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A Comparison of Default and Reduced Bandwidth MR Imaging of the Spine at 1.5 T

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The value of a reduced bandwidth MR imaging technique was tested prospectively in 51 spinal MR examinations by using default (16 kHz) bandwidth, 2000/30, 90 (TR/TEs) and 600/30, and reduced (8 kHz) bandwidth, 2000/46, 92 and 600/30, techniques at 1.5 T.

Bandwidth reduction was used to maintain the signal-to-noise ratio for a reduced scan time. Concerns have been raised as to the effect of bandwidth reduction at high field, since a savings in time or an increased signal-to-noise ratio occur at the expense of increased chemical shift misregistration artifact. However, when appreciable, the chemical shift-related artifact in the spine was typically located in the frequency-encoding direction at the vertebral body/disk space interface or the dural sac/epidural fat interface in the lower lumbosacral region and was easily distinguished from pathologic lesions. There were no missed diagnoses with the reduced bandwidth technique.

This study suggests that chemical shift-related artifact will rarely be confused with pathology by an experienced reader and suggests a clinical role for the bandwidth technique to decrease scanning time in uncooperative patients or to allow acquisition of additional imaging planes in a reasonable time.

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MR imaging is well accepted as the primary method for evaluating the spine and spinal cord. However, there is no general consensus as to the optimal imaging procedure. A technical factor that has not been widely tested in clinical application is the effect of bandwidth manipulation on image quality and lesion detection. The bandwidth, which can be manipulated on many commercial MR imaging systems at the level of the operator interface, has a direct effect on image signal-to-noise ratio (SNR). For example, by reducing the bandwidth by one half, SNR can be preserved while allowing studies to be obtained in approximately half the time. Alternatively, the SNR can be increased by a factor of approximately 1.4 or 2 by a one half or one quarter reduction in imaging bandwidth, respectively, at a constant scan time.

However, the SNR advantage obtained through a decrease in imaging bandwidth comes at the expense of increased chemical shift misregistration artifact (CSA). The CSA is proportionate to the strength of the magnetic field, and although reduced bandwidth techniques have recently been promoted as a low-field technique, concerns have been raised as to the utility of the reduced bandwidth technique at higher fields [1-3].

On the basis of our experience with reduced bandwidth imaging of the head [4], we hypothesized that CSA introduced at high field by bandwidth reduction would occur in characteristic anatomic locations and would be minimal on T2-weighted images. The purpose of this study was to compare prospectively the reduced and default bandwidth techniques at high field in studies of the spine.

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Theory

The bandwidth of an imaging experiment refers to the bandpass of the imager's low-pass filters, which filter the received MR signal prior to digitization. This filtering is necessary because only frequencies within a limited range contain information originating from the MR signal, while outside frequencies predominantly carry noise that would seriously degrade image quality. The cutoff frequency of the filter represents the highest frequency in the data that is used to create an image. In spin-warp MR imaging, the SNR is proportional to the square root of the filter bandwidth (BW), such that

$$\text{SNR} \propto 1/\sqrt{\text{BW}}$$

To the extent that other factors will allow, then, imaging should be performed at the narrowest possible bandwidth.

Detailed consideration of the consequences and limits of reducing the imaging bandwidth have been established previously [2-4]. For practical purposes, in this study, only the presence of an increased chemical shift artifact was considered. This may be understood as follows.

The water and lipid proton resonances that comprise the MR image are separated by about 3.5 ppm, which at 1.5 T corresponds to a frequency separation of approximately 220 Hz. Assuming an image matrix of 256 points in the frequency-encoding direction and a default bandwidth of ± 16 kHz, the width of an individual pixel is 125 Hz. Under these conditions, water and lipid protons from the same anatomic location are displaced in the image by ≈ 1.8 pixels. If the bandwidth is reduced to ± 8 kHz and the image field of view and resolution are held constant, the pixel width becomes 62.5 Hz. Water and lipid signals are now displaced by 3.6 pixels. Effectively, the $\sqrt{2}$ advantage accomplished by halving the bandwidth is accompanied by a doubling of the CSA. As the image SNR is proportional to the square root of the number of excitations (NEX), the earlier equation may be expanded to

$$\text{SNR} \propto \left(\frac{\text{NEX}}{\text{BW}} \right)^{1/2}$$

If the image resolution is held constant, a twofold bandwidth reduction will therefore provide an image SNR equal to that of a default bandwidth image acquired with twice the NEX. In situations in which a NEX of two or greater is required to achieve a desired image SNR, bandwidth reduction offers appreciable scan time savings. Where a single NEX is adequate, a reduced bandwidth provides improved SNR. The radiologist must decide when the increased CSA will not permit exploitation of this advantage.

Materials and Methods

This prospective controlled study was based on MR examinations in 27 consecutive patients referred for cervical, thoracic, or lumbosacral spine studies with the following exclusion criteria: patients with an unstable clinical condition with contraindication for prolonged study; patients requiring anesthesia or sedation; or patients with severe claustrophobia. Emergency add-on patients were excluded to minimize delays in the imaging schedule. The patient population

consisted of 14 males and 13 females, 15 to 78 years old (mean age, 42.3 years).

Fifty-one default and reduced bandwidth comparison MR studies were obtained. All studies were obtained at 1.5 T on the GE Signa MR system with the body coil as transmitter and an 18×32 -cm rectangular surface coil as a receiver. The frequency-encoding direction was craniad to caudad in all studies. The material includes 30 lumbosacral, four thoracic, and 17 cervical spine studies. Intermediate and T2-weighted sagittal or T1-weighted sagittal spin-echo series were acquired with both a default imaging bandwidth (16 kHz) with two excitations and a reduced bandwidth (8 kHz) with one excitation. The order of examination was random. The intermediate and T2-weighted default bandwidth spin-echo series were acquired with a TR/TE combination of 2000/30, 90 and a field of view of 20-32 cm, depending on the area of interest. A 128×256 matrix with 3-mm-thick slices and 1.5-mm interslice gap with flow compensation was used. One default bandwidth series was performed with cardiac gating. Flow compensation was omitted in one reduced bandwidth series. The imaging time was 8 min, 41 sec. The T1-weighted studies included interleaved 3-mm-thick slices obtained with a TR/TE combination of 600/30. Imaging parameters were otherwise the same except that flow compensation was not used. The imaging time was 5 min, 12 sec.

The intermediate and T2-weighted reduced bandwidth series were acquired with a TR/TE combination of 2000/46, 92, since at the time of the study reduced bandwidth imaging with flow compensation placed restrictions on echo delay time. Otherwise, imaging parameters were as indicated for the default bandwidth spin-echo series. The imaging time was 4 min, 42 sec. For the T1-weighted reduced bandwidth studies, imaging parameters were held constant except for bandwidth and number of excitations, which were reduced for an imaging time of 2 min, 48 sec. All studies were filmed by the MR technologists without special instructions.

The corresponding default and reduced bandwidth series were coded and reviewed as pairs by three staff neuroradiologists who were blinded to the acquisition bandwidth. Reviewers were asked to grade the relative image quality of the pair, to estimate the effect of technique on the diagnostic value (lesion detection), and to grade the effect of CSA on image interpretation in each series. The quality of the two series was compared by using the following scale: significantly better, better, equal, worse, or significantly worse (Table 1).

TABLE 1: Comparison of Default vs Reduced Bandwidths*

Echo Times	Number of Readings
First echo	
2000/46 RB significantly better	3
2000/46 RB better	10
2000/30 DB significantly better	0
2000/30 DB better	16
RB = DB	43
Second echo	
2000/92 RB significantly better	1
2000/92 RB better	8
2000/90 DB significantly better	0
2000/90 DB better	15
RB = DB	48
SE 600/30	
RB better or significantly better	0
DB better or significantly better	0
RB = DB	9

* Summary of results from 153 readings of 51 images comparing default bandwidth (DB) (2000/30, 2000/90, and 600/30) with reduced bandwidth (RB) (2000/46, 2000/92, and 600/30), respectively.

Results

Table 1 lists the image quality of the 51 pairs of MR examinations, which were blindly read by three neuroradiologists. Altogether there were 153 readings. The three readers graded the image quality of the reduced bandwidth series as better or significantly better in 13 of 72 2000/30 and 2000/46 pairs and in nine of 72 2000/90 and 2000/92 pairs. The studies were considered to be of equal diagnostic quality in 43 first-echo pairs and in 48 second-echo pairs. Reduced bandwidth series were considered to be of worse diagnostic quality in 16 first-echo pairs and in 15 second-echo pairs. In no case was the image quality of the reduced bandwidth series rated significantly worse than that of the default bandwidth series. The nine 600/30 pairs were all of equal diagnostic quality. The diagnostic value (lesion detection) of the

techniques was judged to be equal in all cases. In no case was a lesion inapparent on either the default or reduced bandwidth study (Figs. 1–3).

A characteristic CSA was frequently observed on both reduced and default bandwidth series and appeared in the frequency-encoding direction. It was less prominent on the default bandwidth series. The artifact presented as a high and low signal intensity band projecting over the boundary between the disk and vertebral body on the intermediate and T2-weighted images and was characteristically less obtrusive with greater T2 weighting. A dark band appeared at the fat (bone marrow in the vertebral body)/water (disk space) interface while a high signal band was seen at the water/fat interface (Figs. 4 and 5). The artifact was seen in approximately one third of the cervical spine studies and in two thirds of the thoracic and lumbosacral spine studies. The artifact

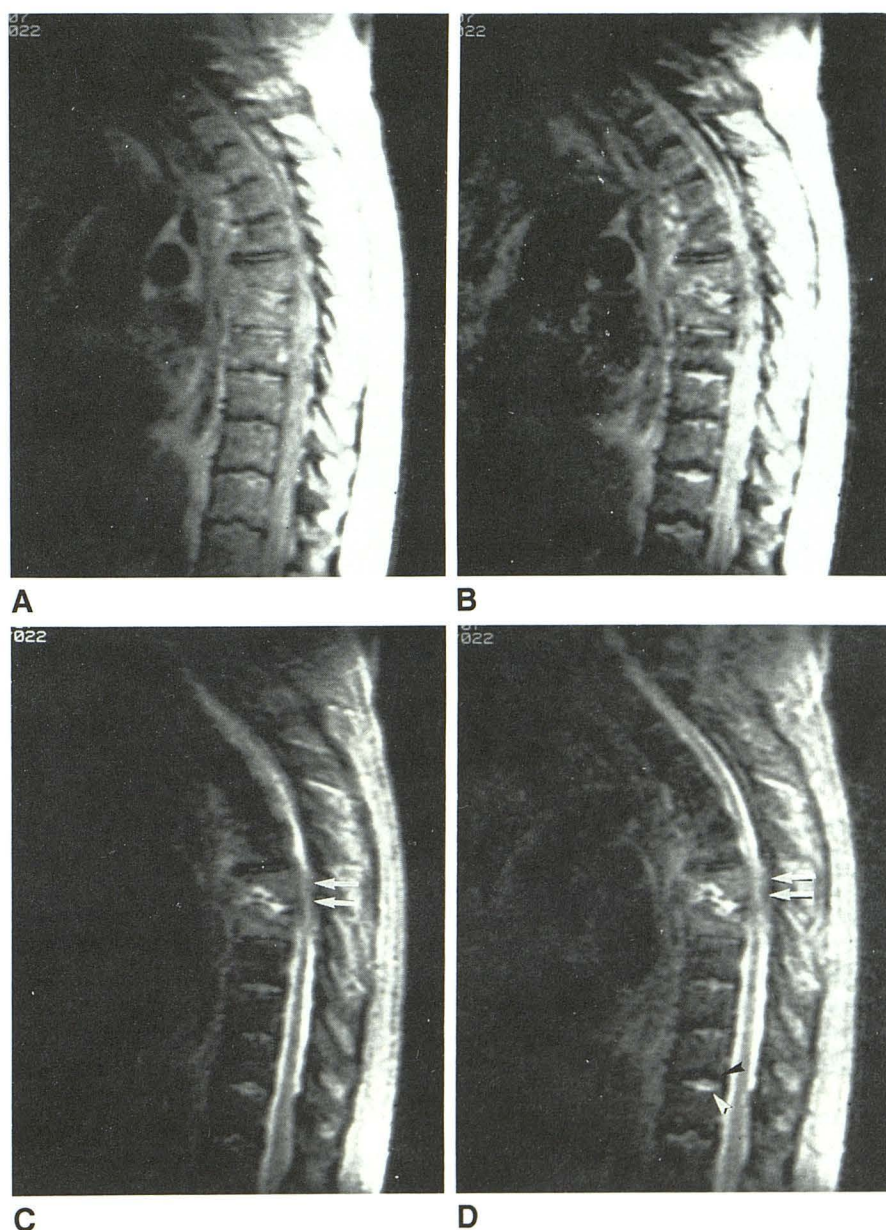


Fig. 1.—A–D, Default bandwidth images (A and C) compared with reduced bandwidth images (B and D) of thoracic spine in patient with proved disk space infection and with infectious debris inside spinal canal (arrows in C and D). For default bandwidth studies, imaging parameters were 2000/30, 90, matrix 128×256 , and two excitations for acquisition time 8 min, 41 sec. For reduced bandwidth studies, imaging parameters were 2000/42, 92, matrix 128×256 , and one excitation for acquisition time 4 min, 42 sec. Although chemical shift misregistration artifact is accentuated in reduced bandwidth image (B), it characteristically appeared less obtrusive with longer echo times, as in D (arrowheads), because of lesser fat intensity. The lesion is depicted with both bandwidth images; however, the reduced bandwidth was rated as significantly better.

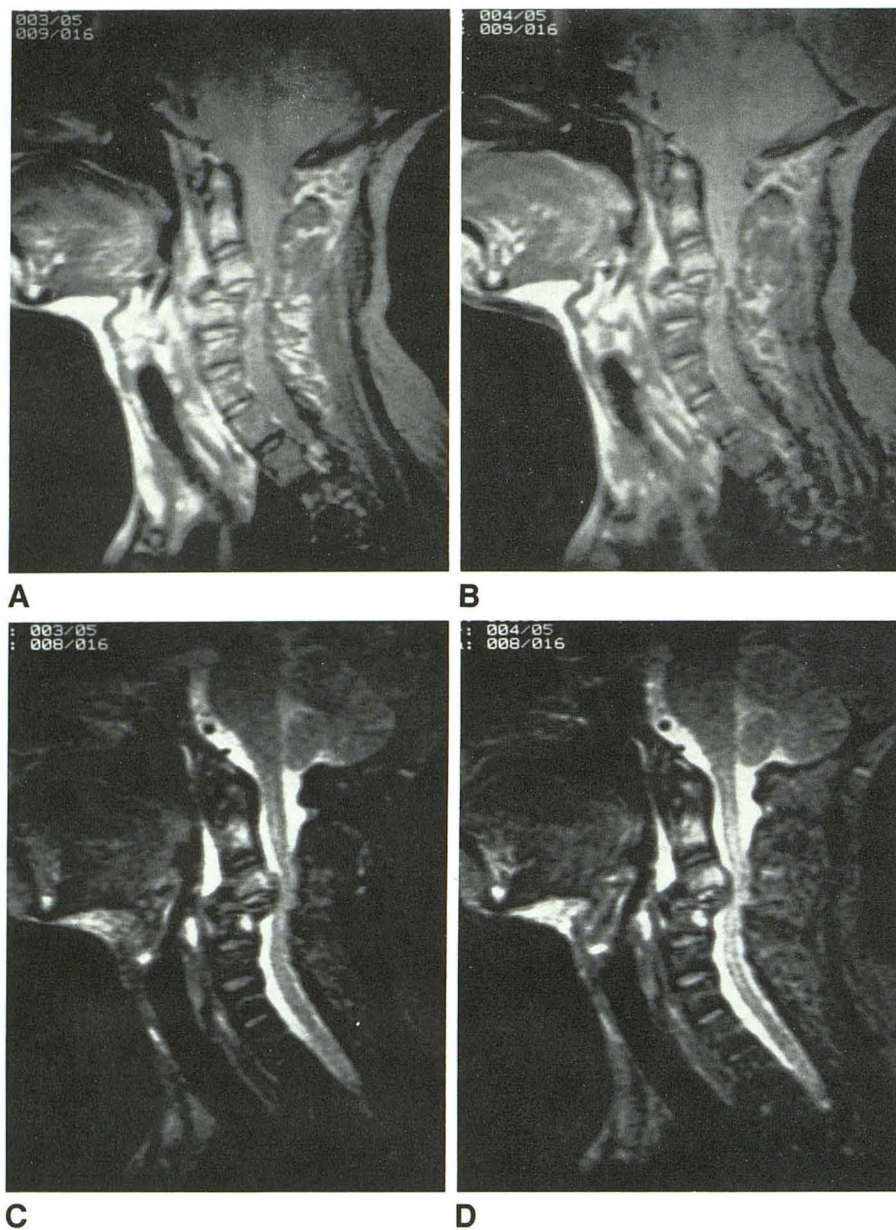


Fig. 2.—A–D, Default bandwidth images (A and C) compared with reduced bandwidth images (B and D) in patient with metastatic involvement of cervical spine with secondary subluxation. Imaging parameters as in Fig. 1, except that in reduced bandwidth study no cardiac gating was used. Chemical shift registration artifacts were generally less prominent in cervical spine studies.

was most prominent in the lumbosacral area. No artifacts were seen to project over the spinal canal or over its contents.

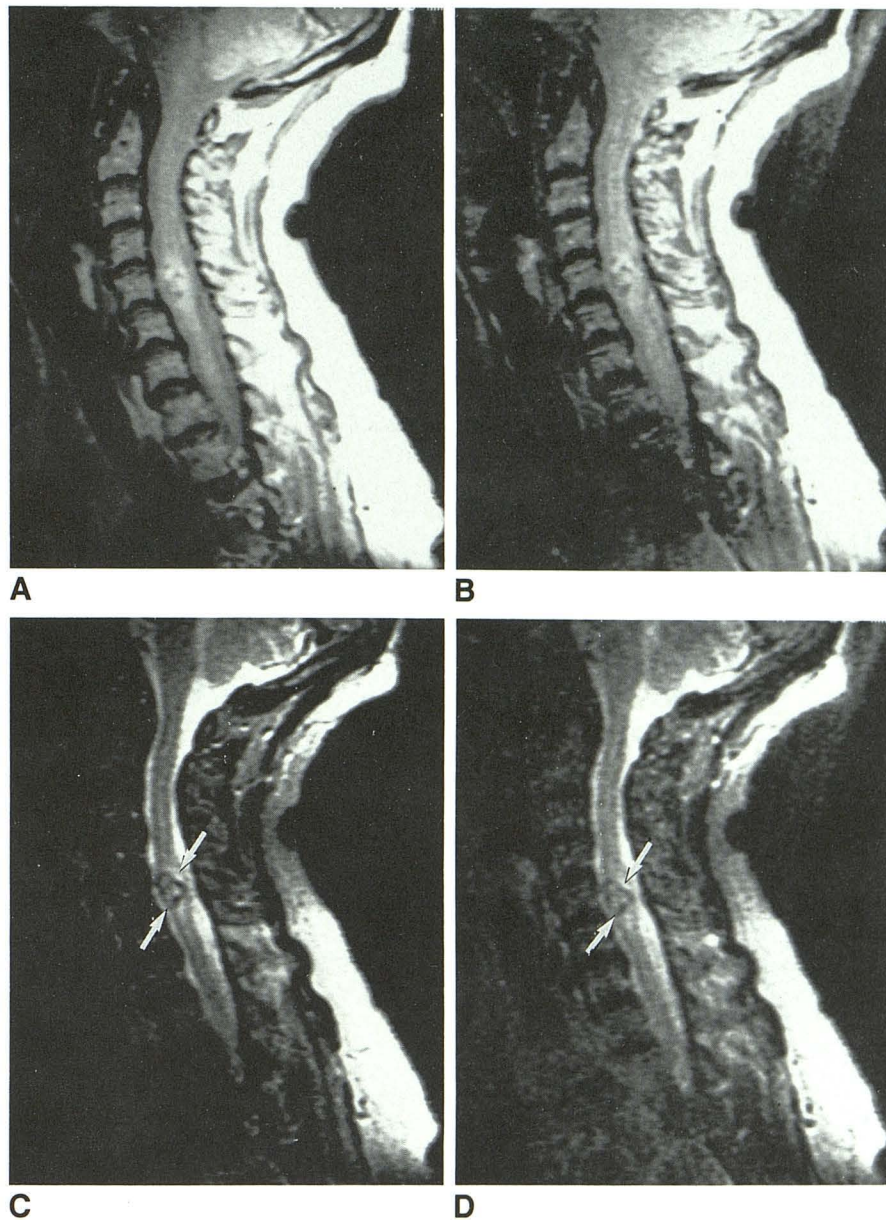
A CSA was also observed at the interface of the dural sac (water) and epidural fat, at the L5/S1 region. The artifact was observed as a vertical, curvilinear bright signal band overlapping the posterior aspect of L5 and/or the S1 vertebral body depending on the amount of epidural fat and the orientation of the sacrum. This artifact was not observed in cervical and thoracic studies.

Discussion

Bandwidth reduction is an easily applied parameter to increase SNR at a constant scan time or, as in this work, to

decrease the scanning time at a constant SNR. Its acceptance for wide use has been limited, at least partly, because of suggestions of unacceptable CSA [2], a decrease in image resolution [3], and restrictions in choice of TE [2]. Our preliminary experience with reduced bandwidth in head imaging [4], however, suggest that the practical importance of these factors may have been overestimated. The need for less time-consuming spine studies in cancer patients and in traumatized or sedated patients motivated us to explore reduced bandwidth methods in spine MR. CSA may be a serious problem in MR because it can simulate true anatomic lesions such as edema, calcification, or hematoma. Optimizing the SNR by decreasing the bandwidth results in increased CSA. In our

Fig. 3.—A–D, Comparison of default bandwidth images (A and C) with reduced bandwidth images (B and D) in patient with a C5-level glioma. Imaging parameters as in Fig. 1. Although the image quality was graded lower for the reduced bandwidth study, the tumor (arrows in C and D) is clearly demonstrated on both reduced bandwidth images.



system, decreasing our default imaging bandwidth from 16 to 8 kHz improves SNR by a factor of approximately 1.4, which offsets an equal magnitude in SNR obtained by halving the excitations. Chemical shift displacement increases from 1.7 to 3.4 pixels (Foster TH, personal communication). As our results show, this artifact was not a limiting factor in routine clinical spine studies, since the appearance of these signal changes is less prominent on the T2-weighted image owing to the relatively short T2 of the fat. This allows the real nature of the "lesion" to be easily discovered.

In addition, the orientation of the spinal cord relative to CSF in the dural sac is such that a clear-cut interface does not exist in the frequency-encoding direction, and the CSA is less

likely to appear. The only spinal area other than the vertebral body/disk space in which a fat/water interface is present in this direction is the lower lumbosacral region. However, reliable recognition of this artifact was routine, and it is unlikely to be mistaken for true anatomic pathology. Concerns about image resolution degradation due to the decreased readout gradient associated with bandwidth reduction have not proved to be realistic. Quantitative resolution measurements at 1.5 T demonstrate that no loss in resolution is observed at bandwidths as low as 4 kHz [5].

In the normal brain it is known that the contribution from lipids to the image is negligible [6], a fundamental observation that can be applied to the other areas of central neural tissue,

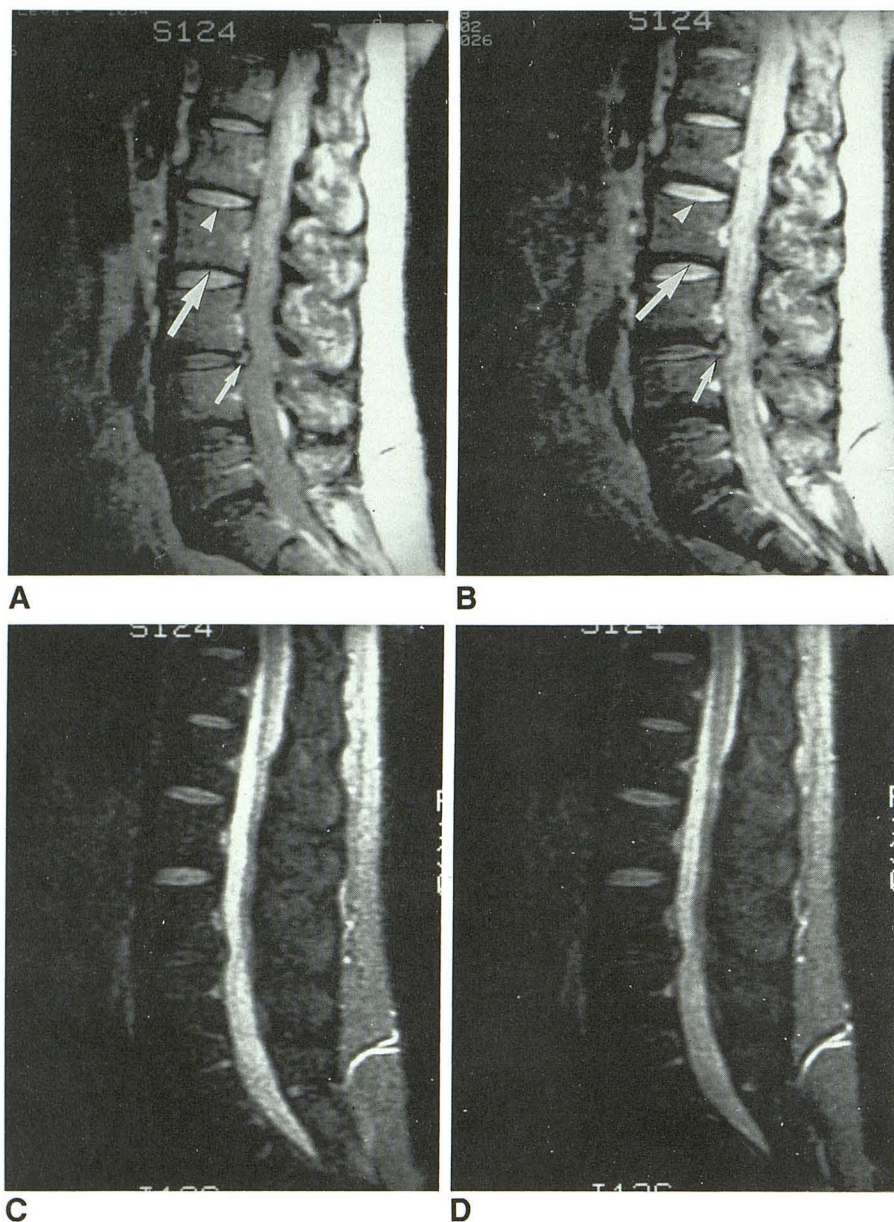


Fig. 4.—A–D, Comparison of default bandwidth images (A and C) with reduced bandwidth images (B and D) in patient with an L3–L4 disk herniation (*small arrow in A and B*) imaging parameters as in Fig. 1. Chemical shift misregistration artifact is seen as a dark band at the bone/disk space interface (*large arrow in A and B*) and a high signal band is seen at the disk space/bone interface (*arrowhead in A and B*). Chemical shift misregistration artifacts are more prominent on reduced bandwidth study, but decrease with increasing TE.

such as the spinal cord. Whether this observation will be affected by pathology remains uncertain.

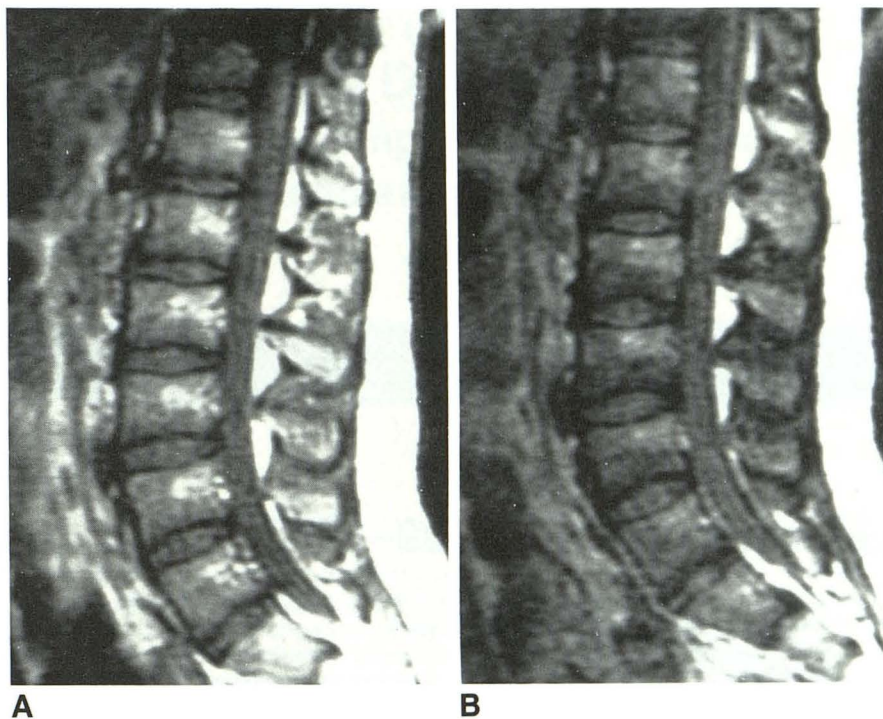
One of the factors that has limited the use of reduced bandwidth has been the restriction of the choice of TE. In the software version used during this study, the shortest TE allowed with first-order flow compensation for a two-echo series was 46 msec. In this patient population the potentially greater T2 weighting did not affect the diagnostic value of the images, since the anatomy was equally well seen on both 46- and 30-msec images. More recent software updates have allowed TE reductions to 33 msec.

To please the eye and minimize the CSA, even though it was not positive in this clinical test, studies can be performed

by applying bandwidth reduction only to the later echo [5, 7]. Or, when reducing the bandwidth of both echoes, the later echo could be reduced to a greater degree (hybrid bandwidth studies).

In summary, the need for less time-consuming scans without degradation of image quality is especially important in extensive spine studies (such as metastatic surveys), in pediatric examinations, and in examinations of restless patients. The time saved can be used for additional projections or multiple sequences in complicated cases. The results of this study suggest the clinical usefulness of the reduced bandwidth technique without the risk of technique-related misdiagnoses.

Fig. 5.—A and B, Comparison of default bandwidth (A) with reduced bandwidth (B) in a T1-weighted study (600/30) in a patient with no abnormality.



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