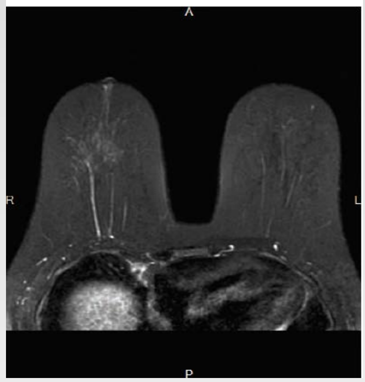
MRI Anatomy and Positioning Series

Module 12: Fat Suppression Techniques

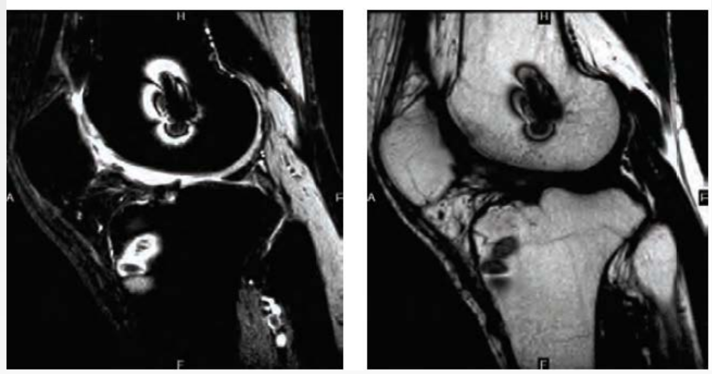
Water Excitation

RF Fat Saturation



Inversion Recovery

FatSep



HITACHI
Inspire the Next

Introduction 3
RF FatSat 4
HOAST 4
FatSat 5
Segment FS 8
PhaseCycle 9
Water Excitation 10
STIR 12
FatSep 14
Gradient Echo FatSep 16
Single Echo 17
Multi Echo 18
Fast Spin Echo FatSep 18
Single Echo 19
Multi Echo 20
Conclusion 20
Appendix A: References for Fat Suppression Techniques Module 21
Appendix B: References for Pictures for Fat Suppression Techniques Module 22

Introduction

Signal from fat can play a critical role in determining the useful contrast of MR images in many situations. Being able to control the signal developed by fatty tissue is a powerful and perhaps under-rated method available in our scan library.

Fat tissues have a short T1 relaxation time (when longitudinal recovery is occurring), and appear as hypersignal in T1-weighted sequences. The T2 relaxation time of fat is also relatively short (when transverse decay is occurring), but fat still appears as a relatively high signal intensity in T2-weighted sequences with multiple echoes, such as FSE (**F**ast **S**pin **E**cho). Fat can be helpful in the display of anatomy and pathology. In T2-weighted FSE images of the lumbar spine, bright fat outlines the exiting nerve roots in a manner normally associated with T1-weighted images, while the high signal from CSF (**C**erebro**S**pinal **F**luid) provides high contrast to display the intra-thecal nerve roots clearly. However, the high signal intensity of fat can hide enhancement after a Gadolinium contrast injection in T1-weighted sequences, or an edematous hypersignal in fatty organs in T2-weighted sequences. It may be difficult to distinguish fat from other tissues with high T1 and T2 signal intensities, such as blood degradation products in a hematoma. Fat is responsible for chemical shift artifacts, and is also clearly visible in motion artifacts. There are many situations in clinical MRI where it is desirable to remove the fat contribution from the total MR signal, without affecting the water signal- in other words, fat suppression. Fat suppression techniques can be used to enhance tissue contrast and lesion conspicuity, to determine if the tissue of interest has high or low lipid content, and to remove artifacts. Specific examples include suppression of the marrow signal from around joints and in vertebrae, and the suppression of the fat signal in the orbits to better differentiate tissues of interest (cartilage and ligaments, bone metastases, optic nerve, etc.) from surrounding fatty tissue. Fat suppression techniques can definitely add a useful “extra dimension” to the manipulation of image contrast.

There are two basic families of techniques that are used to reduce or even suppress the signal from fat tissue:

- Those based on the particular T1 of fat; the T1 values for fat are much shorter than those of water; STIR sequences are based on the T1 of fat
- Those based on chemical shift, which is the difference in hydrogen resonance frequency in fat molecules compared to hydrogen resonance frequency in water and other soft tissues; hydrogen protons in water resonate slightly faster than those in fat; spectral or RF fat saturation, fat separation (Dixon technique), and selective excitation of water are based on chemical shift

Each of the fat suppression methods to be discussed in this seminar comes with pros and cons. Selection of a specific method depends on the field strength used for scanning, the field-of-view size, whether regional or global fat suppression is required, whether an increase in scan time is acceptable, etc. The choice of technique may not be motivated by the absolute quality of fat suppression, but more importantly by the contrast between tissues. Additional challenges include field homogeneity, metal susceptibility, scan time increase, and reduction of SNR (**S**ignal to **N**oise **R**atio).

RF FatSat

RF (**R**adio **F**requency) FatSat (**Fat Sat**uration) techniques take advantage of the difference in resonant frequencies between fat and water. This difference increases with increasing magnetic field strength through a scaling factor called the chemical shift. Chemical shift occurs because the electron clouds surrounding hydrogen nuclei behave differently in fat and water. In triglyceride molecules of fat, the electron clouds are evenly shared, and they serve to "shield" the hydrogen nuclei from the external magnetic field. The stronger the "shielding" fields are, the more they can reduce the magnetic field that the hydrogen nuclei experience, so the nuclei will precess at a lower Larmor frequency. In water molecules, the electron-negative oxygen atom "steals" the electrons from the hydrogen nuclei, leaving them "de-shielded". The hydrogen nuclei in water experience a higher magnetic field than the hydrogen in fat, and precess at a higher Larmor frequency. Since fat and water are precessing at different Larmor frequencies, a frequency selective RF pulse can be applied that will only affect the magnetization of the fat protons. RF fat saturation methods available on Hitachi's Oasis and Echelon Oval MR systems include FatSat, Phase Cycle, Segment FatSat, and Water Excitation (Figure 1). The RF FatSat methods that are available will vary based on the pulse sequence and additional parameters that have been selected. Parameters available in the Saturation section will also vary with the type of Saturation that is selected, or may default to a specific selection.

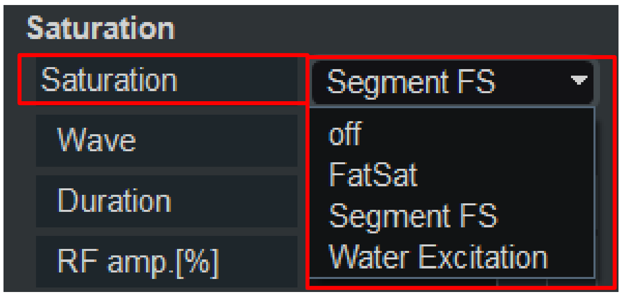


Figure 1 Saturation parameters available with RF FatSat

HOAST

HOAST (**H**igher **O**rder **A**ctive **S**him **T**echnology) provides uniform RF FatSat, outstanding large FOV (**F**ield **O**f **V**iew) capabilities, and excellent off-isocenter imaging. In a uniform, or homogeneous, magnetic field, fat and water peaks have a constant frequency separation. Without HOAST, the patient's body makes the magnetic field non-uniform, which makes fat saturation inconsistent. With HOAST, the effect of the patient's body is reduced, promoting consistent fat saturation, even across large FOV's. Higher order active shimming adjusts for each patient, which maximizes image quality. Use of Hitachi's Regional Shim parameter produces excellent off-isocenter fat suppression, enabling high uniformity on FatSat images for anatomy that must be scanned out of isocenter.

FatSat

Routine FatSat involves the application of a 90° RF pulse that is tuned to the resonant frequency of fat. This pulse is integrated into the pulse sequence, and occurs prior to the excitation pulse for the MR pulse sequence. The FatSat pulse causes the magnetic vector of fat to be flipped into the transverse plane. The RF excitation pulse that is applied when the MR sequence begins will flip the fat-based nuclei further, so they are now below the transverse plane. With no component of transverse magnetization, the fat nuclei do not produce a signal.

When FatSat is selected as the type of Saturation, additional parameters available for selection include:

- **Wave** – Provides options for the waveform of the FatSat pulse; each of the waveforms maintains a minimum TR, which limits the number of slices available. Oasis system choices are Sinc, H-Sinc Light, and H-Sinc Heavy; OVAL system choices are Sinc, H-Sinc, H-Sinc Light, H-Sinc Heavy. H-Sinc Light suppresses lipids, while H-Sinc Heavy suppresses lipids, as well as fatty protons that precess at the same frequency as water.
- **Duration** – Sets the time (in milliseconds) for the FatSat pulse to be active. This value determines the frequency bandwidth for the patient signal that is suppressed by the FatSat pulse. Time and frequency bandwidth are inversely related, so a shorter time results in a wider frequency bandwidth, while a longer time results in a narrower frequency bandwidth.
- **RF amp**. **%** – Sets the strength (RF amplitude) of the FatSat pulse. If this value is changed, the suppression effects of the fat signals will change; 100% of the initial value is the optimal strength calculated from the **Wave** and **Duration** parameters.
- **Off**. **Freq [Hz]** – Displays the offset frequency, or frequency difference, between the fat peak and the water peak. This value is field strength dependent, and should not be changed. It should be set at -173Hz for the Oasis system, and -224Hz for the Echelon Oval system. This parameter field does not appear when the **Freq. graph** field is set to Auto or ON (Figures 2-4).
- **Freq**. **graph** – Setting determines whether or not a Frequency Graph is displayed in the Frequency Prescan window. If set to off, the Frequency Graph does not display, but the **Off Freq.** parameter field will display. If set to Auto, the Frequency Graph displays when the Off. Freq. is determined in the Exam window during the acquisition. If set to ON, the Frequency Graph is displayed.

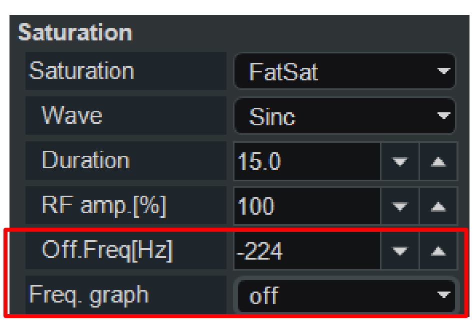


Figure 2 Offset Frequency displays when Frequency Graph is turned off

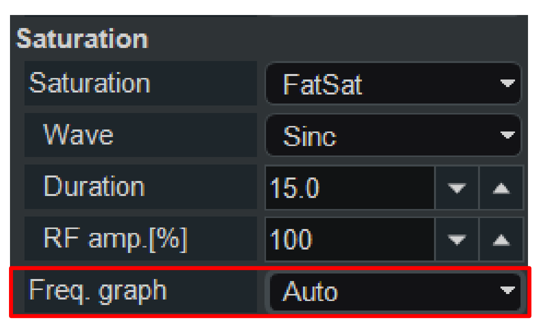


Figure 3 Frequency Graph set to Auto

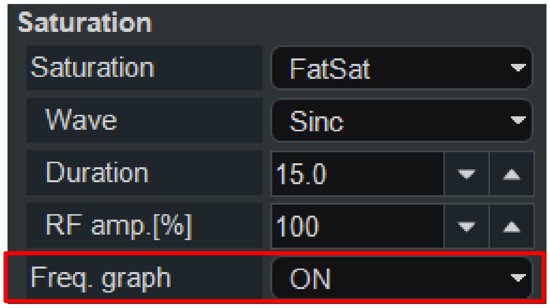


Figure 4 Frequency Graph set to ON

Frequency graph results are displayed in the Frequency Prescan window when any type of saturation has been selected in the Saturation parameter field, and the Freq. graph selection is set to ON, or Auto, under select conditions (with FatSat on Oasis, with FatSat or Segment FatSat on Echelon Oval). The Frequency Prescan window opens after the Prescan is performed (Figure 5). The settings displayed for the frequency graph include:

- **Frequency (MHz)** – Displays the central frequency
- **Offset Frequency (Hz)** – Displays the FatSat pulse's frequency, as a value relative to the central frequency; set at -173 for Oasis, and -224 for OVAL; this setting is changed if something other than fat is to be suppressed (e.g. silicone or saline)
- **Noise Threshold (%)** – Used only in conjunction with the Weighted selection for Search Mode (Hitachi recommends using the Peak method for Search Mode)
- **Search Mode** – Select search method for frequency values, either Peak or Weighted method; Hitachi recommends the Peak method, where center frequency is set at the signal's maximum frequency value
- **Reset Param** – Resets the above parameters to their initial settings

Items displayed on the frequency graph include:

- **Vertical axis** – Signal value
- **Horizontal axis** – Frequency (MHz)
- **Green vertical line** – Offset frequency (fat peak)
- **Blue vertical line** – Center frequency (water peak)

The blue vertical line should be positioned so that it is centered at the base of the water peak, splitting the base into two equal parts. The water peak is the peak on the right. It is acceptable if the blue line does not go through the exact point of the water peak. The green vertical line will move in conjunction with movement of the blue vertical line, in order to maintain the proper offset frequency between fat and water.

Figure 5 Frequency Graph display

FatSat can be applied to virtually any sequence with any weighting (Figure 6). It can be used for fat suppression after Gadolinium injections, and will not modify the contrast of other tissues. Using FatSat adds another RF pulse, so TR and acquisition time will increase, and SAR will increase as well. FatSat does require a homogeneous magnetic field, so shimming should be performed prior to its use.

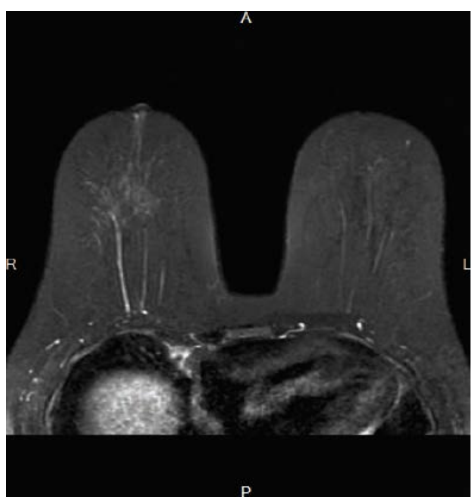


Figure 6 FatSat results in breast imaging

FatSat is easier to accomplish at higher field strengths vs. lower field strengths, as the frequency difference between the two resonances increases with field strength. Protons in fat and water molecules are separated by a chemical shift of approximately 3.5 ppm (parts per million). The actual shift in Hertz depends on the field strength of the magnet being used. Hitachi's Oasis magnet (1.2T) has an offset frequency between fat and water of -173Hz (Hertz), while the Echelon Oval (1.5T) has an offset frequency of -224Hz. The offset frequency on the AIRIS Elite (0.3T) is only -45Hz.

The occurrence of chemical shift is responsible for the chemical shift artifact that occurs during frequency encoding. The difference in resonant frequency between water and fat protons at the same location can be mislocated by the Fourier transformation when the MRI signals are converted from the frequency domain to the spatial domain. The chemical shift artifact causes accentuation of any fat-water interfaces along the frequency axis, and may be mistaken for pathology. It is visualized as a bright or dark band at the edge of the anatomy where fat and water are in the same location (e.g. kidneys and orbits). Although chemical shift artifacts increase at higher field strengths, the use of FatSat (and other fat suppression techniques) can eliminate these artifacts, as they are suppressing or eliminating the fat signal.

Segment FS

When Segment FS (**Segment**ed **F**at**S**at) is selected, the FatSat pulses are applied in numerous segments or sections, in order to maintain uniform fat suppression throughout a dynamic scan. Segment FS is only available when RSSG is selected as the Sequence parameter, and the 2D/3D selection is 3D. If TIGRE is selected in the Mode parameter field under RSSG, the Saturation parameter field will default to Segment FS. The 3D RSSG sequence in TIGRE mode with Segment FS is the basis of Hitachi's "TIGRE" sequence.

The Saturation parameters explained above (Wave, Duration, RF amp, and Off. Freq), as well as the frequency graph, are all available with Segment FS (Figure 7). H-Sinc is recommended as the setting for the Wave parameter field when the TIGRE sequence is used, as it provides more consistent fat saturation with TIGRE. Segment FS also incorporates the Segment # parameter, found in the Seq. Parameter area. This setting has been optimized in Oasis and Echelon Oval protocols, and should not be adjusted. If the Segment # is increased, scan time is decreased, but the effects of the fat suppression are also reduced.

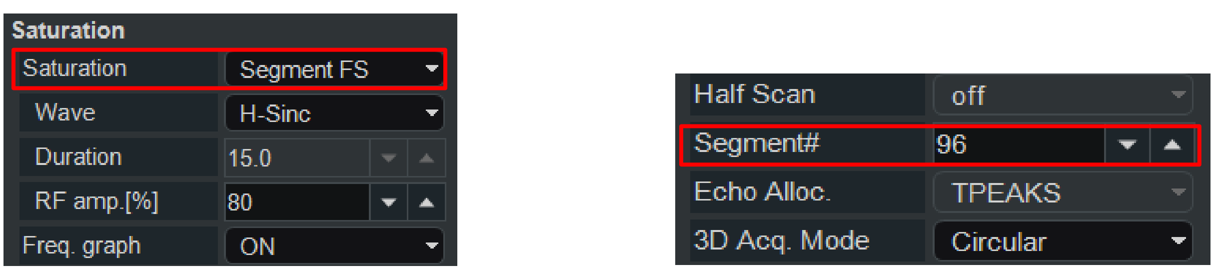


Figure 7 Segment FS selected as Saturation parameter; additional parameter Segment# also utilized

Segment FS is primarily used in conjunction with the TIGRE (**T1 GR**adient **E**cho) sequence, which is a fast 3D T1-weighted spoiled gradient echo with fat suppression. TIGRE is used for dynamic studies of the breast, liver, prostate, and kidneys. The use of Segment FS helps to provide uniform fat suppression throughout these dynamic studies (Figures 8-9).

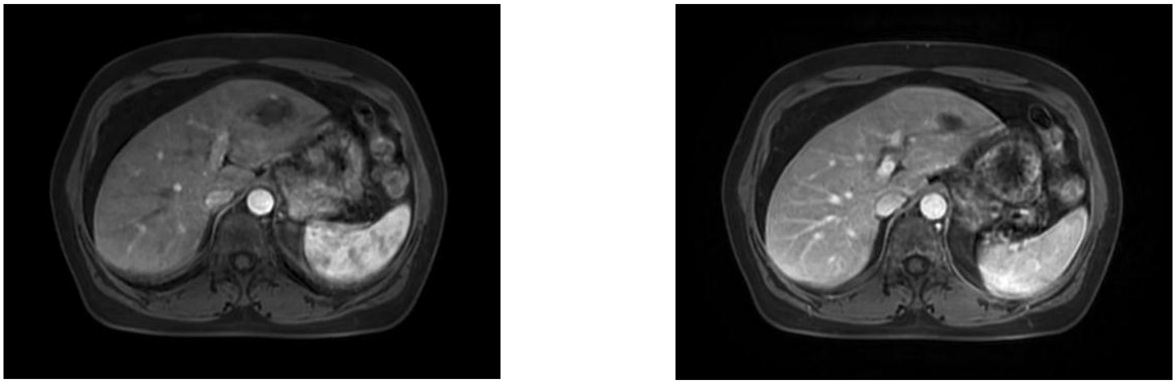


Figure 8 Images from TIGRE sequence in abdomen; arterial image on left, venous image on right

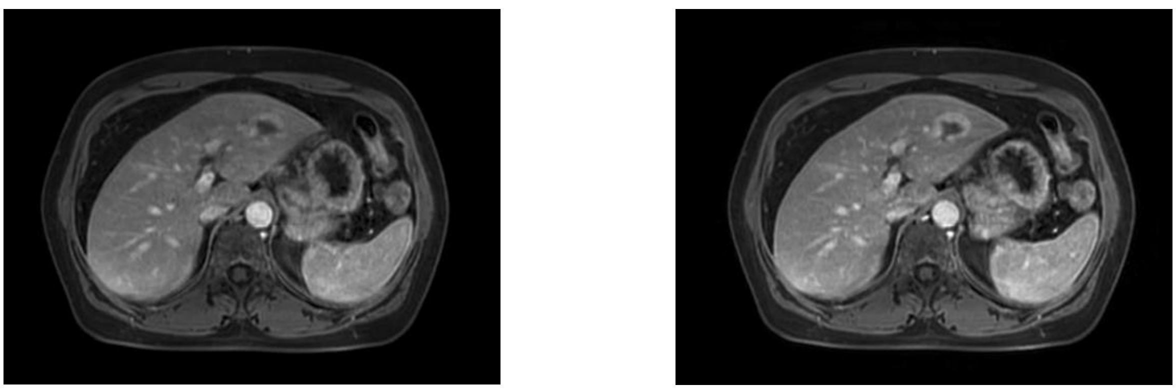


Figure 9 Images from TIGRE sequence in abdomen; 90 second delay image on left, 3 minute delay image on right

PhaseCycle

When PhaseCycle fat saturation is used, scanning is performed multiple times, and fat signals are selectively suppressed. When fat and water based nuclei are within the same voxel, the differences in their precessional frequencies will cause the MR signals from each to move in- and out-of-phase with each other. This constructive and destructive interference causes the signal level to vary in strength cyclically after the excitation pulse. The frequency of this variation is equal to the chemical shift, so it varies with field strength. This “phase cycling” effect is also the basis for FatSep, or the Dixon method.

In-phase and out-of-phase images can be selected by choosing an appropriate TE (**T**ime to **E**cho). Images obtained when the fat and water vectors are in-phase will have similar contrast to Spin Echo images. Images obtained when fat and water vectors are out-of-phase will display a chemical how Phase Cycle fat saturation misregistration artifact, or India ink artifact, at borders of fatty and water based tissue. This artifact appears as a dark outline of organs, and occurs when voxels contain equal amounts of fat and water spins, causing a complete cancellation of signal. If there are not equal amounts of fat and water spins in the voxels, varying degrees of signal loss will occur, compared to the in-phase image. However, this varying signal loss can be used to identify fatty infiltration of the liver, and tumor infiltration of marrow spaces. T2* decay causes a rapid decrease in magnetization, so it is important for image quality to use the earliest possible TE for out-of-phase imaging. At 1.5T, this TE time is 2.2msec, so partial echo techniques may be used to implement this short TE. Although some SNR may be sacrificed, that loss is preferable to waiting for the next out-of-phase period and incurring T2* decay.

Use of PhaseCycle fat saturation requires that the Multi scan mode parameter be set to Fluoro or Dynamic, and the Sequence must be a BASG. Again, the Saturation parameters explained above (Wave, Duration, RF amp, and Off.Freq), as well as the frequency graph, are all available with PhaseCycle. In addition, there is a Quasi TimeRes field that can be set to off or ON. Time resolution may be improved if this parameter is set to ON, and data is shared.

PhaseCycle fat saturation can be used as a method to characterize tissues based on differences in water and fat resonance frequencies. This method may be used in abdominal imaging to characterize certain diseases, such as adrenal adenomas and hepatic steatosis. As mentioned above, it can also be used to identify fatty infiltration of the liver, and tumor infiltration of marrow spaces.

Water Excitation

The water excitation technique uses a short series of RF pulses to selectively excite only water protons, leaving the fat spins unaffected. This series of RF pulses are called binomial pulses, which are correctly phased broadband RF pulses that selectively excite water by exploiting the phase cycling effect. Their net effect is to produce a 90° pulse for the water spins, and a 0° pulse for the fat spins. Although these binomial pulses may be slightly longer in duration than normal excitation pulses, they are a quick way to achieve fat suppression.

Binomial pulses are a class of composite pulses with flip angles that follow the pattern of coefficients of the binomial expansion of $(a + b)^n$. Binomial excitation methods are described numerically, with the number referring to the relative amplitude of the pulse. The total of the flip angles of the pulses will add up to 90°. A 1:1 pulse would be a pair of pulses, each with 45° flip angles, shown as (45°-45°). A 1:2:1 pulse would be a (22.5°-45°-22.5°) triplet. A 1:3:3:1 pulse would be a (11.25°-33.75°-33.75°-11.25°) quadruplet. Any combination whose ratios follow the binomial pattern and add up to 90° will work to selectively excite water and leave the fat resonance unchanged.

For further understanding, below is an explanation of how two appropriately timed broadband non-selective 45° pulses (1:1) result in selective excitation of the water signal only (Figure 10):

- At equilibrium, the magnetization vectors of water and fat both point along the z-axis in the direction of the main magnetic field ($B_{0)}$
- The first 45° pulse causes both vectors to be tipped partially toward the transverse plane and begin to precess; since fat and water protons precess at different frequencies, after a few msec the fat and water vectors will be exactly 180° out of phase; the time it takes for fat and water to get 180° out of phase is used as the inter-pulse delay time

- After the inter-pulse delay time, a second non-selective 45° pulse will rotate the fat vector back to its original position along the z-axis, while rotating the water vector entirely into the transverse plane
- The combination of the two non-selective 45° pulses had the same effect as a single frequency-selective 90° water excitation pulse

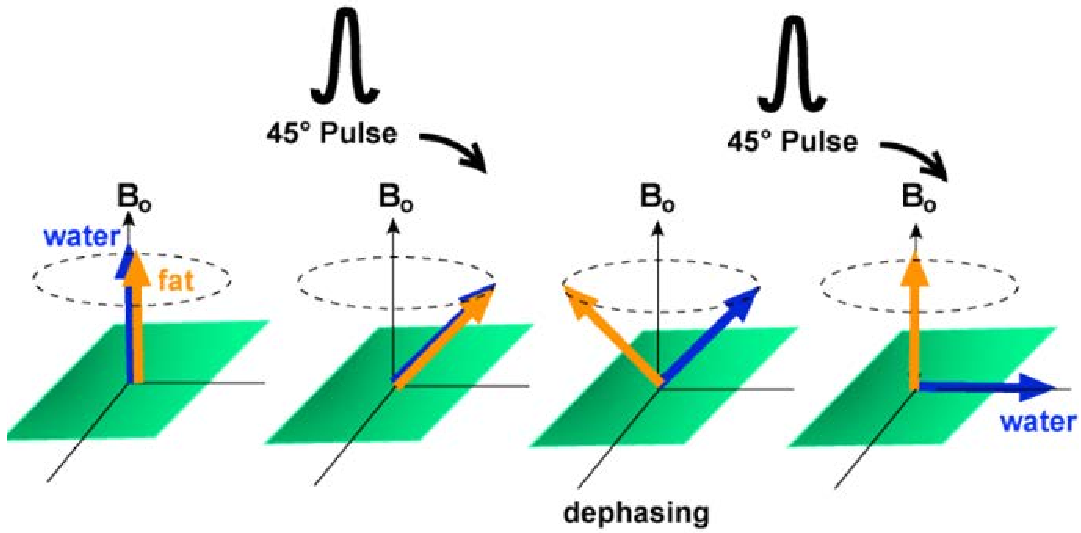


Figure 10 1:1 water excitation pulses

Water excitation as a fat saturation method can be used with specific sequences on the Oasis and Echelon Oval MR systems, namely 2D SE (**S**pin **E**cho), 2D/3D GE (**G**radient **E**cho), 2D/3D RSSG (**R**F **S**poiled **S**AR**G**E), 2D/3D TOF (**T**ime **O**f **F**light), and 2D/3D BASG (**BA**lanced **S**AR**G**E). The Saturation parameters explained above (Duration, RF amp, and Off.Freq), as well as the frequency graph, are all available with Water Excitation. The Wave parameter field displays the groups of composite pulses that are available (Figure 11).

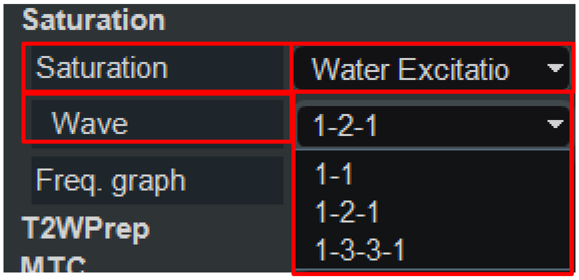


Figure 11 Water excitation wave parameter choices

As the number of waveforms, or RF pulses, increases, the effect of water excitation is increased. However, the minimum TR and TE are restricted because of the increased duration of the RF pulse. A triplet or higher binomial chain may slightly prolong the water excitation sequence. Water excitation pulses are less sensitive than most other techniques to non-uniformities in RF pulse transmission, including variations in flip angle. The nulling of fat is primarily controlled by precise timing of the inter-pulse delays that allow water and fat to go out of phase. Even if the flip angles are not perfect, and water is not exactly at 90°, the total flip angle for the fat spins will still be 0°. Water excitation is somewhat sensitive to B_0 magnetic field inhomogeneities.

Water excitation has been found to be valuable in musculoskeletal imaging for excellent depiction of cartilage in all extremities (Figure 12). Additional reported uses include 3D applications in the breast and liver.

Figure 12 Water excitation image

STIR

STIR is an acronym for **S**hort **T**I **I**nversion **R**ecovery or **S**hort **T**au **I**nversion **R**ecovery. STIR works as a fat suppression method by exploiting the difference in T1 relaxation times between fat and water, not their chemical shift. The value of the inversion time, TI, is selected so that the fat signal does not contribute to the resulting image. The TI value depends on field strength, since the T1 of fat increases with field strength. Using a flip angle of 180°, the total signal (fat and water) is initially inverted, and allowed to relax back to equilibrium via T1 relaxation. As the spins relax back to their equilibrium configuration, the signal for each spin group evolves from a negative signal, through zero (the null point), to a positive signal, at a rate that is determined by the T1 of the spin group. Since fat has such a short T1 time, the null point for fat signal typically occurs much sooner than for other tissues. If the MR sequence is started when the fat signal is at its null point, the fat spins will not contribute to the resulting image. Tissues with a T1 time that is different from fat will have a signal, as they have either not yet reached their null point, or have recovered past it.

Fat suppressed images resulting from STIR sequences will be inherently T1-weighted. However, the T1 contrast will be inverted relative to conventional T1-weighting. Tissues with a short T1 will appear dark, while tissues with a long T1 will be bright. The signal from tissues with a T1 time close to the T1 time of fat will also be substantially suppressed when STIR fat suppression is used, leaving STIR images with an intrinsically lower SNR. STIR, as well as other short and medium TI sequences, has an additional useful feature termed additive T1 + T2 contrast. In routine Spin Echo imaging, lesions with prolonged T1 and T2 have competitive effects on signal intensity, namely that increased T1 reduces signal, while increased T2 increases signal. In STIR imaging, the effects of increased T1 and increased T2 are additive (Figure 13). This occurs because the longitudinal magnetization of long T1 lesions remains inverted on STIR, and produces a high signal. Additive T1 and T2 effects allow for better visualization of MS plaques on a STIR image as opposed to a Spin Echo image.

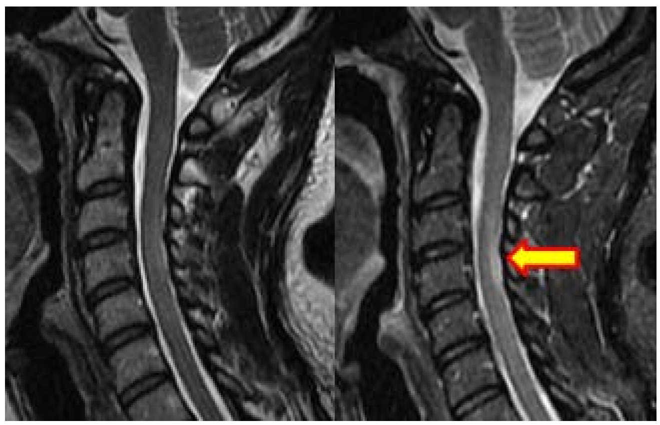


Figure 13 Additive T1 and T2 effects; MS plaque seen better on STIR image on right vs. Spin Echo image on left

STIR is a widely used method of fat suppression, as it is available at all field strengths. It is often the preferred method of fat suppression in situations where RF FatSat techniques may not be ideal (e.g. large fields-of-view, lower field strengths, areas of high magnetic susceptibility). STIR is not sensitive to magnetic field homogeneities, and offers uniform fat suppression, even when imaging away from isocenter. It is often the only fat suppression method available for lower field strength magnets (≤ 0.3T).

The most important limitation when using STIR for fat suppression is that it cannot be used post-gadolinium to demonstrate contrast. Signal suppression achieved with STIR is not specific to fat. Any material that has a short T1 time will be nulled, including melanin, methemoglobin, mucus, proteinaceous material, etc., so overall SNR is decreased.

FatSep

The principle behind FatSep (**Fat Sep**aration) is based on the Dixon technique, which was proposed in 1984. Dixon suggested use of a chemical shift imaging method based on the in-phase/out-of-phase cycling of fat and water to create fat only and water only images. Water only images are therefore fat suppressed.

Water and fat protons have slightly different resonance frequencies, so their spins go in- and out-of-phase with each other as a function of time. The period of this phase cycling is 1/Δf, where Δf is the frequency offset between the spins. At 1.5T, the phase cycling period totals 4.4ms, while at 1.2T, it is 5.8ms. In-phase and out-of-phase conditions occur twice per cycle, or approximately every 2.2ms at 1.5T, and every 2.9ms at 1.2T. Out-of-phase times at 1.5T (Echelon Oval) are 2.2, 6.6, and 11.0ms, and in-phase times are 4.4, 8.8, and 13.2ms. Out-of-phase times at 1.2T (Oasis) are 2.9, 8.7, and 11.6ms, with in-phase times of 5.8, 11.6, and 17.4ms. If the in- and out-of-phase images are added, the result is a water-only image, which is fat suppressed. If the in- and out-of-phase images are subtracted, the result is a fat-only image, which is water suppressed (Figure 14). This sequence type can deliver up to four contrasts in one measurement—out-of-phase, in-phase, water, and fat images (Figures 15-16).

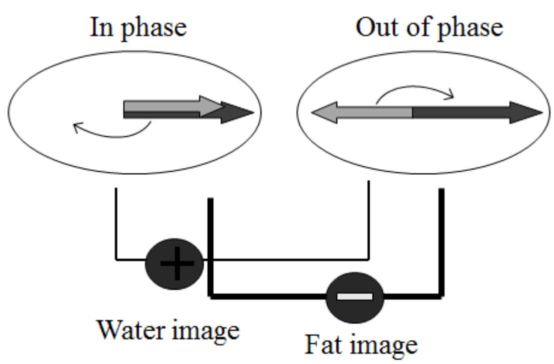


Figure 14 When added, fat vectors cancel out, resulting in water-only image (fat suppressed); when subtracted, fat-only image remains (water suppressed)

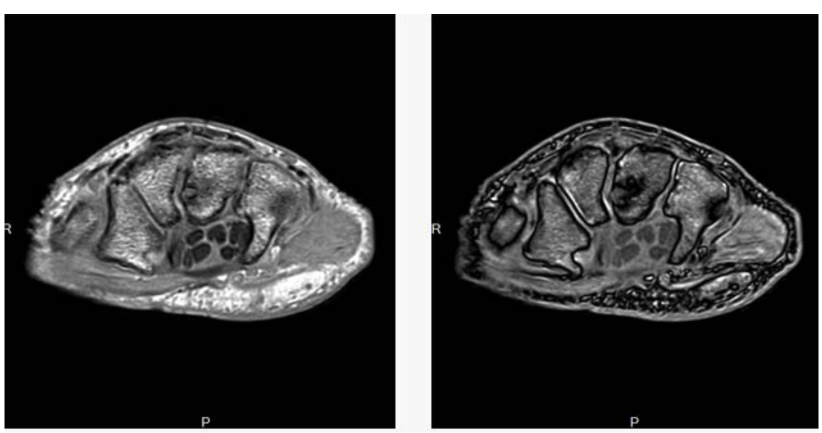


Figure 15 Oasis In-Phase image on left, Out-of-Phase image on right

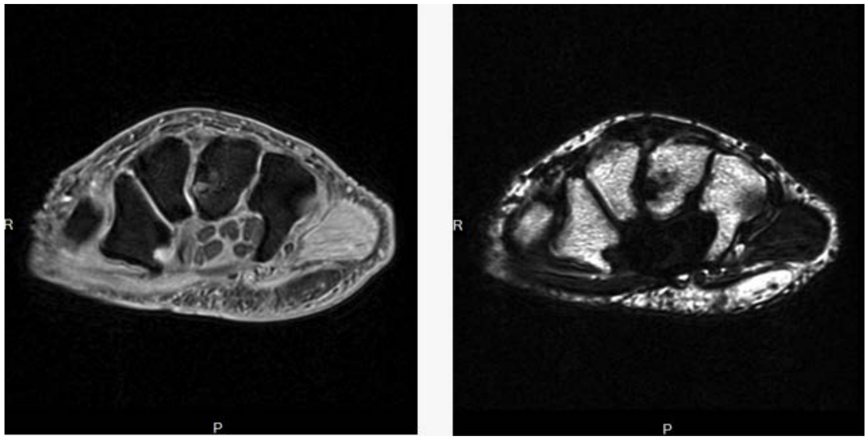


Figure 16 Oasis Water image (fat suppressed) on left, Fat image (water suppressed) on right

In- and out-of-phase images can be obtained from separate acquisitions, or as different echoes of the same acquisition. The number of points referred to with the Dixon technique (typically 2-point or 3-point) indicates the number of image sets that will be acquired at different TE values within the same acquisition. Early applications of the Dixon technique (in the 1980's) were not always successful, as the 2-point method required assumptions of perfect B_0 homogeneity, with no significant local susceptibility effects. Modifications were proposed during the 1990's, but it wasn't until the early 2000's that the Dixon technique experienced a resurgence. Modern magnet designs, improved shimming techniques, better algorithms, and faster Dixon methods have increased its popularity.

FatSep has been found to be a robust fat suppression technique, and can be used throughout the body. Scanning with the Dixon technique is a standard part of most abdominal imaging protocols. Out-of-phase imaging offers the benefit of a dark border between fatty and non-fatty tissues in the abdomen. Abdominal lesions whose signal intensity decreases on out-of-phase images are more likely to contain microscopic fat, which helps to differentiate adrenal adenomas (which usually contain fat) from carcinomas and metastases (which do not contain fat). FatSep can be helpful in the diagnosis of a variety of abdominal lesions, including angiomyolipomas, clear cell renal cell carcinoma, and focal fatty infiltration of the liver. When combined with **G**radient **E**cho (**GE**) sequences, the Dixon technique is beneficial for liver imaging, as four image types can be acquired with one breath-hold. The Dixon technique combined with **F**ast **S**pin **E**cho (**FSE**) sequences offers excellent fat suppression with high resolution, which is beneficial for extremity scans. FatSep also offers effective fat suppression near metallic implants and metallic prostheses, which is not the case with other fat suppression methods.

FatSep has the advantage of offering four image sets, each with different contrast. FatSep is effective in areas of high magnetic susceptibility, where other fat suppression techniques may fail, as it is less sensitive than FatSat to B_0 and B_1 inhomogeneities. FatSep scan times are comparable to scan times of other fat suppression techniques. Larger FOV scans benefit from more uniform fat suppression when FatSep is used.

The Hitachi Oasis and Echelon Oval systems offer a variety of sequences that incorporate FatSep, including Gradient Echo and Fast Spin Echo sequences with single echo and/or multi echo capabilities. (A variety of FatSep sequences are available on the AIRIS family of MR systems, as well as the Altaire MR system). The chart below provides a reference guide as to the types of FatSep sequences offered on the Oasis and Echelon Oval systems, including differentiation between single echo and multi echo, use of 2-point or 3-point Dixon method, and use with 2D and/or 3D acquisitions (Figure 17).

FatSep Sequences	GE Single Echo	RSSG Single Echo	RSSG Multi Echo	FSE Single Echo	FSE Multi Echo
Oasis	N/A	N/A	2D or 3D, 2-pt. Dixon	2D, 2-pt. Dixon	2D, 3-pt. Dixon
Echelon Oval	2D or 3D, 2-pt. Dixon	2D or 3D, 2-pt. Dixon	2D or 3D, 2-pt. Dixon	2D, 2-pt. Dixon	2D, 3-pt. Dixon

Figure 17 FatSep sequences for Oasis and Echelon Oval systems

The Hitachi Oasis and Echelon Oval systems also offer a selectable FatSep Strength parameter, which is used to determine the fat suppression strength in the water image. This parameter is available in the Saturation parameters section (Figure 18). The choices listed under FatSep Strength are Light, Medium, or Heavy, which indicate the degree of suppression of the fat signal. This setting can be adjusted to the Radiologist's preference, depending on the extent of fat suppression desired in the water images.

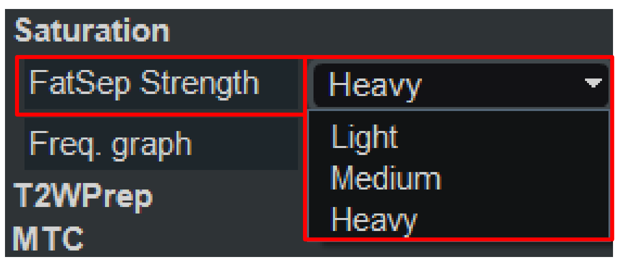


Figure 18 FatSep Strength parameter

Gradient Echo FatSep

FatSep sequences are available as both single echo and multi echo, with combinations of GE and RSSG sequences available on the Hitachi Oasis and/or Echelon Oval MR systems. Although scan time is increased, it can be compensated for by the increased flexibility offered with other parameters, as well as the addition of RAPID.

Single Echo

Single echo GE and RSSG FatSep sequences are available on the Echelon OVAL. These sequences measure the out-of-phase echo after the first RF excitation, and the in-phase echo after the second RF excitation. Both of these sequences use the 2-point Dixon technique, and both can be used with 2D or 3D acquisitions. Both the single echo GE and RSSG FatSep sequences allow for the use of smaller FOV with high resolution, and more parameter flexibility. The single echo RSSG FatSep sequence offers a variable TE, and more flexibility for FOV and bandwidth parameters. When the single echo RSSG FatSep sequence is used with 3D acquisitions, it is recommended that the 3D Acq. Mode field be set to Circular, in order to reduce scan time and improve SNR. Both the single echo GE and RSSG sequences are used with orthopedic and spine scanning, with the GE resulting in T2*- weighted images, and the RSSG resulting in T1-weighted images (Figure 19).

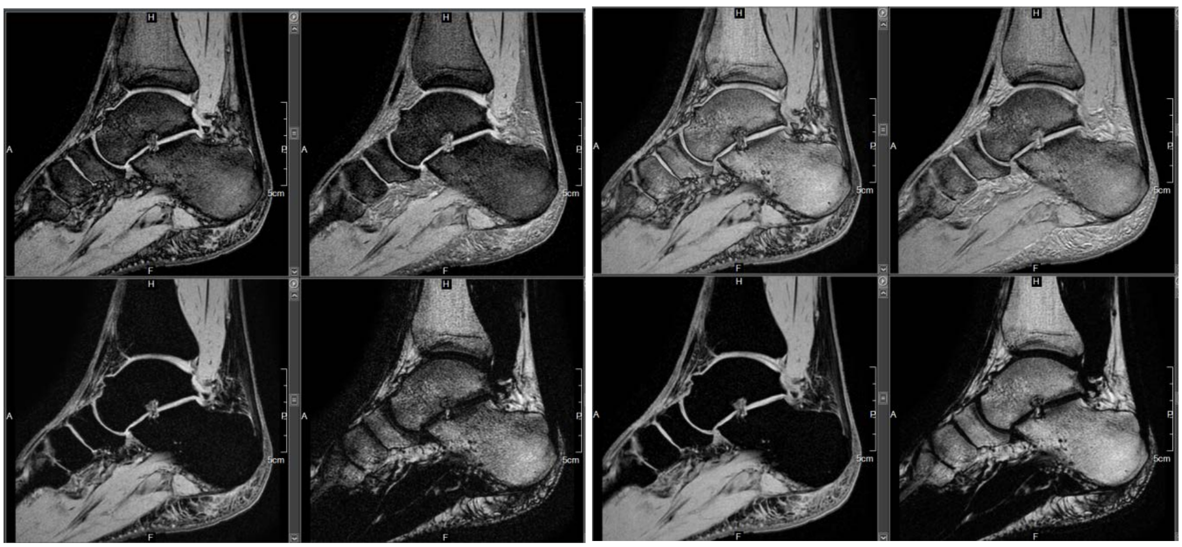


Figure 19 Single Echo GE T2* FatSep images on left; Single Echo RSSG FatSep images on right; both sets of images display out-of-phase image on top left, in-phase image on top right, water image (fat suppressed) on bottom left, and fat image (water suppressed) on bottom right

Multi Echo

The Multi Echo GE FatSep sequence is the RSSG sequence, which is available on both the Oasis and Echelon Oval systems. This sequence can be a 2D or 3D acquisition, and uses the 2-point Dixon technique to produce fat suppressed images. The TE parameter is set at an intermediate value that is in between the first echo (out-of-phase) and the second echo (in-phase). The Oasis system has a fixed TE time of 4.4ms, which falls between the out-of-phase time of 2.9ms and the in-phase time of 5.8ms. On the Echelon Oval, the TE field displays settings that are at fixed intervals between the out-of-phase and in-phase times on this system (e.g., TE of 3.4ms., which is between the initial out-of-phase time of 2.2ms. and in-phase time of 4.4ms.; TE of 7.8ms., which is between the out-of-phase time of 6.6ms. and the in-phase time of 8.8ms., etc.), up to a maximum TE setting of 79.5ms. When the multi echo RSSG FatSep sequence is used with 3D acquisitions, it is recommended that the 3D Acq. Mode field be set to Circular, in order to reduce scan time and improve SNR. The Multi Echo RSSG FatSep sequence does have some FOV and bandwidth restrictions. This sequence is recommended for abdominal scanning, as the shorter scan times mean shorter breath holds for patients (Figure 20). It is also suggested for use with orbit, pituitary, and enterography scans.

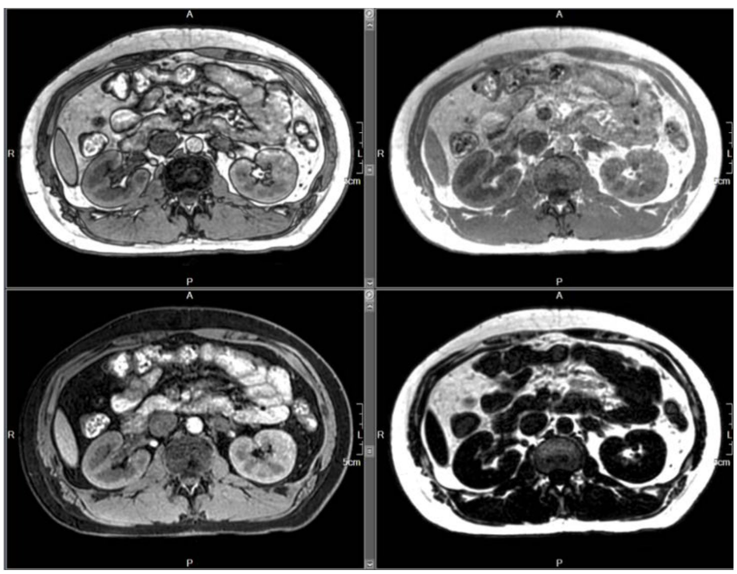


Figure 20 Multi Echo RSSG FatSep images; out-of-phase image on top left, in-phase image on top right, water (fat suppressed) image on bottom left, fat (water suppressed) image on bottom right

Fast Spin Echo FatSep

FatSep FSE sequences are available as both single echo with 2-pt. Dixon, and multi echo with 3-pt. Dixon. They are available on both the Oasis and the Echelon Oval MR systems, and can be used with 2D acquisitions only.

Single Echo

When performing the Single Echo FSE FatSep sequence, each echo is acquired in between each of the 180° refocusing pulses. As an example, if we used an Echo Factor of 3, the first , second, and third echoes, (acquired after the first, second and third refocusing pulses associated with the initial 90° excitation pulse), will all contribute to the out-of-phase image. After the second 90° excitation pulse, the first, second, and third echoes (acquired after the first, second, and third refocusing pulses associated with the second 90° excitation pulse), will all contribute to the in-phase image. The Inter Echo Time parameter can be decreased to achieve a lower TE by increasing the Bandwidth. The E. Factor (**E**cho **F**actor) and Echo Alloc. (**E**cho **A**llocation) parameters can be set to achieve the desired tissue weighting, so these sequences can be used for T1-weighted scans, short TE proton density- weighted scans, as well as T2-weighted scans. Although scan time is increased on Single Echo FSE FatSep sequences, it can be compensated for with the increased flexibility offered with other parameters, including the addition of RAPID. These sequences also have fewer restrictions on bandwidth and FOV, as well as the advantage of reductions in metal susceptibility and flow artifacts. They are often used for brain and spine scanning, as well as for arthrograms in orthopedic scanning (Figure 21).

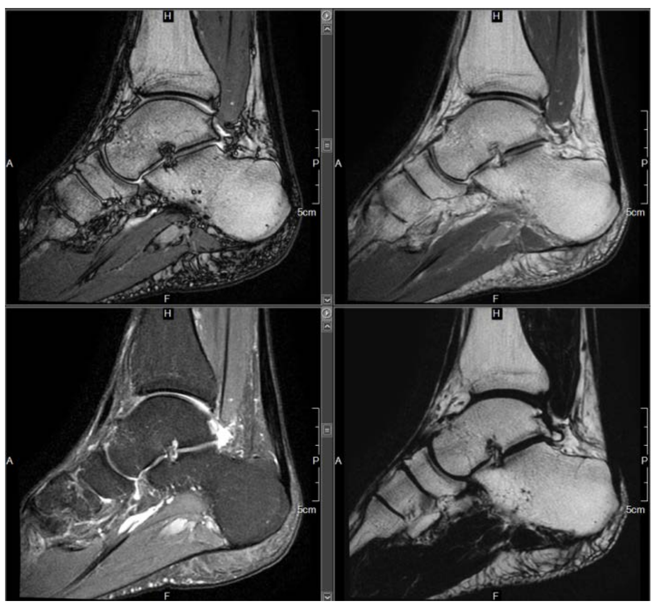


Figure 21 Single Echo FSE FatSep images; out-of-phase image on top left, in-phase image on top right, water image (fat suppressed) on bottom left, fat image (water suppressed) on bottom right

Multi Echo

The Multi Echo FSE FatSep sequence acquires multiple echoes after each 180° pulse, and uses the 3-point Dixon technique. With the 3-point Dixon technique, image results include an out-of-phase, an in-phase, and a second out-of-phase image. The multiple echoes from each echo train have different phase encodes, and will contribute to different out-of-phase and in-phase images. Using the example of an echo factor of three, the three echoes produced after the first 180° refocusing pulse will be placed in the first out-of-phase, the first in-phase, and the second out-of-phase images, respectively. The three echoes produced after the second 180° refocusing pulse will be placed in the first out-of-phase, the first in-phase, and the second out-of-phase images, respectively, and so on. The IET (**I**nter **E**cho **T**ime) is set at a default value, which is 17ms. on the Oasis, and 15ms. on the Echelon Oval. The TE parameter is calculated by the system, based on the Echo Factor and Echo Allocation parameters. Due to their higher TE values, these sequences should only be used for T2-weighted imaging. Multi Echo FSE FatSep sequences offer increased SNR with a decrease in scan time, but have more bandwidth and FOV restrictions. When used for abdominal scanning, Multi Echo FSE FatSep sequences allow for shorter breath hold times for patients, as opposed to Single Echo FSE FatSep. These sequences can also be used for orthopedic cases where metal is involved, as there is considerably less artifact from metal on FatSep images compared to routine FatSat images (Figure 22).

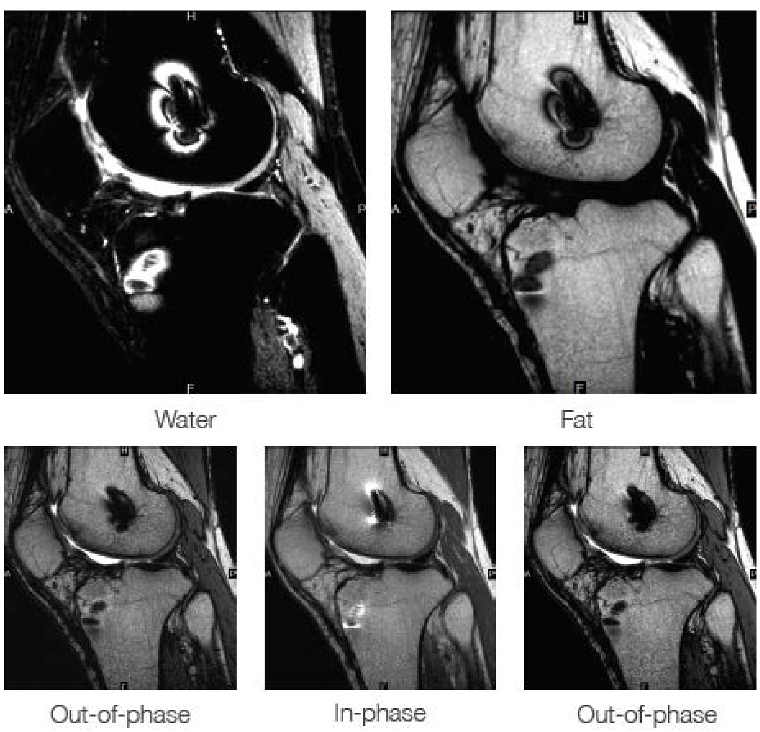


Figure 22 Echelon Oval Multi Echo FSE FatSep with 3-point Dixon technique, which results in additional out-of-phase image; 3-point Dixon technique also reduces the effects of field inhomogeneities and metal artifact susceptibility

Conclusion

This concludes the Fat Suppression Techniques module. You must complete the post-test for this activity with a score of 75% or better in order to receive Continuing Education credits.

Appendix A: References for Fat Suppression Techniques Module

- Brown, Greg. (n.d.) *Fat Suppression Techniques.* Retrieved from http://users.on.net/~spinupdownunder/papers/fatsup/fatweb.htm
- Cameron, Ian, PhD. (n.d.). *Techniques of Fat Suppression.* Retrieved from http://cds.ismrm.org/protected/09MProceedings/files/Tues%20C36_01%20Cameron.pdf
- Elster, Allen D., M.D. (n.d.) *Dixon Method.* Retrieved from http://mriquestions.com/dixon-method.html
- Elster, Allen D., M.D. (n.d.). *CHESS/Fat-Sat Pulses.* Retrieved from http://mriquestions.com/fat-sat-pulses.html
- Elster, Allen D., M.D. (n.d.). *Fat Suppression Methods.* Retrieved from http://mriquestions.com/best-method.html
- Elster, Allen D., M.D. (n.d.). *Fat v Water.* Retrieved from http://mriquestions.com/fat--water-properties.html
- Elster, Allen D., M.D. (n.d.). *Fat/Water Chemical Shift.* Retrieved from http://mriquestions.com/f-w-chemical-shift.html
- Elster, Allen D., M.D. (n.d.). *In-Phase v Out-of-Phase.* Retrieved from http://mriquestions.com/in-phaseout-of-phase.html
- Elster, Allen D., M.D. (n.d.). *Short TI Inversion Recovery.* Retrieved from http://mriquestions.com/stir1.html
- Elster, Allen D., M.D. (n.d.). *Water Excitation Pulses.* Retrieved from http://mriquestions.com/water-excitation.html
- Higgins, Dave. (12February2010). *Revising MRI- Fat Suppression.* Retrieved from http://www.revisemri.com/blog/2010/fat-suppression/
- Hoa, Denis. (n.d.). *Fat signal suppression by short TI inversion-recovery (STIR).* Retrieved from https://www.imaios.com/en/e-Courses/e-MRI/Improving-MRI-contrast-Imaging-water-and-fat/stir
- Hoa, Denis. (n.d.). *Imaging water and fat.* Retrieved from https://www.imaios.com/en/e-Courses/e-MRI/Improving-MRI-contrast-Imaging-water-and-fat/fat-signal-suppression
- Hoa, Denis. (n.d.). *Improving MRI contrast: Imaging water and fat.* Retrieved from https://www.imaios.com/en/e-Courses/e-MRI/Improving-MRI-contrast-Imaging-water-and-fat
- Hoa, Denis. (n.d.). *MRI Fat Saturation (Fat Sat, CHESS, SPIR, SPECIAL).* Retrieved from https://www.imaios.com/en/e-Courses/e-MRI/Improving-MRI-contrast-Imaging-water-and-fat/fat-saturation
- Magnetic Resonance- Technology Information Portal. (n.d.). *Fat Suppression.* Retrieved from http://www.mr-tip.com/serv1.php?type=db1&dbs=Fat%20Suppression

Appendix B: References for Pictures for Fat Suppression Techniques Module

- Figures 1-9 – Hitachi Healthcare Americas
- Figure 10 – http://mriquestions.com/water-excitation.html
- Figures 11, 12 – Hitachi Healthcare Americas
- Figure 13 – http://mriquestions.com/stir1.html
- Figure 14 – Hitachi Medical Corporation
- Figures 15-22 – Hitachi Healthcare Americas