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Metallic Artifacts on MR Images of the Postoperative Spine: Reduction with Fast Spin-Echo Techniques[1]

PURPOSE: **To determine whether the relative insensitivity of T2-weighted fast spin-echo (FSE) techniques to magnetic susceptibility can be exploited to reduce metallic artifacts on images of the postoperative spine and, thus, improve the interpretation of the postoperative study.**

MATERIALS AND METHODS: **Three neuroradiologists retrospectively evaluated sagittal T2-weighted conventional spin-echo and FSE images obtained in 15 patients with metallic artifacts from various sources including drill particles from anterior cervical diskectomy, posterior fixation wires, fixation rods or plates, and an inferior vena cava filter. The amount of artifact present and whether these artifacts affected image interpretation were evaluated.**

RESULTS: **Among the 45 paired evaluations, the artifact was judged to be less apparent with FSE sequences in 39. In eight of 45 evaluations (18%), the interpretation of the area of interest was possible only on the FSE images.**

CONCLUSION: **FSE imaging, especially when performed with shorter echo spacing, increases the amount of T2-weighted information in the presence of metallic artifact because it decreases magnetic susceptibility effects.**

Index terms: Magnetic resonance (MR), artifact • Magnetic resonance (MR), rapid imaging, 30.121416 • Magnetic resonance (MR), comparative studies, 30.121411, 30.121416 • Spine, MR, 30.121411, 30.121416 • Spine, surgery, 30.453

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Various metallic substances can preclude magnetic resonance (MR) imaging because of safety (1–3) and image degradation (4). This is a serious problem for spine imaging, because MR imaging may be the only modality capable of depicting certain lesions (eg, intramedullary disease). Spine stabilization surgery, by its very nature, utilizes extensive metallic hardware. Anterior cervical diskectomy with fusion can generate a considerable number of artifacts from minute drill particles, even without the installation of hardware (5,6). After safety considerations are met, the magnetic susceptibility effects of ferromagnetic and paramagnetic substances may obscure further imaging of the operative site when using standard spin-echo (SE) pulse sequences.

Fast SE (FSE) imaging is a relatively new technique that may largely replace standard T2-weighted SE imaging. T2-weighted FSE pulse sequences can be performed in a fraction of the time of standard SE pulse sequences, often with improved signal-to-noise ratios and contrast (7). Preliminary studies have shown comparable lesion conspicuity in both cranial and spinal evaluation compared with conventional SE techniques (8–11). The small echo spacing inherent in the technique should lead to decreased magnetic susceptibility effects (8,12–15). The purpose of our study was to determine whether the relative insensitivity of FSE techniques to magnetic susceptibility could be exploited to reduce metallic artifacts on T2-weighted images. Moreover, we evaluated whether the artifact reduction was substantial enough to improve one's ability to evaluate a study.

MATERIALS AND METHODS

We retrospectively evaluated MR images obtained in 15 consecutive patients over a 4-month period; all images were obtained with a 1.5-T imager (Signa; GE Medical Systems, Milwaukee, Wis) and were degraded by metallic artifacts. The patient population included patients with minute drill particles from anterior cervical diskectomy and fusion (n = 4), posterior cervical fusion wires (n = 4), posterior fusion rods and/or plates (thoracic and lumbar) (n = 4), anterior cervical fusion plates (n = 2), and a Bird's Nest inferior vena cava filter (Cook, Bloomington, Ind) (n = 1). Conventional SE and FSE images were obtained in the sagittal plane at T2-weighted imaging in all patients. Both techniques were performed during the same examination. Parameters for SE imaging included a repetition time (TR) of 1,800–2,000 msec, an echo time (TE) of 30, 80 msec, a 256 × 128 matrix, two signals averaged, 3- or 4-mm-thick sections with a 1-mm gap, a 32-kHz bandwidth, and an examination time of 8–11 minutes. FSE imaging was performed with a TR of 2,000–4,000 msec, an effective TE of 17, 80–102 msec, an echo space of 17 msec, an echo train length of eight or 16, a 256 × 256 matrix, two or four signals averaged, 3- or 4-mm-thick sections with a 1-mm gap, a 32-kHz bandwidth, and an examination time of 2–4 minutes.

All images were evaluated by three neuroradiologists (L.M.T., A.E.F., D.P.F.), for a total of 45 paired evaluations. The neuroradiologists were blinded to all imaging parameters, and image pairs were evaluated in a random order. For each set of images, a subjective comparison was made as to the amount of artifact present. Each observer chose which image, if any, had less artifact. The following three-point scale was used by each observer to subjectively evaluate whether the artifact reduction improved the ability to interpret the study: 1 = not at all, 2 = somewhat, 3 = interpretable only on the study with decreased artifact.

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Abbreviations: FSE = fast spin echo, SE = spin echo, TE = echo time, TR = repetition time.

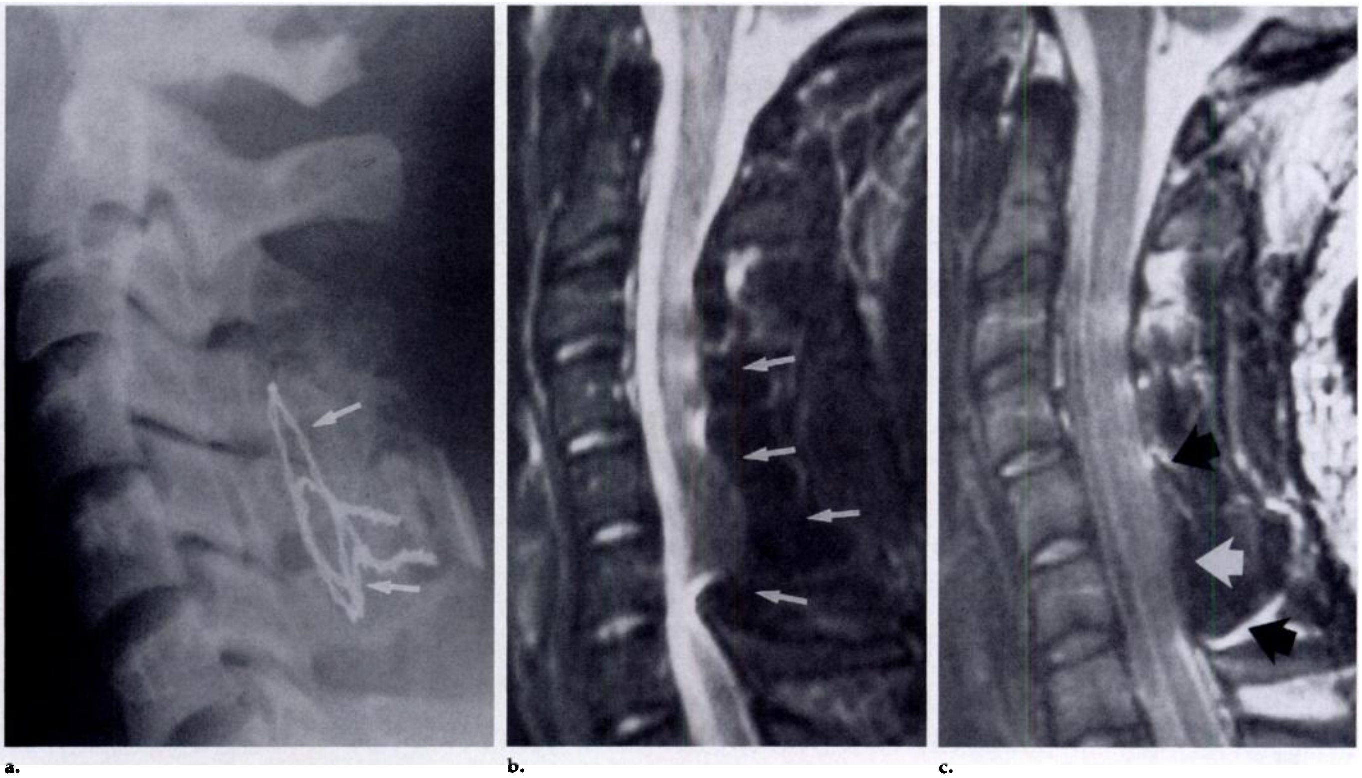


Figure 1. Posterior fusion wires. **(a)** Lateral plain radiograph of the cervical spine shows posterior fusion wires (arrows) extending from C-4 to C-6. **(b)** Sagittal T2-weighted SE MR image (TR msec/TE msec = 2,000/80, two signals averaged, 256 × 128 matrix, 4-mm-thick sections, examination time = 8 minutes 56 seconds) of the cervical spine shows marked distortion of the posterior aspect of the canal and cord by metallic artifact (arrows). **(c)** Sagittal T2-weighted FSE MR image (2,000/102, two signals averaged, echo space = 17 msec, echo train length = eight, 256 × 256 matrix, 4-mm-thick sections, examination time = 2 minutes 12 seconds) at the same location shows marked improvement in the amount of distortion (arrows) compared with **b**.

Observers then evaluated which sequence was best for resolution of vertebral bodies and intradural contents (including spinal cord when applicable). The same three-point scale was applied to subjectively evaluate whether the difference in resolution was due to decreased artifact and/or technical differences. This latter choice was included to minimize the effect of increased signal-to-noise ratio from the differences in matrix size and number of signals averaged between the FSE and SE sequences.

Finally, observers were asked whether the sequences provided adequate T2-weighted sagittal information for evaluation of the vertebral bodies and intradural contents. Statistical analysis was performed with the sign test and the χ^2 test.

RESULTS

Of the 45 paired evaluations, the artifact was judged to be less apparent with FSE sequences in 39 (87%) (Fig 1). In six of the paired evaluations, the artifacts were judged to be not significantly different, and in no case was the conventional SE technique judged to be better ($P < .001$, sign test). The overall reduction in artifact aided in the interpretation of the study in 34 of the 45 (75%) paired evaluations (Fig 2). This included eight of 45 paired evaluations (18%) in which interpretation was only possible with the FSE images and 26 (58%) in which the ability to interpret was somewhat improved. Those cases with posterior fusion rods showed the least improvement; although the artifact was reduced, the reduction was not substantial enough to aid in image interpretation.

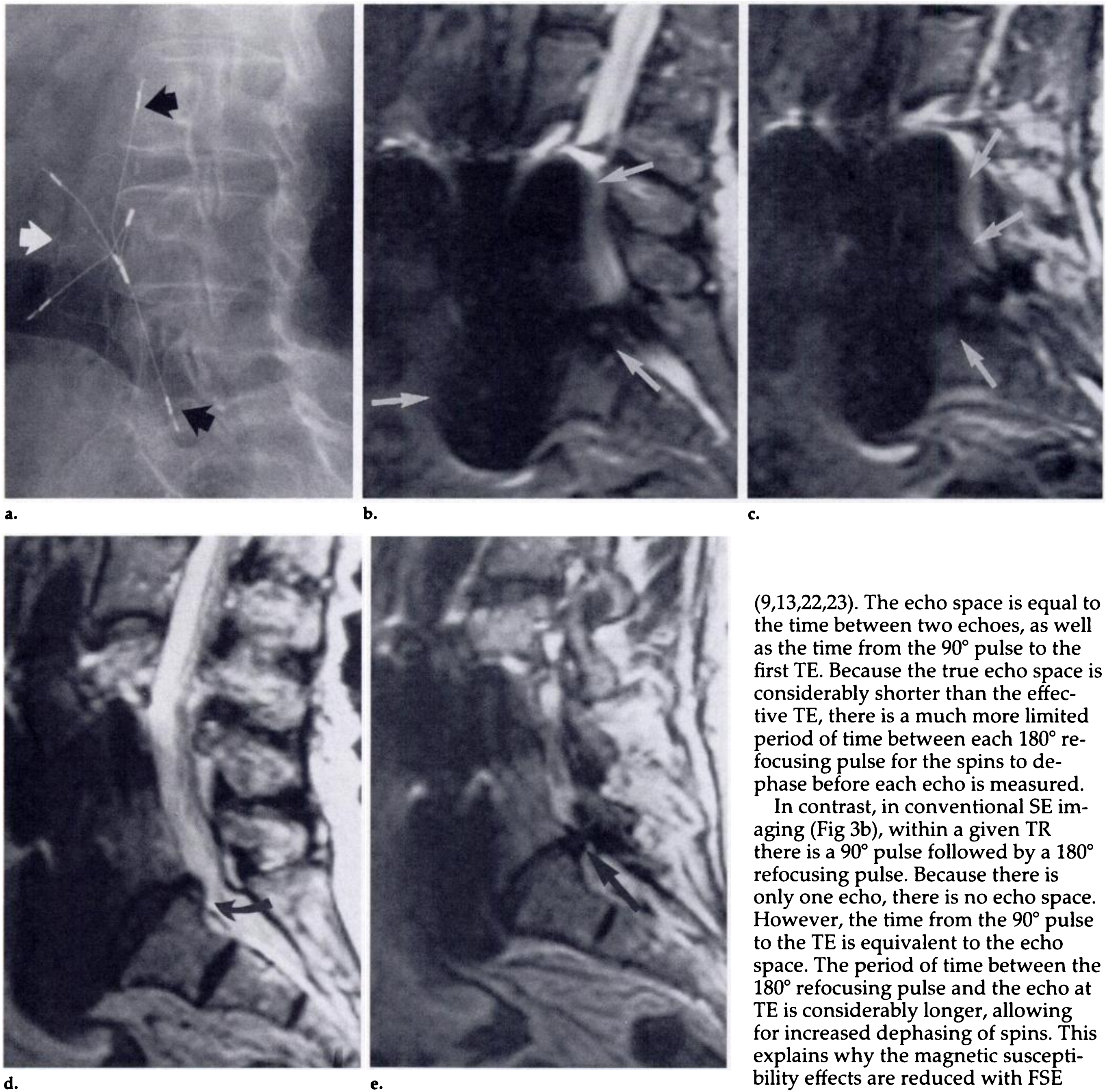
Resolution of intradural contents and vertebral bodies was almost always improved by the higher-spatial-resolution imaging parameters of FSE imaging (89% and 83%, respectively). However, the reduction in the artifact seen on FSE images was judged to further improve the resolution (69% and 61%, respectively).

FSE imaging was judged to provide adequate information about the vertebral bodies in 33 of the 45 paired evaluations (73%); SE imaging provided adequate information in 27 (60%). Though a trend was seen, this difference was not statistically significant ($P = .69$, χ^2 test). FSE imaging was judged to provide adequate information about the intradural contents in 27 of the 45 paired evaluations (60%); SE imaging provided adequate information in 16 (36%). This difference was statistically significant ($P = .03$, χ^2 test).

DISCUSSION

Magnetic susceptibility causes local field inhomogeneity and local field distortions leading to increased dephasing of the spins. This effect will increase with the length of time the spins have to dephase. Many factors will influence magnetic susceptibility effects, including field strength, chemical structure, density, spatial resolution, TE, echo spacing, and sampling bandwidth (16–19). The effect is greatest for ferromagnetic substances, less for paramagnetic substances, and least for diamagnetic substances (17). All patients in our study had some amount of ferromagnetic material related to surgery or a previously performed interventional procedure. The difference in TE and/or echo spacing between FSE and conventional SE imaging is the primary reason for the decreased artifact seen in our patients.

The FSE pulse sequence (Fig 3a) is based on the Carr-Purcell-Meiboom-Gill echo train. This technique, originally called RARE (rapid acquisition



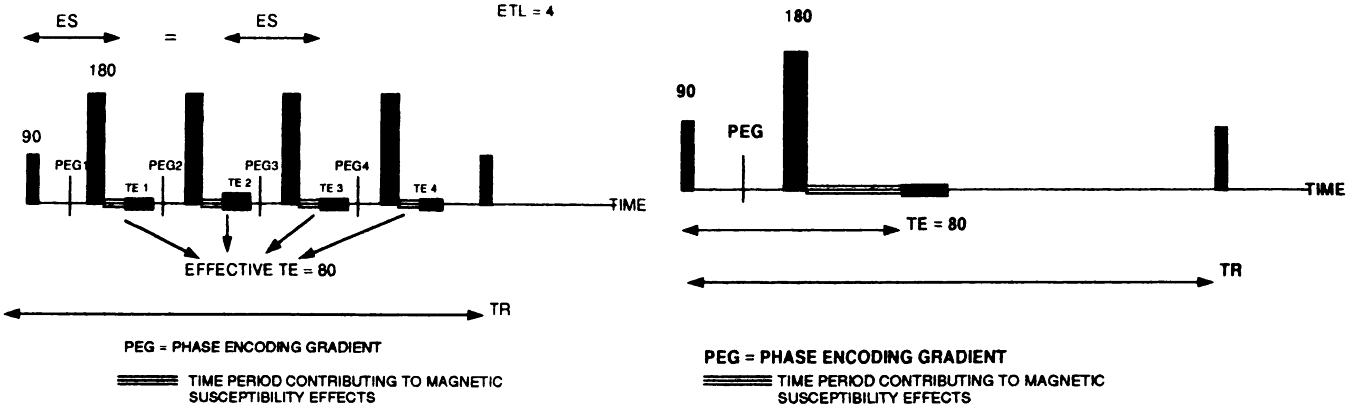
a. b. c. d. e.

Figure 2. Stainless steel Bird's Nest filter. **(a)** Oblique plain radiograph of the lumbar spine shows position of Bird's Nest filter (arrows). **(b)** Midline and **(c)** right parasagittal T2-weighted SE images (2,000/80, two signals averaged) of the lumbar spine show extensive metallic artifact (arrows), precluding evaluation of the lower disk spaces and canal. The patient was being evaluated for a right S-1 radiculopathy. **(d)** Midline and **(e)** right parasagittal T2-weighted FSE images (2,967/96, four signals averaged, echo train length = 16) obtained at the same location show a right paracentral disk herniation (arrow in **e**) and osteophyte (arrow in **d**) at L-5–S-1. This abnormality correlated with the patient's right S-1 radiculopathy.

with relaxation enhancement), was first described by Hennig et al (20) and later elaborated on by others (13,14,21,22). After the 90° pulse, multiple 180° refocusing pulses are used per TR, each with a separate phase-encoding gradient and read-out in the presence of a frequency-encoded gradient. In the FSE pulse sequence, the TE is in actuality an effective TE made up of one to 16 echoes (echo train length). Therefore, multiple TEs are present, each corresponding to a different echo. T2 contrast is determined by those echoes occurring at the desired operator-chosen effective TE to fill the contrast-dependent areas of k space (low frequency), while the remainder of the echoes fill the detail-dependent areas (high frequency) (9,13,22,23). The echo space is equal to the time between two echoes, as well as the time from the 90° pulse to the first TE. Because the true echo space is considerably shorter than the effective TE, there is a much more limited period of time between each 180° refocusing pulse for the spins to dephase before each echo is measured.

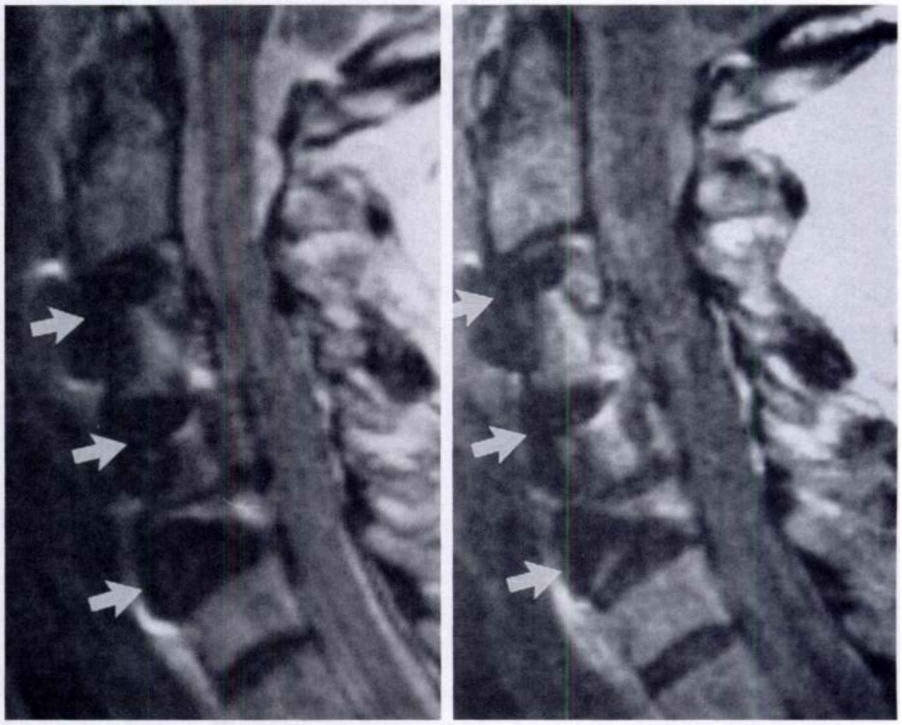
In contrast, in conventional SE imaging (Fig 3b), within a given TR there is a 90° pulse followed by a 180° refocusing pulse. Because there is only one echo, there is no echo space. However, the time from the 90° pulse to the TE is equivalent to the echo space. The period of time between the 180° refocusing pulse and the echo at TE is considerably longer, allowing for increased dephasing of spins. This explains why the magnetic susceptibility effects are reduced with FSE techniques (Figs 1, 2). In addition, with conventional SE sequences, only a single phase-encoding gradient is applied per TR, filling only a single line of k space, regardless of how many echoes are measured; this explains its longer imaging time.

The importance of echo spacing on susceptibility effects has been shown previously (12) and is demonstrated in Figure 4, which shows two T2-weighted FSE images that were acquired with different echo spacing (17 and 11 msec, respectively). One might postulate that this difference in magnetic susceptibility effects due to echo spacing will be greatest between FSE and T2-weighted SE images because of the larger difference between the TE and the echo space. Correspond-



a. b.

Figure 3. Comparison of conventional SE and FSE pulse sequences. **(a)** Diagram of FSE pulse sequence shows that the echo space (*ES*) is much shorter than the effective TE. There is a shorter period of time for the spins to dephase from each 180° refocusing pulse to the echo measurements. *ETL* = echo train length. **(b)** Diagram of conventional SE pulse sequence shows the sample time between the 180° refocusing pulse and the TE.



a. b.

Figure 4. Effect of varying echo spacing on degree of artifact reduction. **(a)** Sagittal T2-weighted FSE image (2,000/85, two signals averaged, echo train length = eight, echo space = 17 msec) of the cervical spine in a patient with anterior fusion plate and screws from C-3 to C-5 shows moderate artifact over the vertebral bodies (arrows). **(b)** Sagittal T2-weighted FSE image (2,000/88, two signals averaged, echo train length = eight, echo space = 11 msec) obtained at the same location as **a** shows decreased artifact (arrows). Note that noise increased as a result of the higher receive bandwidth that was required to obtain the shorter echo spacing.

ing proton density–weighted images (Fig 5b–5e) have a smaller difference between the TE and echo space and, therefore, should have a visibly smaller artifact difference. Although this reduction in magnetic susceptibility effects may be a disadvantage for detecting hemorrhage or calcium, it is of considerable benefit in patients who have ferromagnetic or paramagnetic substances distorting T2 information in the spine. In theory as well as practice, it is possible to minimize metallic artifacts. In several of our cases, diagnosis was possible only with FSE images (Fig 2). Similarly, T1-weighted FSE sequences should not appreciably reduce the artifact when compared with T1-weighted SE images because there would be little difference between the echo space and TE. Although anatomic structures may be better seen on T1-weighted images, T2-weighted information is critical for evaluating intramedullary abnormalities and myelographic effect.

The difference in magnetic susceptibility effects is further illustrated when comparing gradient-echo techniques that have no 180° refocusing pulse and a moderate TE (24). More severe artifacts are seen with gradient-echo sequences than with either FSE or SE T2-weighted techniques. This is an important consideration because a gradient-echo sequence is often the only axial sequence performed in many routine examinations. It has become standard practice at our institution to omit axial and sagittal gradient-echo sequences when metallic artifact is present in the region of interest and replace them with FSE sequences.

One criticism of this study is that it is not possible to blind an experienced reader to whether an FSE or a conventional SE image is being evaluated. Vertebral marrow will have high signal intensity on FSE images. Therefore, it is possible that a certain bias may still exist. We do not believe that this significantly altered the results.

In conclusion, at T2-weighted MR imaging, FSE techniques offer improved evaluation of the spine in the presence of metallic artifacts when compared with conventional SE pulse sequences. These improvements are secondary to decreased magnetic susceptibility. Moreover, these benefits can be achieved in a shorter period of time. Although susceptibility artifacts are not eliminated, they may decrease sufficiently to provide diagnostically

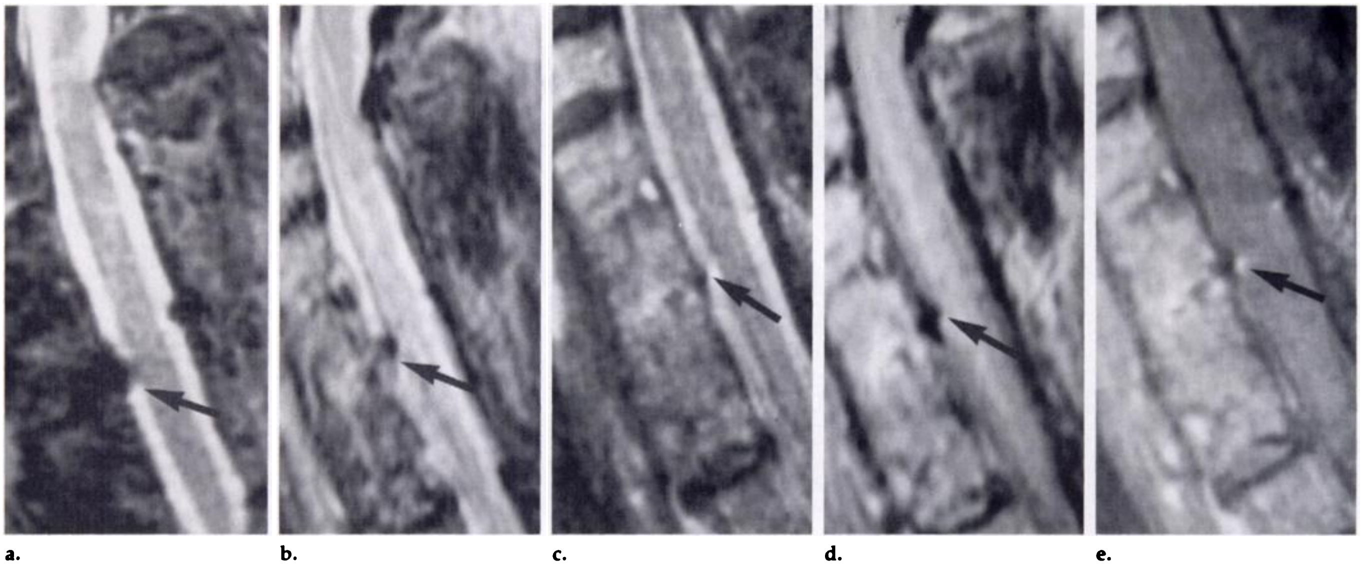


Figure 5. Variable appearance of metal shaving artifacts on gradient-echo, conventional SE, and FSE images. The patient had undergone anterior cervical diskectomy and fusion. **(a)** Sagittal T2*-weighted gradient-echo image (450/14, 15° flip angle) shows moderate distortion at the C5–C6 disk space, simulating an osteophyte (arrow). **(b)** Sagittal conventional T2-weighted SE image (1,800/80, two signals averaged) obtained at the same location as **a** shows a smaller artifact; however, it is still simulating an osteophyte (arrow). **(c)** Sagittal T2-weighted FSE image (2,200/85, two signals averaged, echo space = 17 msec, split echo train length = 16) obtained at the same location as **a** shows further reduction in the C5–C6 artifact (arrow). **(d)** Sagittal conventional proton-density–weighted SE image (1,800/30, two signals averaged) obtained at the same location as **a** shows the artifact (arrow) to be smaller than that seen in **b**. This is due to the shorter TE. **(e)** Sagittal proton-density–weighted FSE image (2,200/17 two signals averaged, echo space = 17 msec) shows the artifact (arrow) to be similar to that seen in **c**. This is because the echo spacing is equal in both. When compared with the conventional proton-density–weighted SE image **(d)**, even though the artifact is smaller, the difference is less than when comparing T2-weighted images because of the corresponding smaller difference in echo spacing.

useful T2-weighted information not otherwise available. Use of a shorter echo space will further decrease susceptibility-induced artifacts. Currently, the minimal echo space is limited by the width of the radio-frequency pulses, gradient amplitude, switching time, and duty cycle. As new software and instrumentation that allow larger echo train lengths with considerably shorter echo spacing become available, it is expected that these undesired artifacts will be further reduced. ■

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