



Spin Echo

a
Magnetic Resonance
Contrast Simulator

Introduction

The contrast visible in MR images is a function of the intrinsic differences in the the magnetic properties of human tissue; in particular its characteristic longitudinal (T1) and transverse (T2) relaxation rates as well as the proton density of the tissues. In addition, the field strength of the imaging magnet strongly affects the contrast behavior, through both its influence on the tissue T1 and T2 and by the change in effective contrast resulting from the differences in the background noise level and its consequent effect on the "contrast to noise" ratio.

Spin Echo is a magnetic resonance contrast simulator. Given knowledge of the magnetic properties, T1 and T2, it is possible to predict the signal intensity produced by a given tissue when imaged in the Magnetom™. Technically, this involves solving the Bloch equations for the particular tissue and imaging sequence.

The relaxation parameters, T1 and T2 change with the surrounding magnetic field. In general, the T1 times increase and the T2 times will decrease. For the purposes of the present simulation the T1 time for a given tissue is presumed to increase approximately as the square root of the field strength, so that a tissue with a T1 of 1 second at 0.5 Tesla will have a T1 of approximately 1.4 seconds at a field strength of 1 Tesla. In a similar fashion the T2 relaxation parameters are known to decrease with increases in field strength. As a result of these changes in relaxation times, the contrast seen in a spin echo image with a single choice of TR and TE will be drastically different in a magnet at a higher field strength. It is generally accurate to say that, using the same imaging parameters, any image will have a larger degree of both T1 and T2 contrast at a higher field strength than at a lower one.

As the field strength of a magnetic imaging system is increased the maximum attainable signal to noise ratio in the images is likewise increased. One result of this is that the effective dynamic range of image contrast is increased. Spin Echo will display the changes of noise intensity as magnetic field strength is increased.

Please note that although the program attempts to simulate contrast and noise effects as accurately as possible, some of the assumptions made by the program are a bit simple-minded (see the technical appendix) and the ultimate contrast curves obtained *must* be taken "with a grain of salt." In particular the program cannot account for such factors as surface coils, patient size, eddy currents and so on.

The program then, is intended as a training tool on the effects of the choice of imaging sequences on the contrast detectability of image features and to give a gross view of the effects of field strength on image contrast. It is the purpose of the spin echo program to demonstrate the effect of changes in magnetic relaxation and to allow the physician or physicist to predict the contrast that he or she will see in the MR images with a given choice of sequence parameters. It may also aid in the comparison of images acquired from machinery operating with different sequence parameters and at different field strengths.

Spin Echo is not a Siemens product and as such Siemens cannot take any responsibility for its use or misuse. The program, Spin Echo is considered to be in the public domain. This means that it may be freely copied and distributed. The program however, is copyrighted. You are not free to sell the program or alter it *in any way*. A great deal of time has gone into its development - please respect this. Be sure that you include a copy of the manual on any disks which you circulate. Note also that there are likely to be frequent changes in the program. Check the version number to keep current. Please note that if the version number differs from that shown in the manual, you should anticipate that there have been some changes in the program...

If you already own a magnetic resonance imaging system you could do much to aid in the SpinEcho project. I would appreciate sincerely receiving images acquired with a variety of imaging magnets in order to compare the "real" images with the predicted contrast from the SpinEcho program. If you can send me any such images we potentially can work together to improve the accuracy of this simulation. Your cooperation would be sincerely appreciated.

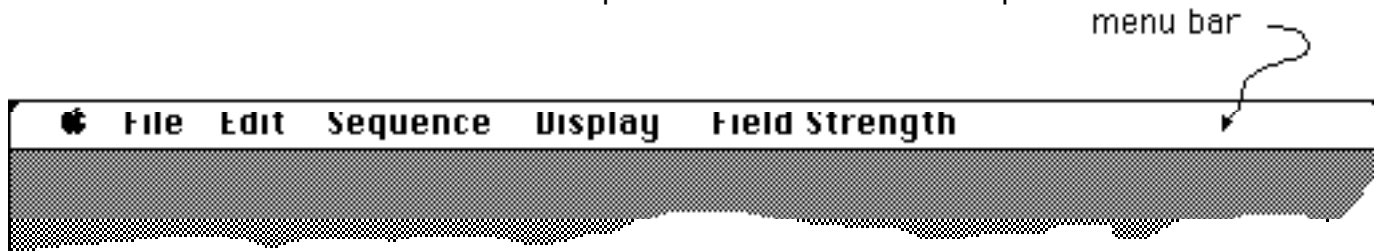
Using Spin Echo (a short tutorial)

To start the Spin Echo program turn the computer on and insert the program disk into the slot on the front of the Macintosh computer. If you are unsure as to how to get this far in the process, you will probably do well to consult your local computer guru. Alternatively, you should find the Apple Macintosh owner's manual and familiarize yourself with the basic operational features.

After a few seconds the computer screen should display a white framed rectangle (a window) with a small picture of a Magnetom™ magnet (as well, perhaps as other objects). This is the program icon for Spin Echo. Using the mouse, move the arrow cursor over to that icon and press on the mouse button. The picture of the magnet should then turn into a spinning proton to indicate that the program is selected. Now use the mouse once again to move the arrow cursor over to the top line of the screen where the word File is displayed. Press down on the mouse button again and a "menu" will appear below the top line. While still holding the mouse button down, move the cursor to the menu selection labelled Open then release the button. After a moment the following window (called an alert) will appear:



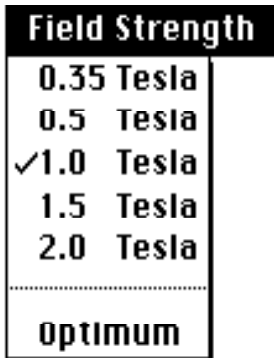
This tells you the current revision number of the Spin Echo program. Move the cursor any place within the alert window and press on the mouse button. The alert will disappear and you will be left with a screen that is blank except for a "menu bar" on the top as shown below:



Using the program requires that you

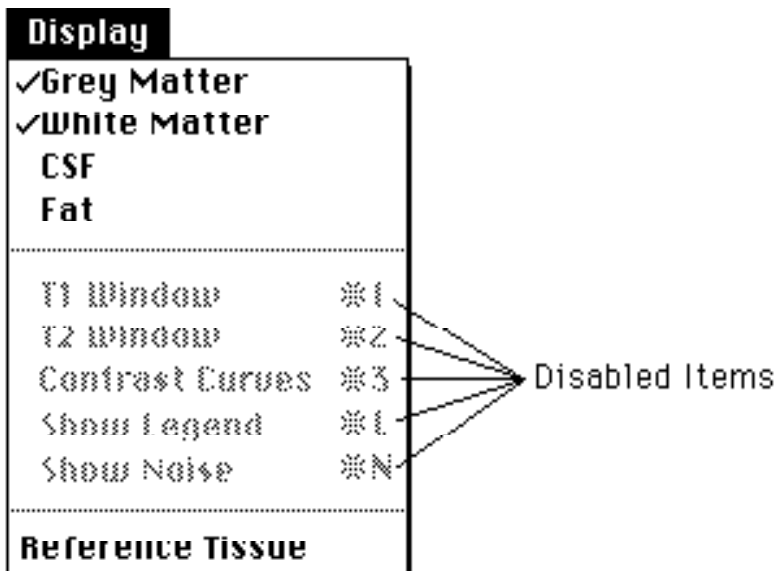
1. Select a field strength
2. Choose an imaging protocol
3. Initiate the simulation

To select a field strength move the cursor over to the field Field Strength menu and hold down the mouse button to "pull down" the menu. The menu should look like this:



You may now select a field strength from 0.35 to 2.0 Tesla. The selected field strength is indicated with a check mark (initially, 1 Tesla is selected). For now, leave the selection at 1.0 T.

Now move the cursor over to the Display menu and pull that menu down as shown below:



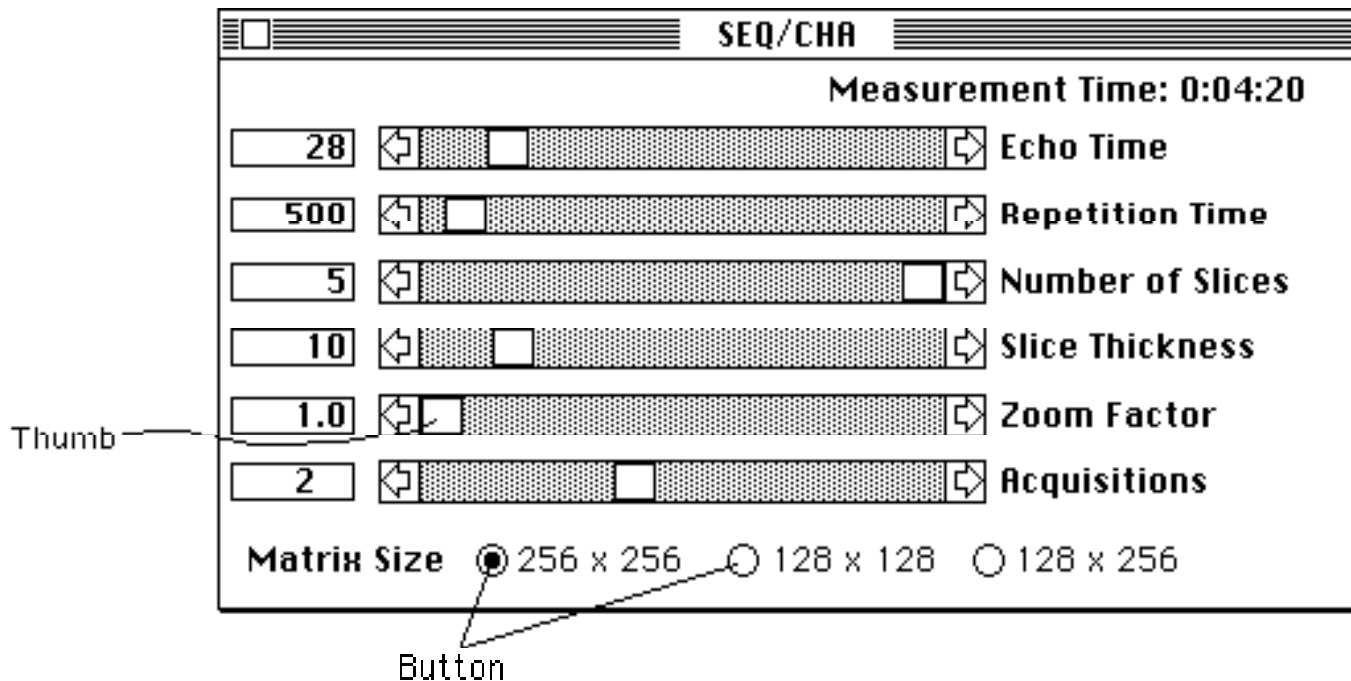
Grey Matter and White Matter are selected by default, but you may show any of four different tissues. Note at this point that not all of the menu items are valid at this time. These disabled items are indicated in grey type. In this menu, only the four tissue type options are available initially. Go ahead and select all four tissues for right now by releasing the mouse button next to the CSF and Fat items one at a time (the menu must be pulled down each time). If you release the mouse button next to a selected tissue, grey matter for example, that item will become unselected. When you are finished the menu will appear as shown:



Now move the cursor over to the Sequence menu. This menu contains several preprogrammed protocols which conform to recommended standard protocols for acquiring most MR images. These protocols are automatically corrected for magnetic field strength, so that, for example, the "T1-weighted" protocol at 1.0 T is distinctly different than that at 2.0 T. Pull down the menu and release the mouse button over the T1-weighted selection. You may review the timing at any time (even if the window is hidden) by selecting Set Timing

Note also that the Set Timing option can be selected by holding down the cloverleaf key and pressing 'T' as indicated by the marking on the menu.

The following window will then be displayed:



This control panel will be your mechanism for selecting a choice of imaging parameters to test. With a field strength of 1.0 Tesla, the standard T1-weighted imaging parameters will be a TR of 0.5 seconds and a TE of 28 msec as shown. This leaves time to acquire 5 slices with standard Magnetom™ sequences. For reasonable signal to noise performance, 2 acquisitions are used for a total imaging time of approximately four minutes and 20 seconds (in the real magnet, not in the simulation) as shown at the upper right of the control panel.

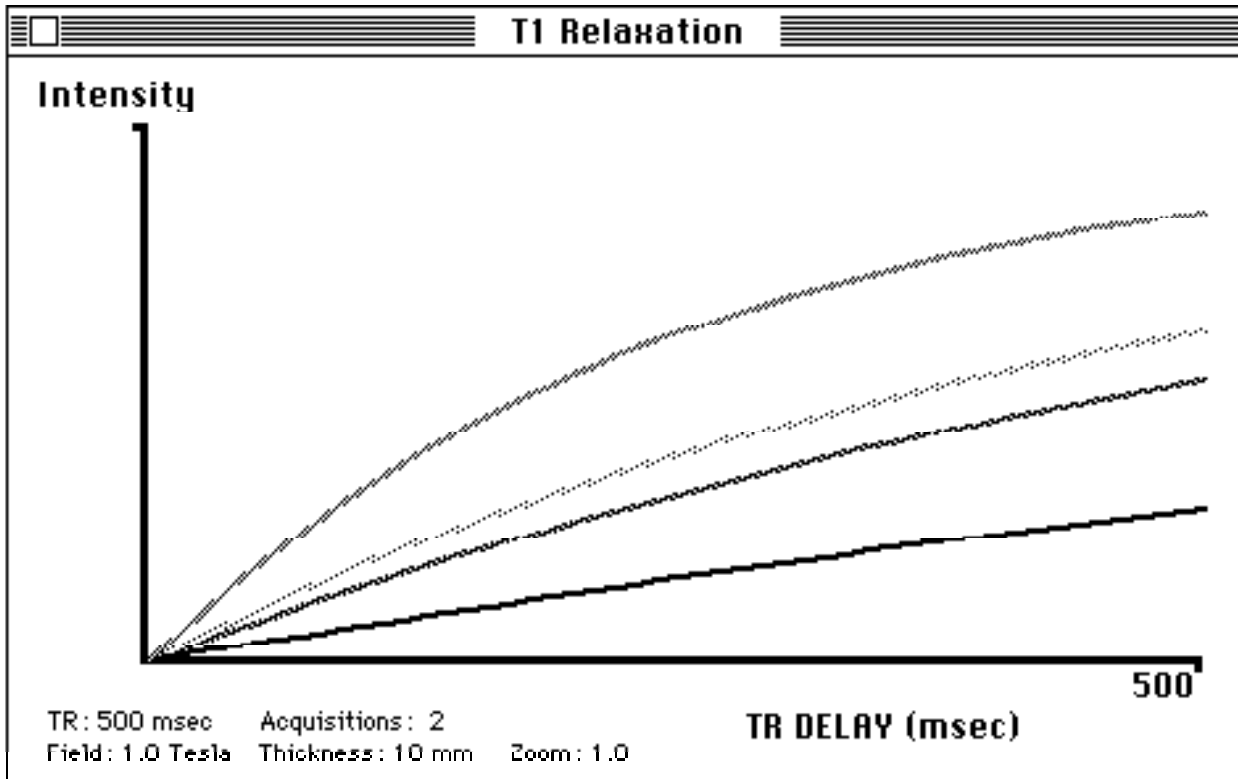
The small white square in each of the controls is called the thumb. You may change the setting of the controls by pointing the cursor over the "thumb" and holding down the mouse button. At this point you may drag the thumb to the left or right to alter the control settings. Try moving Acquisitions control to the right and note that the number indicator to the left of that control is updated accordingly. In addition the total time measurement is altered - the imaging time is multiplied by the number of acquisitions. As you experiment with different sequences, be sure to look at the total imaging time: time is money here. Speaking of time, you may substantially alter the imaging time by selection of a lower resolution matrix, such as 128 x 128 or the 128 x 256 matrix. To do so, move the cursor over to the corresponding button and press the mouse button. Unfortunately the simulator is unable to demonstrate the change in resolution that results from these choices, but it will show the change in signal to noise performance.

Go ahead and experiment with the controls, using the mouse to move the thumb to the left and right. If you push the mouse button down while the cursor is in the small arrows at the ends of the control, then the control will glide smoothly in the indicated direction. When the mouse button is pressed within the grey area, the control will jump up or down by several increments (the exact amount of the jump depends on which control is being activated.) When you are done experimenting with the controls, select the T1-Weighted sequence and note that the controls return to a reasonable 1 Tesla imaging sequence. In order to follow this tutorial, you will want to set all of the parameters back to their original positions as shown in the diagram above.

Now that you've established an imaging protocol it is only necessary to move over to the Sequence menu and select START.

Sequence	
Set Timing	⌘ T
START	⌘ S
<hr/>	
Spin Echo	
Inversion Recovery	
FAST	
<hr/>	
T1-Weighted	
T2-Weighted	
Spin Density	

Immediately after making this selection the arrow cursor will turn into a wrist watch to indicate that time will be required for the program to calculate the contrast curves. Various windows will appear to show the progress of the calculations. After about 10 seconds two new windows will appear which contain the contrast curves. The window on top, labelled "T1 Relaxation" shows the intensity of each of the tissues as the TR approaches the final value selected in your choice of protocols. If you have followed this tutorial so far it will extend to a TR of 500 milliseconds and will indicate only partial T1 recovery for each of the tissues.



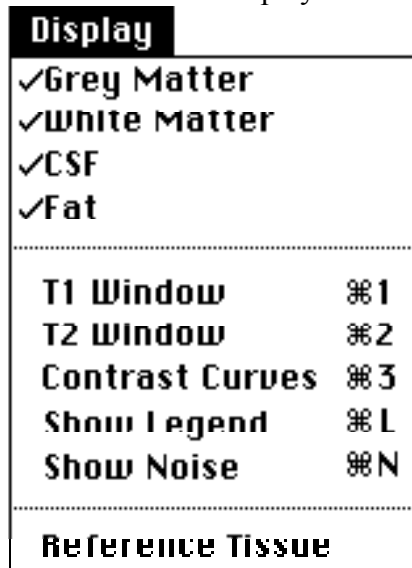
Note that all of the intensity contrast between tissues on this set of curves is due to T1 and proton density differences.

To find out which curve belongs to which tissue, you may pull down the Display menu and select Show Legend. This will result in the display of a legend similar to that shown below:

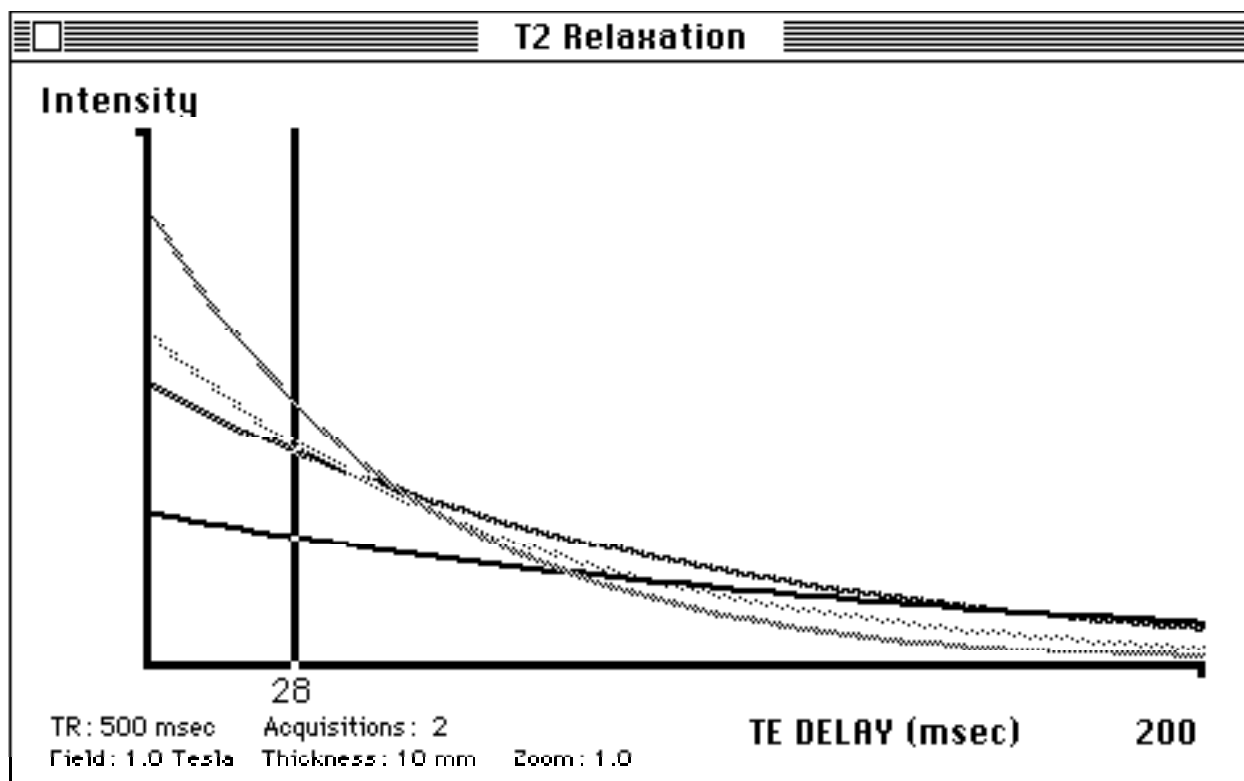
Legend	
~~~~~	Grey Matter
-----	White Matter
————	Cerebrospinal Fluid
-.-.-.-	Fat

If you wish to remove the legend from the screen, go once again to the Display menu and select Hide Legend. The legend may be moved around on the screen by moving the arrow cursor to the top of the legend window (for instance over the word, "Legend"), holding down the mouse button and dragging the legend window to a new position.

Notice that the Display menu now has several more enabled options as shown:



In order to view the second contrast curve window, pull down the Display menu and select T2 Window. This will bring the T2 relaxation curve window to the front of the screen. The echo time that you selected in your protocol setup is indicated by the vertical black bar; the relative signal intensities of the four selected tissue at that TE are displayed. Note that the brightest signal here is from fat. There is relatively little contrast between grey and white matter and CSF is the darkest feature on the screen.

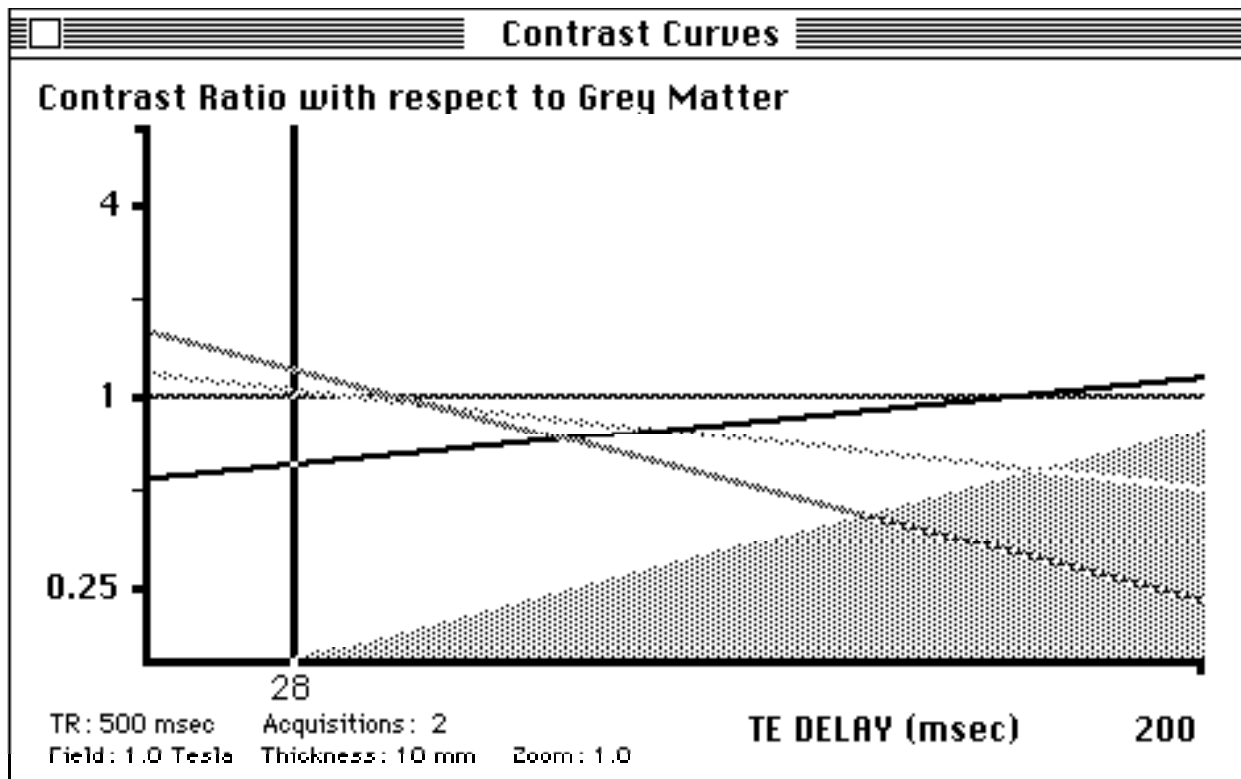


Move over to the Display menu once again and select Show Noise. The T2 relaxation window will now show a grey region at the bottom of the graph indicating the approximate relative noise level. In general, if the tissue signal has dropped below this level, it will be impossible to distinguish it from the background noise. In this case, a TE of greater than 120 msec could be

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expected to contain very little information, because so much of the signal would be below the noise level in the image.

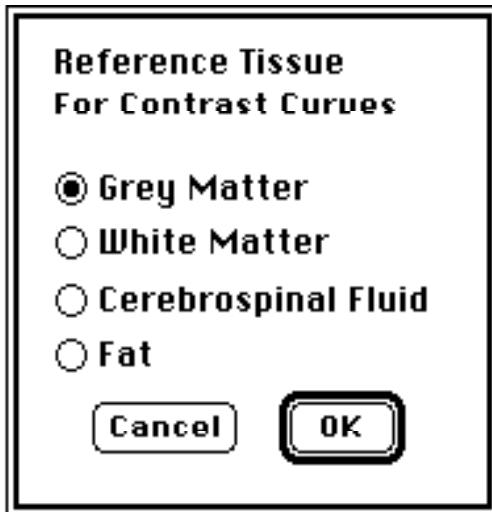
It is possible to display the relative intensities of the tissues and the background noise in a perhaps slightly more appealing format on a logarithmic intensity scale. To do so, select Contrast Curves. This will bring up a display of the intensities of each tissue relative to that of grey matter.



The grey triangular region in the bottom right corner of the graph indicates the intensity of the noise relative to that of the grey matter tissue. This noise value can be removed from the curve with the Hide Noise option on the Display menu.

Tissues brighter than the grey matter show up above it and tissues darker than grey matter show up below. Note how this changes as a function of echo time. The scale on the left indicates the ratio of intensities between the tissues. In this example, CSF is approximately half the intensity of grey matter. Note that it is a psychophysical fact that the discriminability of image features depends in part upon the ratio of this contrast ratio to the level of the background noise. With these scan parameters, the contrast detectability of features in the image will be reduced dramatically with echo times beyond about 70 msec. To see low contrast features you must utilize an imaging sequence which minimizes the noise.

If you prefer to see the contrast relative to some other tissue, select Reference Tissue from the Display menu. This will initiate the display of the control panel shown below:



Use this control panel to select the tissue to be utilized for reference intensity. To select the tissue, move the cursor over to the button corresponding to your choice of reference and press the mouse button. When you have the appropriate tissue press the OK button (or the RETURN key on the keyboard) and a new contrast chart will appear. The Cancel button redisplay the previous contrast curves.

Use the Sequence menu to select Set Timing. With the control panel in place you may now move the Echo Time indicator back and forth on the T2 Relaxation curves to indicate the contrast at different points.

Go ahead and try various combinations of field strength and imaging parameters now (that is the point of the simulation). Simply choose your magnet strength and protocols then select START from the Sequence menu.

To leave the spin echo program, simply move the cursor over to the File menu and select Quit. The program will terminate neatly at this point and bring you back to the desktop display.

## Technical Notes

Construction of the Spin Echo program required several assumptions concerning the performance of magnets at different field strengths as well as assumptions concerning the deviation in magnetic relaxation as a function of magnetic field. I have also entered starting values for the relaxation rates and proton density of several body tissues. The most important of these assumptions are outlined below.

### Tissue Parameters

For the purposes of the Spin Echo simulation the relaxation rates and proton densities of various tissues at 1.0 Tesla are approximated as follows:

<u>Tissue</u>	<u>T1 time</u>	<u>T2 time</u>	<u>Proton Density</u>
Grey Matter	670	100	1.0
White Matter	480	70	0.95
CSF	1500	145	1.0
Fat	250	50	0.97

The proton density of these tissues of course remains constant as the magnetic field is increased. On the other hand the T1 relaxation rates are presumed to increase as the square root of the magnetic field, so that, for example, the T1 of CSF at 2.0 Tesla will be 1.41 seconds. This method of field strength correction is clearly a bit naive, but at least provides a first order approximation. The T2 parameters are corrected in a somewhat *ad hoc* fashion; the 1 Tesla times are multiplied by a correction factor:

	<u>0.35T</u>	<u>0.5T</u>	<u>1.0T</u>	<u>1.5T</u>	<u>2.0T</u>
<u>Correction Factor</u>	1.3	1.2	1.0	0.85	0.75

These correction factors assure a gradual decrease in T2 relaxation times as the field strength is increased and approximate the change in measured T2 times as indicated in the MR literature. Articles consulted for these relaxation parameters are listed in the reference section.

### Signal to Noise Ratio

The signal to noise ratio in an imaging system is presumed, for the purpose of this simulation to increase as the square root of the field strength. In particular the displayed noise level is decreased in this ratio as the field strength is increased.

I hope that this simulation proves useful in the prediction of expected contrast to noise performance in the real world of clinical imaging and helps to provide some intuitions on the changes in contrast behavior expected when imaging at different field strengths. Please bear in mind that while the simulation can reasonably be expected to demonstrate general trends it would not be appropriate to expect that tissues will have exactly the relative intensities suggested.

**References**

Materials used for tissue parameter reference values are contained in:

Kressel, H.Y. (ed.) *Magnetic Resonance Annual 1986* Raven Press, New York, NY (1986).

Mansfield, P. and Morris, P.G. *NMR Imaging in Biomedicine* Academic Press, Orlando, FL (1982).

Newton, T.H. and Potts D.G. (ed.) *Advanced Imaging Techniques* Clavadel Press, San Anselmo, CA (1983).

Peterson, S.B., Muller R.N. and Rinck P.A. (ed.) *An Introduction to Biomedical Nuclear Magnetic Resonance* Thieme, Stuttgart (1985).

Roth, K. *NMR-Tomography and Spectroscopy* Springer-Verlag, New York, NY (1984).

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Please address all bug reports and comments to:

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Please note also that future revisions are planned and feel free to contact my office for advice as to the current revision level.

*Addendum: New Features of Spin Echo*

In response to many helpful comments and suggestions I have included several new features in version 0.96d, these include:

- More extensive labelling of the imaging parameters used in the derivation of the current contrast curves.
- Reorganization of the contents of the various menus. The number of menus has been reduced and they are a bit more logically coherent in content.
- After calculation the window most recently in front is replaced in the front position.
- The 0.5 T spin density protocol has been changed to conform more closely to current practise.
- The T1 and T2 relaxation time for CSF were adjusted empirically to conform better to actual image data (see my special request in the introduction to this manual).
- The size of the Legend window has been reduced to cut down the clutter on the screen.
- During calculation of the tissue magnetizations the SEQ/CHA (set timing) window is displayed.
- SpinEcho has been tested on all three current models of Macintosh computer. Segmentation of the program has ensured that it will run on all of them.
- The disk that I am distributing SpinEcho on contains a printer driver so that the graphs can be dumped directly to an imagewriter printer with the standard Macintosh command: shift-command-4.
- SpinEcho has been configured to work well with Switcher.

Please note that I plan to implement many of the other suggestions that I have received. With luck, version 1.0 will be ready for the 1986 R.S.N.A.

My thanks to:

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