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Effect of Intersection Spacing on MR Image Contrast and Study Time[1]

The effects of section separation on image contrast and calculated T1 relaxation times were investigated in healthy volunteers and a phantom using an early commercial version magnetic resonance imaging system. The effects are explained qualitatively on the basis of side lobes of excitation occurring outside the selected section resulting in reduction of the time permitted for T1 relaxation. The options for dealing with imperfect section selection, including separation of the sections (i.e., leaving gaps) and nonsequential excitation, are illustrated and the trade-offs involved in each explained.

Index terms: Magnetic resonance (MR), experimental • Magnetic resonance (MR), image processing • Magnetic resonance (MR), physics

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THE effects of changing repetition time (TR) and echo delay time (TE) on the strength of the signal and image contrast have been well documented in the magnetic resonance (MR) literature (1–5). Although less well recognized, the spacing of sections (the thickness of the sections relative to the gaps between them) in a multisection sequence may also have a significant effect on signal strength and image contrast. The purpose of this paper is to illustrate and explain these effects.

Strictly speaking, the results herein apply only to the GE Signa MR system (Milwaukee) in its current state of development. The degree to which this problem affects any given MR system and the precise method in which it is handled will probably differ among manufacturers. Moreover, the Signa system itself will undoubtedly change in the future.

MATERIALS AND METHODS

All the MR studies were performed on an early commerical version of the General Electric MR system (Signa) operating at 1.5 T.

A section profile was obtained using a uniform phantom containing a dilute solution of $CuSO_4$ and a modified imaging program in which the readout gradient was taken along the direction of section selection.

All imaging was performed on healthy volunteers. Informed consent was obtained from all subjects in accord with the procedures of the Human Research Review Committee of the Medical College of Wisconsin. The images were obtained using spin-echo pulse sequence and multisection multiecho acquisition with a 128 × 256 matrix and a 20-cm field of view. The signals from two excitations per line were averaged in all cases. TR, TE, section separation, and section thickness were varied as indicated below. At this point, the software permits the choice of gaps equal to the section thickness, gaps equal to ½ the section thickness, and no gaps between sections (with the no-gap option on the Signa system, the sections are obtained in nonsequential order as explained in the Discussion).

RESULTS

Figure 1 is the section profile of a 5-mm section in which the height is proportional to the projection of magnitude of the magnetization along the thickness of the section. Note the presence of a small amount of magnetization outside the nominal 5-mm width.

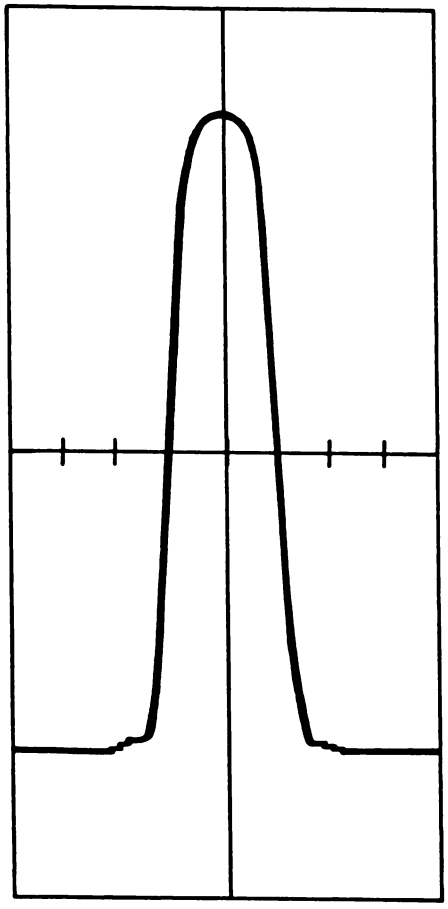

Figure 1. Section profile of a 5-mm section. The vertical markings on the horizontal axis correspond to a distance of approximately 2.5 mm.

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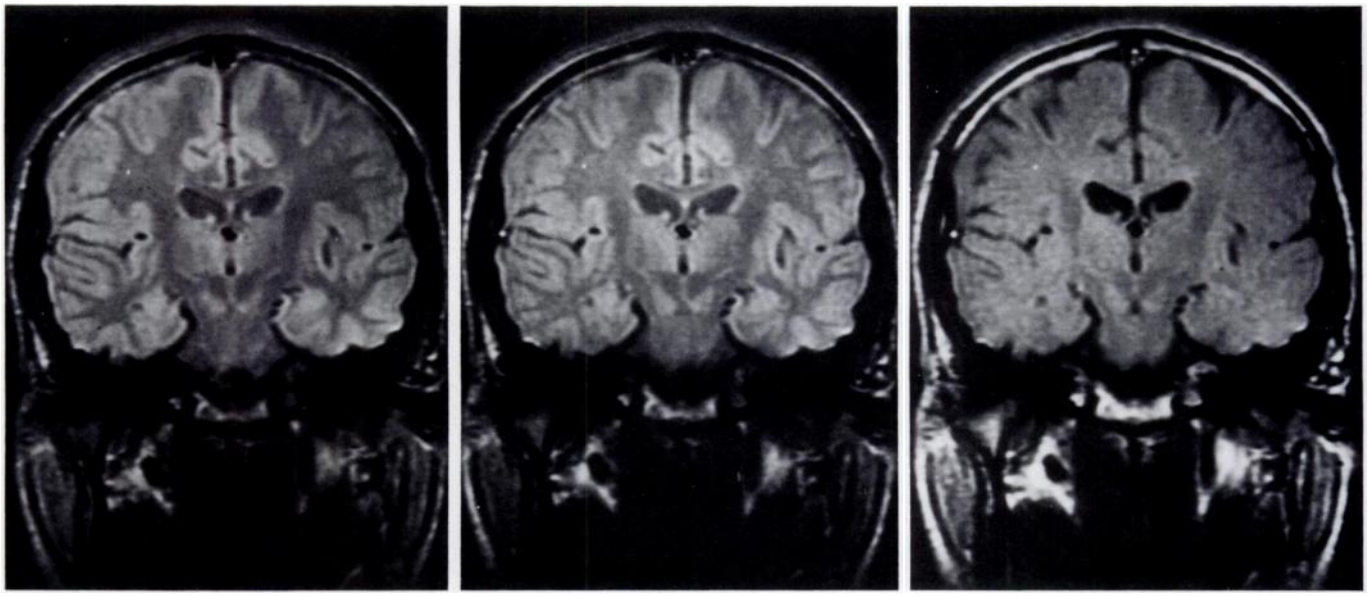
See also the paper by Feinberg et al. (pp. 811–817) in this issue.

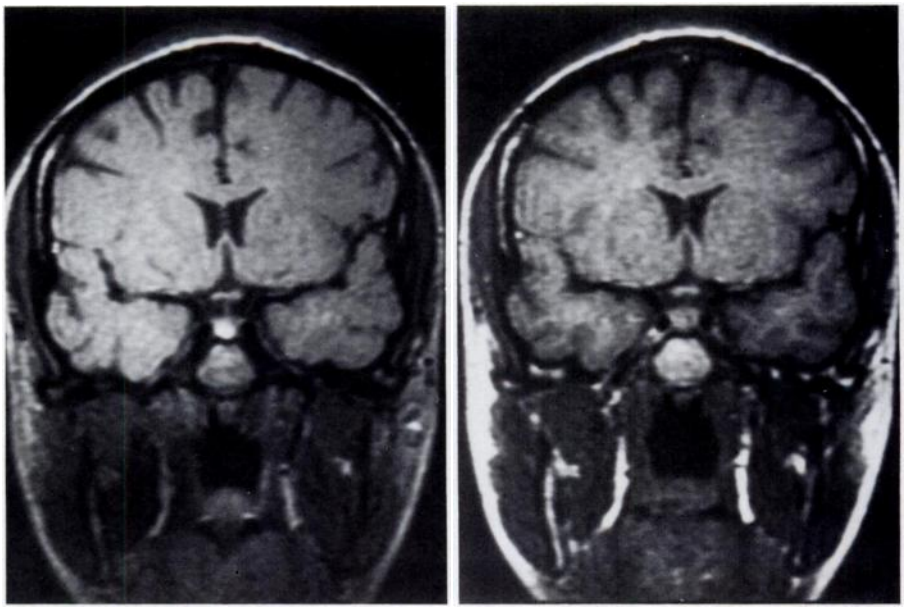


a. b. c.

Figure 2. **(a)** Gap is equal to the section thickness, **(b)** gap is equal to ½ section thickness, **(c)** no gap between sections. Note the striking loss in gray-white matter contrast between **b** and **c**. TR = 2,500 msec, TE = 25 msec, section thickness = 5 mm, field of view = 20 cm.

Figure 2 illustrates a decrease in gray-white matter contrast with a long TR sequence as the gap between sections is decreased. Figure 3 illustrates an increase in gray-white matter contrast with a short TR sequence as the gap between sections is decreased.

Calculated apparent T1 values were obtained for a cylindrical phantom containing a dilute solution of $CuSO_4$ for sections 2 and 3 of two multisection series of which one was obtained with gaps equal to section thickness and the other with no gaps between sections. (T1 values were calculated from four spin-echo pulse sequences with TE = 20 msec and TR = 500, 1,000, 1,500, and 2,000 msec using a least-squares fit and assuming single exponential relaxation.) The calculated T1 values differed between sections 2 and 3 of the no-gap sections (935 and 685 msec, respectively), whereas they were (to within the predicted error) the same for the noncontiguous sections (582 and 583 msec, respectively). Furthermore, the calculated T1 for the noncontiguous sections is significantly lower than either calculated value for the no-gap sections.



a. b.

Figure 3. **(a)** Gap is equal to ½ section thickness, **(b)** no gap between sections. Note that th gray-white matter contrast is the opposite of that seen in Fig. 2, and that it increases when there is no gap between sections. TR = 800 msec, TE = 25 msec, section thickness = 5 mm, field of view = 20 cm.

DISCUSSION

The presence of a small but significant amount of excitation of nuclei outside the section of interest is responsible for the effect we observed. These side-lobes of excitation arise from the use of a section-selective sinc pulse in the presence of a gradient (the method of section selection most commonly referred to in the literature) and are more pronounced for the 180° radiofrequency (RF) pulses than for the 90° pulses (3, 6–8). The size of the side-lobes of excitation can be reduced through the use of longer RF pulses. This, however, does increase the shortest TE that can be used, an effect that becomes more pronounced as the sections become thinner, giving such images an unavoidable, relatively heavy T2 weighting. Although straightforward to implement on the Signa system or any MR imaging system, we have made no attempt to do so or to investigate the potential problems and trade-offs associated with such RF pulses. (Since this article was submitted, Feinberg et al. [9] have implemented long RF pulse sequences on a system and have discussed the trade-offs involved.) Several investigators have proposed methods of improved section selection through the use of

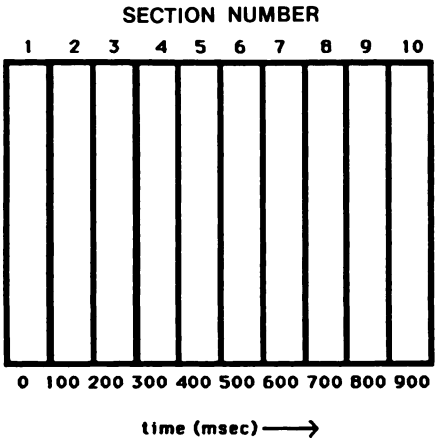


Figure 4. Diagrammatic representation of a ten-section sequence with sequential excitation of the sections. The sections are numbered at the top, and the time of excitation (in milliseconds) is given at the bottom.

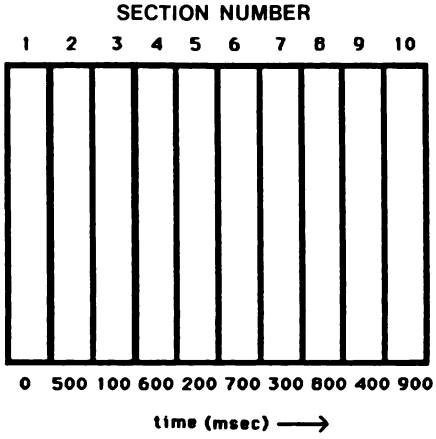


Figure 5. Diagrammatic representation of a ten-section sequence in which the odd-numbered sections are excited, followed by the even-numbered sections. Section number is at the top, time of excitation at the bottom.

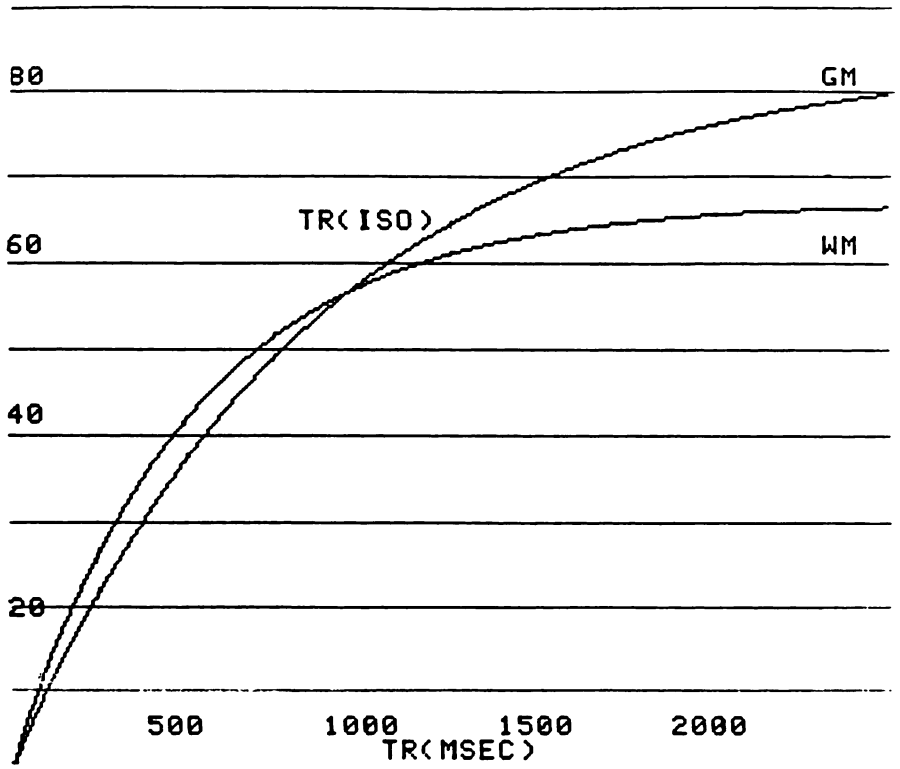


Figure 6. Relative signal strengths of gray matter (*GM*) and white matter (*WM*) in arbitrary units are given as a function of repetition time. *TR(ISO)* is that value of TR for which gray and white matter are isointense. (Graph based on material in [2].)

non-sinc RF pulses (10–12), but we do not know whether they have been implemented on MR imaging systems.

The partial excitation of a given section by the RF pulses used primarily to excite an adjacent section leads to a reduction in the time for recovery of the longitudinal magnetization (T1 relaxation), which in turn results in decreased signal and concomitant changes in contrast.

To illustrate this, let us consider the case of a ten-section sequence of repeated 90° pulses with a TR of 1,000 msec. We further assume that the time is divided equally among the sections yielding a 100-msec interval between the 90° pulses for consecutive sections (Fig. 4). If sections are contiguous, then the RF pulse will partially excite the neighboring section. We will assume, however, that this pulse uniformly excites the entire neighboring section by 90° as well. This means that the recovery time for T1 relaxation in contiguous sections is only 100 msec instead of 1 sec for any given section.

This model represents a considerable simplification for the following reasons: (*a*) the RF pulse does not uniformly excite the adjacent section, but in reality there is a distribution of tip angles at different levels in the axial direction (as well as in the plane of the section); (*b*) real imaging systems almost invariably use a spin-echo pulse sequence so that the time permitted for T1 relaxation is actually the time from the 180° pulse to the next 90°, not the time from the 90° pulse to the next 90° pulse (the former is TE/2 shorter than the latter).

The Signa system offers two methods to alleviate the problem: (*a*) separate the sections and (*b*) excite the sections in nonsequential order (e.g., 1, 3, 5, etc. followed by 2, 4, 6 etc.).

Separating the sections so that the subsequent section is positioned beyond the side lobes of excitation of the prior section does completely eliminate the problem. However, it leaves one with the potential problem of missing disease in the nonexcited (and nonvisualized) gaps. The size of the gaps relative to the anticipated size of the area of disorder or the type of information desired will determine the necessity of repeating the imaging to fill in the gaps.

Exciting sections in a nonsequential order will decrease the effects of excitation of adjacent sections but will not eliminate them. To illustrate this, consider ten contiguous sections (90° pulses with TR = 1 sec), but with an excitation order of 1, 3, 5, 7, 9, 2, 4, 6, 8, 10 (Fig. 5). Consider for example section 6, which is excited at time t = 700 msec. Its neighbor, section 7, was excited at 300 msec leaving 400 msec for T1 relaxation in section 6. (As previously mentioned, the adjacent section is only partially excited. We have made the assumption for the sake of simplicity, however, that the adjacent section is excited uniformly.) Similarly, if we consider section 5, we find that there are 500 msec for T1 relaxation (from 700 msec of one series to 200 msec of the next). Thus, we not only have effective recovery times less than 1 sec, but they differ depending on the location of the section in the sequence. A decrease in the effective recovery time, in turn, leads to an apparent increase in the calculated T1.

T1 relaxation curves for white and gray matter are shown in Figure 6 (2). White matter has a shorter T1 than does gray matter and hence higher signal at shorter TRs. Gray matter, however, has greater proton density than white matter and hence a greater intensity at long TR (2). It is the difference in proton density that causes the gray-white matter differentiation at long TR. A reduction in effective TR at long TR, that is, longer than the isointensity point TR (ISO), will have the effect of moving the relative gray-white matter intensities closer to TR (ISO) on the graph, hence reducing gray-white contrast. This effect is illustrated in Figure 2.

On the other hand, if TR is short (less than TR [ISO]), a reduction in the effective TR will lead to an increase in gray-white matter discrimination, as shown in Figure 3.

The calculated T1 values we obtained are in agreement with our theoretical prediction in regard to an apparent lengthening of calculated T1 in the no-gap, nonsequentially excited sections relative to noncontiguous, sequentially excited sections and the apparent differences in calculated T1s among the different sections in a nonsequentially excited series. In addition, as pointed out by one of our referees, the measurement of T1 values in nonsequentially excited sections will also be affected by the choice TRs from which the data are obtained.

CONCLUSION

We have seen then that section spacing may play a considerable role in image contrast, calculated T1 values, and study time. Although the results demonstrated apply strictly to the Signa system, it is probable that they will apply at to least some degree to many other systems. ■

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