the scan time.

Something to Think About...

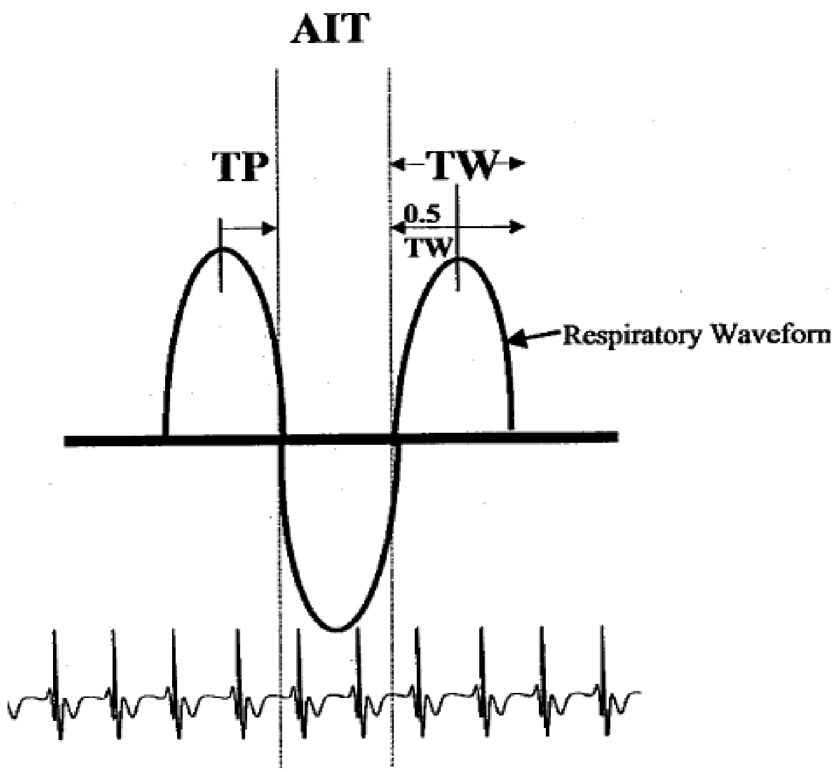
- When Manual Arrhythmia Monitoring is off (Automatic Arrhythmia Monitoring remains enabled), a scan aborts if: more than 8 arrhythmias occur in a scan of less than 25 seconds (a typical breath-hold acquisition); or more than 20 arrhythmias occur in a scan longer than 25 seconds. If a scan aborts because too many arrhythmias were detected, a message is posted.
- [Sequential], along with FastCard-GRE (or FastCard-SPGR), must be selected for a FASTCINE sequence; if it is not, # of Phases to Reconstruct will not be available on the Card/Resp screen.

Respiratory Gating with FastCine/FastCine PC

Combined cardiac and respiratory gating is allowed with FASTCINE and FASTCINE-PC sequences.

The Trigger Point and Trigger Window must be defined at the Card/Resp screen to perform respiratory gating. The Trigger Point defines the point in the respiratory cycle at which data acquisition begins if a valid ECG trigger is detected. This value is expressed as a percentage of the respiratory cycle. The Trigger Window defines the period of the respiratory cycle in which data acquisition does not occur. The Trigger Point and Trigger Window values, together, define the data acquisition window.

The following charts can be used to obtain possible Trigger Point and Trigger Window values to be used for Combined Cardiac/Respiratory Gating in FastCard and FastCine sequences. Three charts are provided; one each for obtaining the image data within 2, 2.5 or 3 RR intervals. The illustration is provided to help understand what is taking place when the values are selected. The objective of these charts is to help the operator prescribe the correct Respiratory Trigger Point and Trigger Window to obtain image data at the most quiescent period of the respiratory cycle.



In this example, the TP and TW are set to capture 2.5 R-Rs in each available AIT of the respiratory cycle.

On the upper left portion of each chart is the number of RR intervals to be included in the available imaging time (AIT) of the respiratory cycle. This is shown as N = 2, N = 2.5, and N =3. The Heart Rate (HR) column runs vertically on the left portion of the chart. The Respiratory Rate (Resp Rate) runs horizontally across the top of the chart. Find the intersection of the patient's heart rate and respiratory rate on the desired chart. The % value shown at the intersection is entered as the Respiratory Trigger Point on the Combined Card/Resp screen. Multiply the

Trigger Point value times two to obtain the Respiratory Trigger Window.

Note: Trigger Window = Trigger Point X 2
N = 2.0

Resp Rate	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Heart Rate																
40	25%	23%	20%	18%	15%	13%	10%	8%	5%	3%	0%	0%	0%	0%	0%	0%
45	28%	26%	23%	21%	19%	17%	14%	12%	10%	8%	6%	3%	1%	0%	0%	0%
50	30%	28%	26%	24%	22%	20%	18%	16%	14%	12%	10%	8%	6%	4%	2%	0%
55	32%	30%	28%	26%	25%	23%	21%	19%	17%	15%	14%	12%	10%	8%	6%	5%
60	33%	32%	30%	28%	27%	25%	23%	22%	20%	18%	17%	15%	13%	12%	10%	8%
65	35%	33%	32%	30%	28%	27%	25%	24%	22%	21%	19%	18%	16%	15%	13%	12%
70	36%	34%	33%	31%	30%	29%	27%	26%	24%	23%	21%	20%	19%	17%	16%	14%
75	37%	35%	34%	33%	31%	30%	29%	27%	26%	25%	23%	22%	21%	19%	18%	17%
80	38%	36%	35%	34%	33%	31%	30%	29%	28%	26%	25%	24%	23%	21%	20%	19%
85	38%	37%	36%	35%	34%	32%	31%	30%	29%	28%	26%	25%	24%	23%	22%	21%
90	39%	38%	37%	36%	34%	33%	32%	31%	30%	29%	28%	27%	26%	24%	23%	22%
95	39%	38%	37%	36%	35%	34%	33%	32%	30%	30%	29%	28%	27%	26%	25%	24%
100	40%	39%	38%	37%	36%	35%	34%	33%	32%	31%	30%	29%	28%	27%	26%	25%
105	40%	40%	39%	38%	37%	36%	35%	34%	33%	32%	31%	30%	29%	28%	27%	26%
110	41%	40%	39%	38%	37%	36%	35%	35%	34%	33%	32%	31%	30%	29%	28%	27%
115	41%	40%	40%	39%	38%	37%	36%	35%	34%	33%	33%	32%	31%	30%	29%	28%
120	42%	41%	40%	39%	38%	38%	37%	36%	35%	34%	33%	33%	32%	31%	30%	29%
125	42%	41%	40%	40%	39%	38%	37%	36%	36%	35%	34%	33%	32%	32%	31%	30%
130	42%	42%	41%	40%	39%	38%	38%	37%	36%	35%	35%	34%	33%	32%	32%	31%
135	43%	42%	41%	40%	40%	39%	38%	37%	37%	36%	35%	34%	34%	33%	32%	31%
140	43%	42%	41%	41%	40%	39%	39%	38%	37%	36%	36%	35%	34%	34%	33%	32%
145	43%	42%	42%	41%	40%	40%	39%	38%	38%	37%	36%	36%	35%	34%	33%	33%
150	43%	43%	42%	41%	41%	40%	39%	39%	38%	37%	37%	36%	35%	35%	34%	33%

Note: Trigger Window = Trigger Point X 2
N = 2.5

Resp Rate	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Heart Rate																
40	19%	16%	13%	9%	6%	3%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
45	22%	19%	17%	14%	11%	8%	6%	3%	0%	0%	0%	0%	0%	0%	0%	0%
50	25%	23%	20%	18%	15%	13%	10%	8%	5%	3%	0%	0%	0%	0%	0%	0%
55	27%	25%	23%	20%	18%	16%	14%	11%	9%	7%	5%	2%	0%	0%	0%	0%
60	29%	27%	25%	23%	21%	19%	17%	15%	13%	10%	8%	6%	4%	2%	0%	0%
65	31%	29%	27%	25%	23%	21%	19%	17%	15%	13%	12%	10%	8%	6%	4%	2%
70	32%	30%	29%	27%	25%	23%	21%	20%	18%	16%	14%	13%	11%	9%	7%	5%
75	33%	32%	30%	28%	27%	25%	23%	22%	20%	18%	17%	15%	13%	12%	10%	8%
80	34%	33%	31%	30%	28%	27%	25%	23%	22%	20%	19%	17%	16%	14%	13%	11%
85	35%	34%	32%	31%	29%	28%	26%	25%	24%	22%	21%	19%	18%	16%	15%	13%
90	36%	35%	33%	32%	31%	29%	28%	26%	25%	24%	22%	21%	19%	18%	17%	15%
95	37%	36%	34%	33%	32%	30%	29%	28%	26%	25%	24%	22%	21%	20%	18%	17%
100	38%	36%	35%	34%	33%	31%	30%	29%	28%	26%	25%	24%	23%	21%	20%	19%
105	38%	37%	36%	35%	33%	32%	31%	30%	29%	27%	26%	25%	24%	23%	21%	20%
110	39%	38%	36%	35%	34%	33%	32%	31%	30%	28%	27%	26%	25%	24%	23%	22%
115	39%	38%	37%	36%	35%	34%	33%	32%	30%	29%	28%	27%	26%	25%	24%	23%
120	40%	39%	38%	36%	35%	34%	33%	32%	31%	30%	29%	28%	27%	26%	25%	24%
125	40%	39%	38%	37%	36%	35%	34%	33%	32%	31%	30%	29%	28%	27%	26%	25%
130	40%	39%	38%	38%	37%	36%	35%	34%	33%	32%	31%	30%	29%	28%	27%	26%
135	41%	40%	39%	38%	37%	36%	35%	34%	33%	32%	31%	31%	30%	29%	28%	27%
140	41%	40%	39%	38%	38%	37%	36%	35%	34%	33%	32%	31%	30%	29%	29%	28%
145	41%	41%	40%	39%	38%	37%	36%	35%	34%	34%	33%	32%	31%	30%	29%	28%
150	42%	41%	40%	39%	38%	38%	37%	36%	35%	34%	33%	33%	32%	31%	30%	29%

Note: Trigger Window = Trigger Point X 2
N = 3.0

Resp Rate / Heart Rate	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
40	13%	9%	5%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
45	17%	13%	10%	7%	3%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
50	20%	17%	14%	11%	8%	5%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%
55	23%	20%	17%	15%	12%	9%	6%	4%	1%	0%	0%	0%	0%	0%	0%	0%
60	25%	23%	20%	18%	15%	13%	10%	8%	5%	3%	0%	0%	0%	0%	0%	0%
65	27%	25%	22%	20%	18%	15%	13%	11%	8%	6%	4%	2%	0%	0%	0%	0%
70	29%	26%	24%	22%	20%	18%	16%	14%	11%	9%	7%	5%	3%	1%	0%	0%
75	30%	28%	26%	24%	22%	20%	18%	16%	14%	12%	10%	8%	6%	4%	2%	0%
80	31%	29%	28%	26%	24%	22%	20%	18%	16%	14%	13%	11%	9%	7%	5%	3%
85	32%	31%	29%	27%	25%	24%	22%	20%	18%	16%	15%	13%	11%	9%	8%	6%
90	33%	32%	30%	28%	27%	25%	23%	22%	20%	18%	17%	15%	13%	12%	10%	8%
95	34%	33%	31%	29%	28%	26%	25%	23%	22%	20%	18%	17%	15%	14%	12%	11%
100	35%	34%	32%	31%	29%	28%	26%	25%	23%	22%	20%	19%	17%	16%	14%	13%
105	36%	34%	33%	31%	30%	29%	27%	26%	24%	23%	21%	20%	19%	17%	16%	14%
110	36%	35%	34%	32%	31%	30%	28%	27%	25%	24%	23%	21%	20%	19%	17%	16%
115	37%	36%	34%	33%	32%	30%	29%	28%	27%	25%	24%	23%	21%	20%	19%	17%
120	38%	36%	35%	34%	33%	31%	30%	29%	28%	26%	25%	24%	23%	21%	20%	19%
125	38%	37%	36%	34%	33%	32%	31%	30%	28%	27%	26%	25%	24%	22%	21%	20%
130	38%	37%	36%	35%	34%	33%	32%	30%	29%	28%	27%	26%	25%	23%	22%	21%
135	39%	38%	37%	36%	34%	33%	32%	31%	30%	29%	28%	27%	26%	24%	23%	22%
140	39%	38%	37%	36%	35%	34%	33%	32%	31%	30%	29%	28%	26%	25%	24%	23%
145	40%	39%	38%	37%	36%	34%	33%	32%	31%	30%	29%	28%	27%	26%	25%	24%
150	40%	39%	38%	37%	36%	35%	34%	33%	32%	31%	30%	29%	28%	27%	26%	25%

Something to Think About...

- The Trigger Window must be larger than the Trigger Point.
- Data acquisition initiates only if a valid ECG trigger is detected during the data acquisition window.
- If the respiratory signal is lost and is not detected within ten seconds, the scan terminates. This prevents the pulse sequence from being caught in an infinite loop.

Associated Imaging Options

In the following table the X's indicate the option available for use with the FastCine/FastCine PC pulse sequences.

Imaging Options			
X	None	X	Variable Bandwidth
X	Flow Compensation	X	No Phase Wrap
	POMP		Extended Dynamic Range
	Square Pixel		Surface Coil Intensity Correction
	Respiratory Compensation		Classic
	Magnetization Transfer	X	Sequential
X	Cardiac Gating/Triggering		Respiratory Gating/Triggering
	Tailored RF		IR Prepared
	DE Prepared		Multi-Phase
	Full Echo Train		CCOMP
	ZIP 1024		ZIP 512
	Zip x 2		ZIP x 4
	SmartPrep	X	Blood Suppression
	Multi Station		Real Time

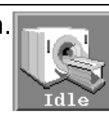
CAUTION: **Provide all patients with ear protection prior to any scan to help avoid possible hearing impairment.** Acoustic noise levels can exceed 99 dBA in the magnet bore.

Setting up a FastCine pulse sequence

The decision matrix is only for prescribing a FastCine scan. The purpose of the decision matrix to help you understand the trade-offs that occur when you change the values for a particular parameter and to provide a framework with which you may build you own unique protocol.

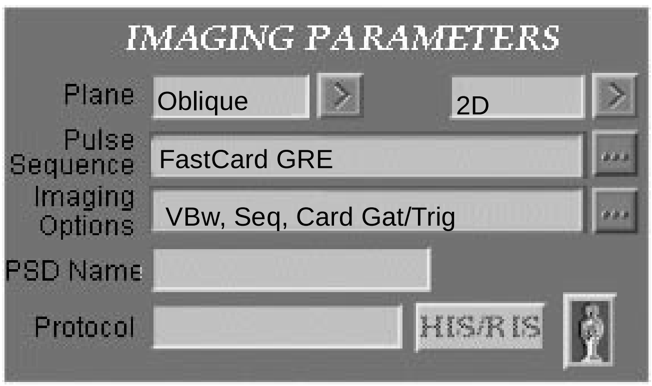
The selected values are only an example of what could be used for a FastCine acquisition and is not to be considered a recommendation by GE Medical Systems. For specific protocols, refer to the protocols on your system.

.

FastCine- What you select	Selection Notes
SCAN DESKTOP screen	
	Select **Scan Desktop** icon.  Click on **[New Patient]** and fill in the patient information. 
PATIENT POSITION area	
Patient Position **[Supine]**	**Position and Entry:** A FASTCINE pulse sequence is compatible with any patient position and entry.

FastCine- What you select		Selection Notes
Patient Entry	**[Feet First]**	
Coil	**[Cardiac]** **[Torso Phased Array on 1.0T]**	**Coil:** Select the coil that produces the optimum coverage and SNR.
Series Description		**Series Description:** Enter a suitable series description. If you don not enter a description, the system enters one for you. The series description default is the selected scan mode, PSD, and imaging options.

IMAGING PARAMETERS area



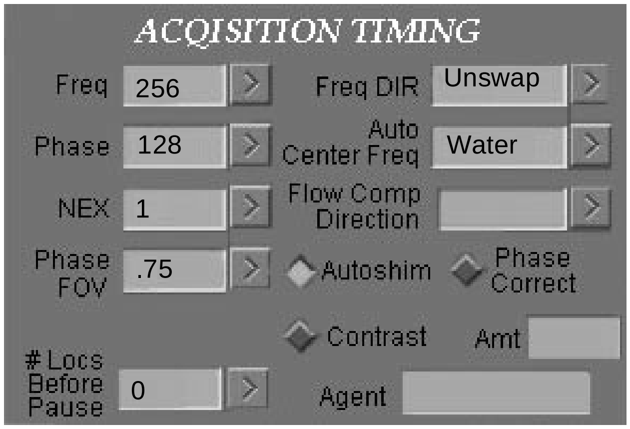
Plane	**[Oblique]**	**Plane:** FastCine is compatible with any scan plane (except 3-plane); select the plane that best meets the clinical need.
Mode	**[2D]**	
Pulse Seq	**[FastCard GRE]**	**Pulse Seq:** Select [FastCard-GRE] for a T2* contrast or to do cardiac tagging. [FastCard-SPGR] can be selected for T1 contribution. Click on the [Accept] button in the window to register the selection. [Fast 2D Phase Contrast] is the selected pulse sequence for FASTCINE PC.
Imaging Options	**[VBw, Seq, Card Gat/Trig]**	**Imaging Options:** [Cardiac Gating/Triggering] and [Sequential] are automatically selected. Do not turn off [Sequential]. Select additional imaging options that optimize SNR and spatial resolution and reduce motion artifacts. Use [FlowComp] to increase signal from blood. Select [Resp Gating/Triggering] for non-breath-hold acquisitions. Click on the [Accept] button to register the selections.
PSD Name	**N/A**	**PSD Name:** Not applicable for FASTCINE.
Protocol	**N/A**	

SCAN TIMING area

# of echoes	**[1]**	**# of echoes:** One or two echoes are allowed. One echo is generally done with Blood Suppression.

FastCine- What you select		Selection Notes
TE	**[Min Full]**	**TE:** Increase the TE to produce: increased T2* contrast, decreased SNR, signal changes at fat/water interfaces, and increased magnetic susceptibility effects. Minimum is a fractional echo and does not allow.5 NEX. Min Full allows the use of .5 NEX.
TR	**N/A**	**TR:** The minimum TR is set automatically.
Flip Angle	**[20]**	**Flip Angle:** Typical flip angle values are 20° to 25°. As the flip angle decreases, T2* weighting increases and SNR decreases. Use the same flip angle at 1.5T and 1.0T.
Echo Train Length	**N/A**	
Bandwidth	**1.5T [31.25 1.0T [15]**	**Bandwidth:** Bandwidths up to 125kHz are allowed. As the RBw decreases, SNR increases, chemical shift artifacts increase, and the minimum TE increases, which can potentially increase motion artifacts. Generally, wider bandwidths are used with Fast sequences to keep minimum TEs and TRs down. However, very large bandwidths may result in only nominally faster scan times. Weigh the SNR decrease with the scan time decrease.
Bandwidth 2	**N/A**	
SCANNING RANGE area		
FOV	**[36-48]**	**FOV:** Select a FOV that covers the anatomy of interest. Anatomy outside the FOV in the phase direction results in aliasing. Small FOVs produce: increased resolution, decreased SNR, and can increase the minimum TE value.
Slice Thickness	**[8-10]**	**Slice Thickness:** Thin slices produce: increased resolution and a decrease in SNR. Thin slices may also increase the number of locations needed to cover the desired anatomy.
Start, End Locations		**Start, End Locations:** Locations are graphically prescribed to obtain the proper angle for the desired anatomy.
# Slices	**as needed to cover the anatomy of interest**	**# Slices:** The number of slice locations is adjusted as needed for coverage of the desired anatomy. FASTCINE scans one slice per acquisition.

FastCine- What you select		Selection Notes
ACQUISITION TIMING area		



Freq	**[256]**	**Freq:** Increasing the frequency matrix increases resolution, and decreases SNR.
Phase	**[128]**	**Phase:** Phase controls scan time and resolution.
NEX	**[1]**	**NEX:** Use lower NEX values for breath-hold scans. Use higher NEX to decrease motion artifacts for patients unable to hold their breath. Fractional NEX is available if Minimum Full TE is selected.
Phase FOV	**[.75]** **[1] when using Torso Phased Array Coil**	**Phase FOV:** Select 0.75 or 0.5 to reduce phase steps and thus decrease scan time, decrease the FOV in the phase direction, and decrease SNR slightly. The phase FOV dimension is displayed next to the phase FOV factor. Use a 1 phase FOV at 1.0T and when using Torso Phased Array Coil.
Freq DIR	**[Unswap]**	**Freq DIR:** The direction displayed is the default frequency direction which is typically the long axis of the image. To swap phase and frequency, select the other direction.
Auto Center Freq	**[Water]**	**Auto Center Freq:** Select the CF peak that is set during prescan.
Flow Comp DIR	**N/A**	
Autoshim	**[On]**	**Autoshim:** Select Autoshim [On] when using fat SAT, an FOV off center, and on the first series of an exam.
Phase Correct	**N/A**	
# of Acqs/Locs Before Pause	**[1]**	**# of Acqs/Locs Before Pause:** Prescribe an automatic pause in the scan at predetermined points for breath-hold studies.
Additional Parameters **SAT Screen**		

FastCine- What you select		Selection Notes
SAT	**None**	**SAT:** FAT Saturation can be used with FASTCINE SPGR to better visualize coronary arteries. Spatial SAT pulses may decrease signal from blood but are not generally used. Spatial SAT and Chem-SAT pulses cannot be selected with tagging. Turn on [Stripe] or [Grid] to define the Tag Type. Specify the Tag Pixel Spacing to define the distance between the tag bands.
Additional Parameters **Card/Resp screen**		
Trigger Type	**[ECG-II]**	**Trigger Type:** Select the lead that provides the best signal. PG is for peripheral gating.
Arrhythmia Rejection Window	**[20]**	**Arrhythmia Rejection Window:** The system calculates the value when [Auto] is selected. It is recommended that 20% to 50% be used.
Trigger Delay	**[Min]**	**Trigger Delay:** The only choices are Minimum and Recommended. When SAT pulses are used, select Recommended.
# of Cardiac Phases to Reconstruct	**[20]**	**# of Cardiac Phases to Reconstruct:** The maximum number of phases allowed decreases as the number of slice locations increases.
Views per Segment	**[6]**	**Views per Segment:** Must be 1 or an even number, from 2-98. As the VPS increases, scan time decreases, edge blurring increases, temporal resolution decreases, and the maximum allowed cardiac phases decreases.
Heart Rate	**[Update Rate]**	**Heart Rate:** Click [update Rate] to let the system obtain an automatic reading of the current heart rate, or you can enter the bpm yourself by observing the monitor.
Respiratory Trigger Point	**see the RT tables to determine the appropriate value**	**Resp. Trigger Point:** Generally, this value is kept small for acquisitions using Resp Gating/Triggering.
Respiratory Trigger Window	**see the RT tables to determine the appropriate value**	**Resp. Trigger Window:** This value must be larger than the Trigger Point.
User CV Screen		
Manual Arrhythmia Monitoring	**[1]**	**Manual Arrhythmia Monitoring:** Enter **"1"** to turn off Automatic Arrhythmia Monitoring. The default, **"0,"** allows the system to monitor for arrhythmias, however, too many triggers detected outside the rejection window results in an aborted scan.

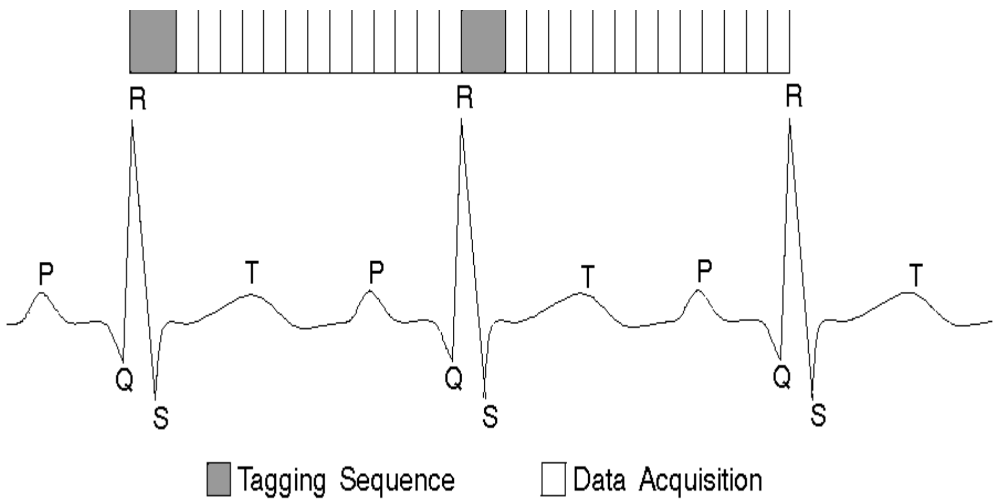
FastCine- What you select		Selection Notes
	Vascular Options Screen	
Projection Images	**N/A**	**Projection Images:** FASTCINE PC does not produce projection images.
Collapse	**[On]**	**Collapse:** Select [**On**] to get a collapsed view in the plane of acquisition.
Flow Recon Type	**[Phase Diff]**	**Flow Recon Type:** Select [Phase Diff] as the Flow Recon Type. Select Flow Analysis [On] with Phase Difference to do Flow Analysis on the image set. [Complex Diff] is generally not used in FASTCINE-PC.
Flow Analysis	**[On]**	**Flow Analysis** must be on to be able do to do post**-**processing.
Velocity Encoding	**[170]**	**Velocity Encoding:** Enter a VENC that represents the fastest blood flow in the imaging area. A VENC value set too low results in flow aliasing.
Acq. Flow Direction	**[S/I]**	**Acq. Flow Direction:** Select the Acq. Flow Direction based on the type of information needed for the exam.
Additional Flow Images	**N/A**	**Additional Flow Images:** If [**All**] was selected for Flow Direction, you can select additional flow direction images. [Magnitude] images cannot be created with FASTCINE-PC.
	GRAPHIC RX Screen	
Click on the image to display the line cursor for Graphic Rx.		To prescribe oblique slices, you must select [Oblique] at the Plane pull-down menu. As the number of slices is increased, total scan time increases; each location is one acquisition. Click [Accept] to exit the Graphic Rx.
	SCAN OPERATIONS area	
	[Save Series] **[Prep to Scan]** **[Auto Prescan]** **[Scan]**	Enter data in all the text boxes and click on **[Save Series]**. The series is saved as RXD. Click [Prepare to Scan] to download the series. The series is now labeled ACT in the RX Manager. Click [Prep Scan]. Auto Prescan is performed and the system will be ready to start scanning immediately when [Scan] is selected. Instruct the patient to hold his/her breath and Click [Scan] to start data acquisition. If a pause has been programmed, the system acquires the data for the defined location(s), stop scanning automatically, and the [Start Scan] button on the keyboard is lit. When ready to obtain the next slice location(s), breathe the patient and press the [Start Scan] button.

Tagging

Tagging is the application of spatial SAT pulses over the anatomy of interest to obtain cardiac images sensitive to tissue motion. Tagging is available for FASTCINE-GRE and FastCard-GRE sequences.

Type:	Stripe or Grid tags can be applied.
Tag Pixel Spacing:	The default is [7]. This defines the spacing between the tags expressed in number of pixels.

Tagging is a spatial SAT pulse that is applied inside the FOV over the entire image. The tagging sequence is applied once per R-R interval before data acquisition begins, and immediately following the R-wave ECG trigger.



There are two Tag Type selections: stripes (diagonal lines) or a grid pattern (rotated 45° in-plane). The Tag Pixel Spacing is defaulted to a value of 7 pixels which defines the distance between the stripes or grid lines. The minimum spacing allowed is 2 pixels; the maximum spacing is determined by the frequency matrix, divided by 2 (XRES/2).

Something to Think About...

- A stripe overlay allows visualization of more anatomy in comparison to a grid overlay.
- A grid overlay allows visualization of motion in two directions. Stripe overlay results in decreased

visualization of motion occurring in the direction of the stripes.

- As the spacing increases, saturation effects decrease, but more anatomy is visualized.
- Tag lines fade as the slice is acquired further from the tag pulse application. Systole and beginning diastole are of most importance in evaluating wall motion. Tag fading is most prevalent during the rest period of diastole, therefore, if you are evaluating only wall motion (as opposed to information on the entire cardiac cycle), use FastCard-GRE with tagging.
- Tagging is only available with sequential FASTCINE GRE.
- Neither spatial nor chemical saturation pulses are compatible with cardiac tagging.

Applications

Tagging is primarily used for tissue motion studies, for example, assessing myocardial wall function. The SAT pulse saturates the tissue, which gives a dark appearance on the image that distorts as the tissue moves.

- Grid overlay is generally used for short axis imaging.
- Stripe overlay is generally used for long axis imaging.

Volume 2

Appendix A

Glossary of Terms and Acronyms

Introduction

This appendix defines the MR terms necessary for a working understanding of Pulse Sequence Databases. We could in no way list all terms associated with MR as it relates to GE equipment, but choose to include a few that may prove helpful when reading the next few chapters.

This glossary also provides the identification of the various acronyms used in this guide. The phrase is written out in full, followed by the acronym enclosed in parentheses, e.g. Pulse Sequence Database (PSD).

Glossary

3D Multi Slab: An image mode used in Time-of Flight vascular imaging for acquiring multiple overlapping 3D slabs.

90° Pulse: A pulse that rotates the magnetization vector 90° from longitudinal static magnetic field direction. This converts the longitudinal magnetization into transverse magnetization.

A/P: See Anterior/Posterior.

AFOV: See Asymmetric Field of View.

AIT: See Available Imaging Time.

Anterior/Posterior (A/P): A patient positioning selection designating the coronal plane alignment in order to ensure that the center of the region of interest is as close as possible to isocenter. The coronal plane divides the body into anterior (front) and posterior (back) sections.

Artifact: An error in the reconstructed image that does not correspond to the patient. There are three major forms of artifacts that can occur in MR imaging and contribute to poor image quality: geometric distortion, inhomogeneous signal intensity, and spurious signal.

Asymmetric Echo: An echo whose peak, at TE, is not centered in the sampling window. Also called fractional echo or partial echo.

Asymmetric Field of View (AFOV): 1. An FOV in which the vertical and horizontal dimensions are not equal. Simular to the rectangular FOV selected. 2. An imaging enhancement activated by choosing one of two FOV options: square pixel or variable FOV. Asymmetric FOV is useful for any scan which has anatomy smaller than the FOV in the phase direction. See FOV and square pixels.

Available Imaging Time (AIT): In cardiac gating, the time during which data can be collected by the MR system.

Average Flow: An Flow Analysis measurement. Summation of voxel values in a given flow region (ml/min), reflecting the volume per minute passing through the defined flow region of a specified cardiac phase or cycle.

Average Velocity: A Flow Analysis measurement. Flow Q (expressed in cm^3/sec) divided by the cross-sectional area A (expressed cm^2) of a vessel: V = Q/A (cm/sec); 1/2 V_{max} for laminar flow.

Averaging: A SNR-enhancing technique in which the same MR signal is added up, and then the sum is divided by the number of signals acquired.

Bandwidth: A range within a band of frequencies that an MRI system is "tuned" to receive. The receive bandwidth of an image determines the number of frequencies encompassed in the image. The system's bandwidth choice depends on the TE, matrix, and FOV you select.

Beats per Minute (bpm): The average heart rate as shown by the cardiac waveform display.

Bipolar Flow-Encoding Gradients: Two gradient pulses of identical shape, but opposite polarity. Used in order to encode velocities as changes of phase, as used in Phase Contrast angiography.

BPM: See Beats per Minute.

Cardiac Phase Images: Images demonstrating different times or phases within a cardiac cycle.

Cine: Generated images for dynamic views of anatomy such as the heart. This option employs retrospective gating techniques and a Gradient Echo pulse sequence.

CNR: See Contrast-to-Noise Ratio.

Collapsed: A Maximum Intensity Projection (MIP), also called Maximum Pixel Projection (MPP) from TOF magnitude images, or PC weighted-phase images. The collapsed image is the MIP in the slice direction.

Complex Difference: A flow reconstruction type for Phase Contrast Vascular Imaging providing control of the Slab Dephasing Gradient and Phase Correction. Complex Difference reconstructions have the Dephase Gradient off and Phase Correction on.

Contrast Resolution: An image function providing the ability to differentiate anatomical density differences with respect to surrounding anatomical regions.

Contrast-to-Noise Ratio (CNR): Ratio of the absolute difference in intensities between two regions to the level of fluctuations in intensity due to noise.

Coronal: The horizontal plane along the longitudinal axis of the body dividing it into anterior (front) and posterior (back) halves.

Decubitus Position: Describes the position of a patient lying on the left or right side.

Diastole: The period between the end of the T-wave and the beginning of the R-wave in the cardiac cycle. Also called ventricular filling.

Dynamic-Range Compression: A method of enhancing Phase Contrast image quality by applying a projection Dephasing Gradient to suppress signal from stationary tissues.

Echo Rephasing: Re-establishment of spin phase coherence, accomplished via a 180 degree RF pulse or gradient switching. See Refocusing.

Echo Time: See Time to Echo (TE).

Echo Train Length (ETL): The number of 180° refocusing pulses played out during one TR period.

EDR: See Extended Dynamic Range.

Effective R-R interval (RR): The inverse of bpm (Beats per Minute) measured in msec: RR = 60,000 divided by bpm.

Effective TR: The "average" repetition time, or TR, in cardiac gating. Measured as the number of RR intervals between successive excitations of a particular slice location - e.g., RR, 2xRR, 3xRR, 4xRR.

Effective value: A typical or average value - for example, effective TR. Since you can not control your patients heart rate, you can not control true TR in a gated study. You can control the effective TR by telling the system not to trigger at every beat.

ETL: See Echo Train Length.

Even-Echo Rephasing: Rephasing of moving spins on symmetric, even echoes (e.g., 2, 4, or 6) in Multi-Echo sequences.

Extended Dynamic Range (EDR): An imaging enhancement that uses 32-bit processing instead of the conventional 16-bits to improve SNR.

F/W: See Fat/Water Suppression.

Fast Cardiac Gating (FastCard): A 2D Time-of Flight, gradient recalled, single-breath PSD for acquiring multiple phases of the cardiac cycle at a single slice location.

Fat/Water Suppression (F/W): An imaging enhancement technique that suppresses signal within the imaging volume from either fat or water by applying a frequency-selective saturation pulse.

FID: See Free Induction Decay.

Field of View (Acquisition FOV): The area of the anatomy being imaged, usually expressed in centimeters. FOV image size is a function of the acquisition matrix times the pixel size.

First-Order Phase Correction: Phase errors in a Phase Contrast image can be modeled as a linear shading across the image in the x and y direction. In first order Phase Correction, the slopes of the x and y shading are determined to reduce the shading.

Flip Angle: Flip angle is the rotational angle of the magnetization vector produced by a RF pulse relative to the longitudinal axis of the static magnetic field. Flip angle adjusts contrast.

Flow Analysis: A flow reconstruction type for Cine-PC and 2D PC providing control of the Slab Dephasing Gradient and Phase Correction. Flow Analysis reconstructions have the Dephase Gradient off and Phase Correction off.

Flow Axis: The orthogonal axis (S/I, R/L, A/P) for which flow has been encoded in a flow image.

Flow Compensation (Flow Comp): An imaging enhancement using the system's gradients to put flowing protons into phase with stationary protons, thereby reducing flow artifacts. Applied in the slice and frequency directions.

Flow Encoding: A technique used in MR to measure or display motion such as blood flow within vessels.

Flow Image Set: An image type produced by Phase Contrast scans. Flow images are phase images that may or may not be magnitude weighted. If magnitude weighted, a multiplicative magnitude mask for noise suppression is applied to the phase image. Phase correction and scaling for velocity encoding may also be applied to the image. The default is for correction to take place, but correction can be turned off by selecting the Flow Analysis reconstruction mode on the vascular options screen.

Flow Recon Type: A user-selectable option for selecting a Slab Dephasing Gradient and a Phase Correction technique. See Phase Difference, Complex Difference, and Flow Analysis.

Flow-Related Enhancement: A process by which the signal intensity of moving fluids, like blood or CSF, can be increased compared with the signal of stationary tissue. Occurs when unsaturated, fully magnetized spins replace saturated spins between RF pulses.

FOV Center: The center of a scan image, which is ideally located at the magnet's isocenter.

Fractional Echo: A feature instructing the system to collect just part of the data it normally would. Reduces susceptibility and flow artifacts.

Fractional NEX: A feature instructing the system to use about half or exactly three-quarters of the phase encoding acquired in conventional imaging. Decreases scan time significantly.

Free Induction Decay (FID): The measurable magnetic resonance signal that occurs as the transverse magnetism, produced by the application of the 90° pulse, decays toward zero.

Frequency: The scanning direction associated with the frequency gradient. Usually corresponds to the image's long axis.

Gating: An MR technique for imaging rapidly moving anatomy such as the heart. Uses equipment such as a standard electrocardiograph to trigger data acquisition.

GMN: See Gradient Moment Nulling.

Gradient Echo Imaging: A pulse sequence that reverses gradient polarity to rephase protons and form echoes. Permits short TRs and flip angles of less than 90° to excite only a portion of the longitudinal magnetization.

Gradient Echo: A basic Fast Scan pulse sequence that uses pulses of 1° to 180° to excite the protons of interest and rephase them. Gradient Echo uses gradients rather than conventional RF pulses.

Gradient Moment Nulling (GMN): The application of gradients to correct phase errors caused by velocity, acceleration or other motion. First-order gradient nulling is the same as Flow Compensation.

Gradient Moment: In MR angiography, the first moment describes a gradient's effect on the phase of a spin with constant velocity; the second moment, its effect on spins experiencing acceleration; the third moment, its effect on spins experiencing jerk.

Gradient-Recalled Acquisition in the Steady State (GRASS): See Gradient Echo and MPGR Gradient Echo.

GRASS: See Gradient-Recalled Acquisition in the Steady State.

G_x, G_y, G_z: Symbols for MR gradients. Subscripts indicate the spatial direction of each gradient.

Intersequence Delay: The time between each image in the cardiac cycle.

Intravoxel Spin-Phase Dispersion: A loss of phase coherence and therefore, signal intensity that can result when a wide spectrum of flow velocities exist, when higher orders of motion like acceleration are present, or when there are minor variations in magnetic field homogeneity.

Inversion Recovery (IR): A pulse sequence that inverts the magnetization and then measures the recovery rate as the nuclei return to equilibrium. This rate of recovery depends on T1.

Inversion Time (TI): The time between the center of the first (180°) inverting pulse and the beginning of the second (90°) refocusing pulse in an IR pulse sequence.

IR: See Inversion Recovery.

Isocenter: The point at which the three gradient planes cross.

Isochromats: Spins sharing the same phase and frequency at a given point in time.

Isometric Contraction: The time immediately after the R-wave when the heart prepares for contraction but does not change in volume.

J-Coupling: Also called Spin-Spin Coupling. The interaction between multiple lines and nuclei. When this interaction takes places the nuclei split their energy levels according to J (the spin-spin coupling constant).

Magnetic Field Gradient: A device for varying the strength of the static magnetic field at different spatial locations. This is used for slice selection and determining the spatial locations of protons being imaged. Also used for Velocity Encoding, Flow Comp, and in place of RF pulses during Gradient Echo acquisitions to rephase spins. Commonly measured in gauss per centimeter.

Magnetic Resonance (MR): The absorption or emission of electromagnetic energy by nuclei in a static magnetic field after excitation by a suitable RF pulse.

Magnetic Resonance Imaging (MRI): The creation of images using the magnetic resonance phenomenon. The current application involves imaging the distribution of hydrogen nuclei (protons) in the body. The image brightness in a given region usually depends jointly on the spin density and the relaxation times. Image brightness is also affected by motion such as blood flow.

Magnetic Resonance Signal: The electromagnetic signal (in the radio frequency range) produced by the precession of the transverse magnetization of the spins. The rotation of the transverse magnetization induces a voltage in the coil. This voltage is amplified by the receiver.

Magnetization Transfer: A technique that improves contrast by saturating the short T2 component of tissue such as gray/white matter and skeletal muscle.

Maximum Intensity Projection (MIP): A technique for producing multiple projection images from a volume of image data (i.e., 3D volume or a stack of 2D slices). The volume of image data is processed along a selected angle and the pixel with the highest signal intensity is projected onto a two-dimensional image.

MIP: See Maximum Intensity Projection.

MPGR: See Multi-Planer Gradient Echo.

MR: See Magnetic Resonance.

MRI: See Magnetic Resonance Imaging.

MSMP: See Multi-Slice, Multi-Phase Imaging.

MSSP: See Multi-Slice, Single-Phase Imaging.

Multi-Planer Gradient Echo (MPGR): A pulse sequence that represents a combination of Gradient Echo and Spin Echo sequences. Acquires data sequentially rather than slice-by-slice.

Multi-Slice, Multi-Phase (MSMP) Imaging: Multi-slice, multi-phase cardiac gating pulse sequence that produces images at multiple heart locations and several different cardiac phases at each location.

Multi-Slice, Single-Phase (MSSP) Imaging: Multi-slice, single-phase cardiac gating pulse sequence that produces images at multiple heart locations, each at a different phase of the cardiac cycle.

NEX: See Number of Excitations.

Number of Excitations (NEX): The number of times a pulse sequence is repeated in a given acquisition.

PD-Weighted: See Proton Density-Weighted.

Phase Difference: A flow reconstruction type for Phase Contrast Vascular imaging providing control of the Slab Dephasing Gradient and Phase Correction. Phase difference reconstructions have the Dephase Gradient off and Phase Correction on.

Phase Encoding: The act of localizing an MR signal by applying a gradient pulse to alter the phase of spins before signal readout.

Phase FOV: The Phase Field of View option provides faster scans by scaling down the size of the field of view in the phase direction by 3/4 or 1/2. The phase FOV option is not compatible with some PSD and imaging options.

Projection Dephasing Gradient: A gradient applied to diminish signal from stationary tissues in thick slab 2D Phase Contrast angiography.

Proton Density-Weighted (PD-weighted): PD-weighted images have contrast that is primarily due to the number of protons in the structures. PD-weighted images result when scan timing parameters are selected that minimize the T1 (long TRs) and the T2 (short TEs) contrast effects.

PSD: See Pulse Sequence Database.

Pulse Length or Width: The duration of a pulse, expressed in milliseconds.

Pulse Sequence Database (PSD): A series of RF and gradient pulses and the intervals between them used in conjunction with gradient magnetic fields to produce magnetic resonance images.

Radio Frequency (RF): The frequency (intermediate between audio and infrared frequencies) used in magnetic resonance systems to excite nuclei to resonance.

Radiofrequency Pulse (RF Pulse): A burst of RF energy which, if it is at the correct Larmor frequency, will rotate the macroscopic magnetization vector by a specific angle, dependent on the amplitude and duration of the pulse.

Ramp Pulse: An RF excitation pulse that has smaller flip angles for spins flowing into the slab. As spins penetrate deeper into the slab, the flip angle increases. For example, a 2:1 Ramp Pulse, with a nominal flip angle of 20°, provides the entry slices with a flip angle of about 13°, and the exit slices with a flip of about 27°.

Readout Gradient: A gradient pulse, applied when an MR signal is collected, used for frequency encoding.

Refocusing: The re-establishment of phase coherence via gradient or RF pulse. See Echo Rephasing, Gradient Echo, and Gradient Moment Nulling.

Relaxation Time: The time required for 63% of the nuclei to revert to their original state in the magnetic field after the RF pulse is turned off.

Repetition Time (TR): The time between successive excitations of a slice. That is, the time from the beginning of one pulse sequence to the beginning of the next. In conventional imaging, it is a fixed value equal to a user-selected value. In cardiac-gated studies, however, it can vary from beat to beat depending on the patient's heart rate.

Rephasing Gradient: A gradient applied in the opposite direction of a recent selective excitation pulse, in order to correct for gradient-induced phase shifts.

RF: See Radio Frequency.

R-R Interval: That part of an ECG waveform representing the heart's electrical activity showing the time between the peak of one R-wave and the peak of the next one. Each R-R interval represents the length of one cardiac cycle.

Saturation Pulse: A slice-selective RF pulse applied, often followed by a Dephasing Gradient, to saturate spins and therefore minimize their signal. Used, for example, to minimize signal from flowing blood in the slice direction.

Saturation: Repeated application of radio frequency pulses in a time that is short compared to the T1 of the tissue, producing incomplete realignment of the net magnetization with the static magnetic field.

Scan Time: The amount of time needed to acquire data.

Sequential IR: An Inversion Recovery sequence in which the system applies the 180°/90°/180° pulses a slice at a time. With the alternative, non-sequential, the system applies the initial 180° pulse to all slices, then returns to each slice to complete the sequence.

Signal-to-Noise Ratio (SNR): The ratio of signal amplitude to noise - i.e., the amplitude of signal emitted by the patient's protons, divided by the amount of patient noises and electronic noise inherent in any electronic instrument.

Slice Select: The scanning direction associated with the slice-select gradient. Usually corresponds to the direction of the scanning range.

SNR: See Signal-to-Noise Ratio.

Spatial Encoding: A method by which data is collected in order to formulate a three-dimensional image in a two-dimensional plane.

SPGR: See Spoiled Gradient Echo.

Spin Echo imaging: A magnetic resonance imaging technique in which the Spin Echo magnetic resonance signal rather than the Free Induction Decay is used.

Spin-Spin Coupling: See J-Coupling.

Spoiled Gradient Echo (SPGR): A Gradient Echo pulse sequence designed for acquiring T1-weighted images in 2D or 3D mode.

Spoiler Pulse: A gradient pulse applied to dephase spins and to minimize or eliminate residual signal.

SSFP: See Steady State Free Precession.

Steady State Free Precession (SSFP): 1. A Gradient Echo pulse sequence designed for acquiring T2-weighted images in 3D mode. 2. A condition achieved by repeatedly exciting an MR sample with phase-coherent RF pulses at a repetition rate (TR) which is shorter than T2.

T1: The characteristic time constant for the magnetization’s return to the longitudinal axis after being excited by an RF pulse. Also called Spin Lattice or Longitudinal Relaxation Time.

T1-Weighted: Scan protocols that allow the T1 effects to predominate over the other relaxation effects.

T2*: The characteristic time constant for loss of transverse magnetization and MR signal due to T2 and local field inhomogeneties. Since such inhomogeneities are not compensated for by gradient reversal, contrast in gradient-echo images depends on T2*.

T2*-Weighted: Scan protocols that allow the T2* effects to predominate over the other contrast effects. There are three primary gradient echo pulse sequences that can be used to produce varying T2*-weighted images: Gradient Echo, SPGR, and SSFP.

T2: The characteristic time constant for loss of phase coherence among spins, caused by their interaction, and the resulting loss in the transverse-magnetization MR signal. Also referred to as Spin-Spin or Transverse Relaxation Time.

T2-Weighted: Scan protocols that allow the T2 effects to predominate over the other contrast effects.

TE Min: The shortest possible TE time for a given prescription, used to minimize flow dephasing and T2 effects.

TE: See Time to Echo.

TE1: The time from the middle of the first excitation pulse to the middle of the first readout in an Asysmmetrical Spin Echo pulse sequence.

TE2: The time between the middle of the first excitation pulse and the middle of the second readout in an Asysmmetrical Spin Echo pulse sequence.

Threshold: A technique for setting the desired pixel signal intensity values the system uses to process an image.

Throughplane: A flow-encoding direction which is perpendicular to the imaging plane.

TI: See Inversion Time.

Time to Echo (TE): The time between the center of the excitation pulse and the peak of the echo, which usually occurs at the center of the readout.

Time-of-Flight (TOF) Angiography: A 2D or 3D imaging technique that relies primarily on flow-related enhancement to distinguish moving from stationary spins in creating MR angiograms. Blood that has flowed into the slice will not have experienced RF pulses and will therefore appears brighter than stationary tissue.

TOF Angiography: See Time-of-Flight Angiography.

TR: See Repetition Time.

Trigger Delay: The time between the occurrence of the triggering pulse and the actual onset of imaging.

Trigger Window (TW): In cardiac gating, a period during which no further data can be acquired. During this period, the system waits for the next R-wave trigger, which initiates a new sequence of data acquisition.

Trigger: In cardiac/respiratory gating, signal sent by the cardiac/respiratory monitor to activate data acquisition.

TW: See Trigger Window.

Variable Bandwidth (VB): An imaging option that lets you narrow the system's receiver bandwidth to increase SNR. Narrowing the bandwidth forces the system to detect signals from a small range of frequencies. This means the system discards more random electronic noise, improving SNR. The system narrows the Variable Bandwidth only as much as the selected TE allows.

VB: See Variable Bandwidth.

Velocity Encoding (VENC): A value entered to prescribe the highest velocities to be encoded without aliasing in Phase Contrast angiography.

VENC: See Velocity Encoding.

Very Selective Saturation (VSS): Used in spectroscopy.

Volume Imaging: An acquisition technique in which signal is collected from an entire volume rather than individual slices. Permits reconstruction of extremely thin slices, and usually enhances SNR.

VSS: See Very Selective Saturation.

Water Suppression: The suppression of the water signal in a MR spectrum, usually by a specialized excitation sequence.

Weighted-Phase Images: Images that present flow data. Directional-flow images demonstrate flow along a single axis; speed-flow images combine all flow information into a single presentation.

Symbols

Numerics

A

Q

R

S