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Original Research

Invited

Nerve Root Infiltration of the First Sacral Root With MRI Guidance

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The purpose of this clinical trial was to describe the methodology and evaluate the accuracy of optical tracking-based magnetic resonance (MR)-guided infiltration of the first sacral (S1) root. Thirty-five infiltrations were performed on 34 patients with a 0.23-T open C-arm magnet installed in a fully equipped operation room with large-screen (36 inches) display and optical navigator utilizing infrared passive tracking. T1 and T2 fast spin-echo (FSE) images were used for localizing the target and fast field echo for monitoring the procedure. Saline as contrast agent in single-shot (SS)FSE images gave sufficient contrast-to-noise ratio. Twenty-four patients had unoperated L5/S1 disc herniation, and 10 had S1 root irritation after failed back surgery. Needle placement was successful in 97% of the cases, and no complications occurred. Outcome was evaluated 1–6 months (mean 2.2 months) after the procedure and was comparable to that of other studies using fluoroscopy or computed tomography guidance. MR-guided placement of the needle is an accurate technique for first sacral root infiltration. J. Magn. Reson. Imaging 2000;12:556–561. © 2000 Wiley-Liss, Inc.

INFILTRATION OF LUMBAR and sacral nerve roots with local corticosteroids and anesthetics has been used for preoperative evaluation of sciatic patients (1,2), but it may also have a therapeutic effect in discogenic sciatic pain (3,4). Fluoroscopy and computed tomography (CT) are the standard interventional radiologic guidance modalities for nerve root infiltration due to good temporal resolution, excellent bone-tissue contrast, and real- to near real-time imaging (5,6). However, the unavoidable ionizing radiation risk, the need for a contrast agent, and the low soft tissue contrast tend to mitigate against these methods. Moreover, infiltration of the S1 root is technically unsatisfactory by fluoroscopy (7).

MRI offers unique contributions to the development and application of image-guided, minimally invasive interventions. MRI presents a considerably smaller health hazard to the patient and operator alike, yet still provides superior tissue contrast. The unique three-dimensional information of MRI allows nerve root infiltration to be monitored and controlled in ways not possible with other imaging techniques. Intervention with MRI guidance is a method that combines the advantages of MRI and the possibility of identifying the pain locus by local injection (8).

In this study, we describe the methodology and evaluate the accuracy of optical tracking-based interactive MRI-guided infiltration of the first sacral root.

MR Imaging System and Operation Room

The imaging system presented here is based on the 0.23-T open-configuration C-arm magnet (Proview, Marconi Medical Systems, Cleveland, OH). The scanner is installed in a fully equipped operation room and supplied with a commercially available hardware and software suite (iPath 200, Marconi Medical Systems) containing an MR-compatible in-room console, large-screen (36 inches) display, and optical navigator. The console consists of an industrial membrane keyboard and track-ball mouse on a control pedestal. The display uses a high-resolution data projector capable of producing 600 ANSI Lumens with an ANSI contrast ratio of 100:1. The back-projected image has a wide viewing angle, which, together with the brightness and size of the display surface, makes it possible for more than one physician to access simultaneously the screen information and follow the progress of the operation. The use of multiple mirrors inside the display cabinet reduces the space requirements, resulting in a modest floor stamp of 0.8×0.9 m. The display is large enough to show four to six images with excellent resolution from 2 to 4 m of viewing distance (Fig. 1).

The navigator camera head is positioned approximately 2 m from the magnet isocenter. It utilizes infrared passive tracking: the feature elements of trackable objects comprise reflecting spheres in unique geometric configurations. Different configurations make it possible to track multiple objects at the same time. Here the camera sees two trackers simultaneously: one is attached to the magnet pole-piece and provides a fixed reference frame, and the other attaches to the needle.

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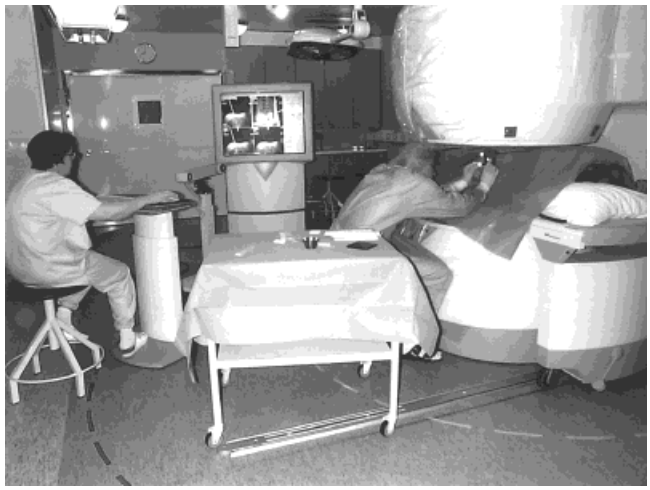
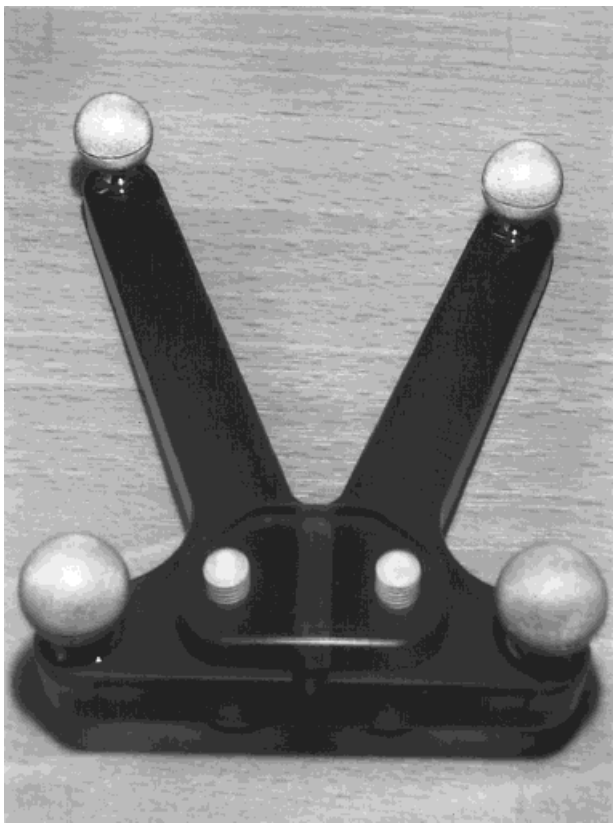


Figure 1. Fully equipped operation room with Marconi Medical Systems' Proview C-arm magnet and iPath 200 interventional system, including large-screen (36 inches) display and optical tracking system with instrument holder.

The fixed reference frame allows repositioning of the camera during the operation, in case the line-of-sight to the needle holder becomes blocked.

The software supports needle-guided scanning whereby image planes have a defined relationship to the orientation of the needle holder (Fig. 2), and the image set centers follow the needle tip with an user-defined offset. In these nerve root infiltrations, the offset is set to zero, and two orthogonal planes with the common axis directed along the needle shaft are used to produce images, so that any needle bending is readily visible.



Figre 2. Instrument holder for optical tracking.

Subjects

Thirty-five first sacral root infiltrations were done with MR guidance for 34 consecutive patients referred for first sacral root infiltration. The mean age of the patients was 48 years (range 32–62 years); 24 had an unoperated L5/S1 disc herniation, and 10 had S1 root irritation after failed back surgery. All patients had sciatica, which was their main reason for contacting a doctor. Patients with indications for acute surgery such as cauda equina were excluded from the study. Three of the patients had minor neurologic deficits. The outcome was evaluated as effect on radicular pain 1–6 months (mean 2.2 months) after the procedure by clinical examination or questionnaire. The effect on radicular pain was graded as follows: 1, good to excellent = no pain or no disturbing pain at the time of outcome evaluation; 2, temporary good to excellent = temporary relief of pain; 3, no relief of pain; and 4, worsening of pain.

Method

Informed consent was obtained from all patients in advance of the procedure. The procedures required one technician to use the control panel in the operation room; no other staff besides this technician and a physician were needed during the procedure. The patient and the nonsterile surroundings were covered with a fenestrated drape. An MR-compatible 20-G needle (MD-Tech) was attached to the optically tracked needle-holder. A multipurpose loop coil with a diameter of 21 cm was wrapped into sterile drapes and taped to the focal area. A spherical oil capsule (Peter Moller av Orkia, Oslo, Norway), taped to the skin, marked the side of the first sacral root of interest with respect to the spine. The operation started by positioning the needle at the prepared spot. A multislice, T2-weighted fast spin-echo [FSE; TR/TE 4000/220 msec, echo train length (ETL) 32] sequence in the sagittal plane at the tip of the needle was selected to show the anatomy, especially the nerve root and the neural foramen. The slice thickness was 7 mm, the field of view (FOV) 380 mm, the acquisition matrix 216 × 256, and the time of aquisition (TA) 1 minute 20 seconds. Imaging was done with needle guidance, and no preoperative scans were needed.

The resulting images show the oil capsule and the target anatomy. Using superimposed needle projection, the position of the first sacral neural foramen in the craniocaudal direction was indicated with the needle shaft. The desired axial plane was selected with the needle, and a set of T1-weighted images was obtained (FSE, TR/TE 500/18 msec, ETL 4, 7-mm slices, FOV 380 × 380, matrix 216 × 256, TA 1 minute 48 seconds/10 slices). The plane was now perpendicular to the previous slices, resulting in axial presentation with the desired angle. Together these two image-sets

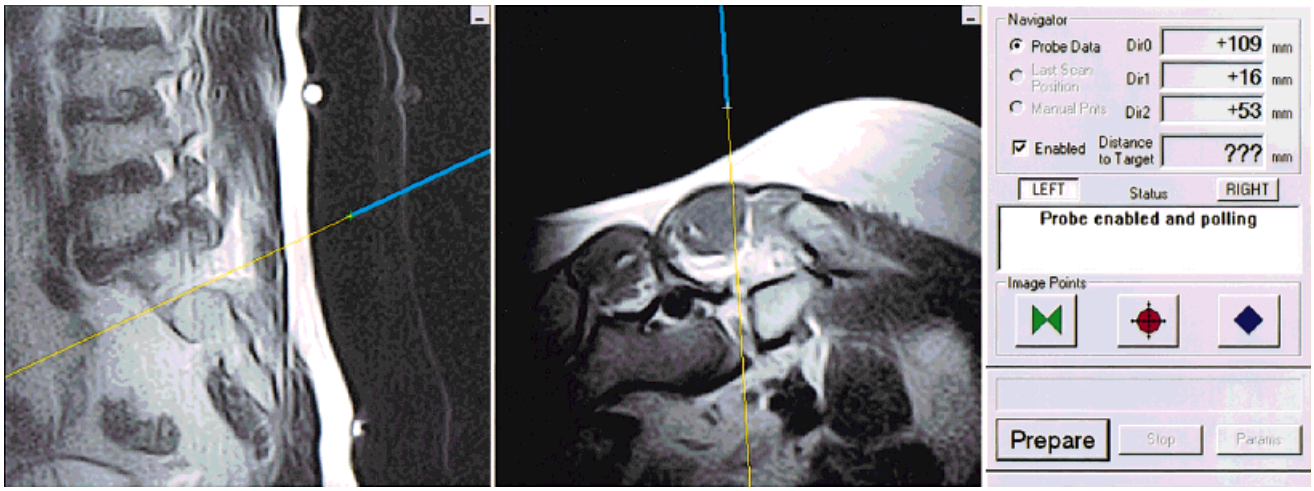


Figure 3. Optical tracking on the large-screen display. The extension line (yellow) of the needle (blue) is crossing the first sacral root in sagittal T2 FSE and axial T1 FSE images. Some of the technical data is shown on the right.

formed an aiming tool when the projection of the extension line (yellow) calculated from the needle shaft (blue) was shown on the images, as demonstrated in Fig. 3.

Before needle insertion, lidocaine (5 ml) infiltration was used for local anesthesia. No other medication, sedation, or monitoring was used. The needle was inserted through the subcutaneous fat and dorsal sacral ligaments. Multislice (three to five) image sets were taken en route to monitor the progress and ensure that the needle did not stray from its course. With optical tracking the monitoring slices were taken in the plane of the needle at the desired angles; usually one set gave sufficient information to continue the needle insertion. The extra slices were used to indicate possible bending of the needle: this would show as an artifact on the next slices of the center slice. The parameters of the T1-weighted field echo (gradient-echo) sequence used for monitoring were as follows: TR/TE 125/9 msec, flip angle 90°, 7-mm slices, FOV 380 × 380, matrix 216 × 256, and TA 20 seconds for three slices and 34 seconds for five slices. At this stage the needle shaft artifact was verified to ensure progress in the right direction, and the visibility of the first sacral root was also checked (Fig. 4A).

The needle was pushed further to the level of dorsal sacral surface and the situation checked again; the needle direction was slightly adjusted and the needle inserted into the first sacral nerve dorsal root foramen. The monitoring sequence was run with perpendicular planes to provide necessary resolution in all directions. The resulting nearly axial and sagittal images are shown in Fig. 4B and C.

Saline solution (2 ml) injected into the nerve root sheath was the contrast agent when single-shot fast spin-echo (SSFSE) images were used. The correct placement of the needle was corroborated with 128-echo SSFSE (TR/TE 9000/274 msec, five 7-mm slices, TA 9 seconds; Fig. 4D). This technique was used in the last 29 infiltrations. Possible pain provocation by the injection was also used as confirmation of correct needle placement. Thereafter, either 2 ml of methylprednisolone-bupivacaine solution (Solomet, methylprednisolone 40 mg/ml, bupivacaine 5 mg/ml; Orion, Finland) for 32 infiltrations or 2 ml bupivacaine (three infiltrations) was injected into the nerve sheath, and the fluid signal was detected with the SSFSE sequence. In the first eight procedures, fluoroscopy was used with MRI either for determining the puncture site to the skin or to confirm the final placement of the needle in the nerve sheath with a contrast agent.

RESULTS

Needle placement was successful in 34 (97%) cases. The needle tip had to be moved 5 mm with one patient (second in our series) after fluoroscopy confirmation of the needle tip position. No procedure was prematurely terminated before completion of needle placement, all patients being able to remain still and tolerate the insertion. No complications, such as intrathecal infiltrations, occurred. Instruments did not adversely affect image quality or induce a low signal-to-noise ratio. Furthermore, the scanner's operation was not affected by the presence of the instruments used during the procedure. The lengths of the procedures varied from 12 to 62 minutes (mean 32 minutes). These times do not include the time required for patient and operation room preparing. The average length of the first five procedures was 34 minutes, and that of the last five was 23 minutes 30 seconds.

Outcome was evaluated 1–6 months (mean 2.2 months) after the procedure by clinical examination or questionnaire. Thirty-two of the infiltrations were done with the methylprednisolone/bupivacaine solution, and the outcome was good to excellent for 18 patients (56%) and temporarily (1–4 weeks) good to excellent for 9 (28%). Four patients (12%) had no effect at all, and one (3%) had temporary (2 weeks) worsening of pain.

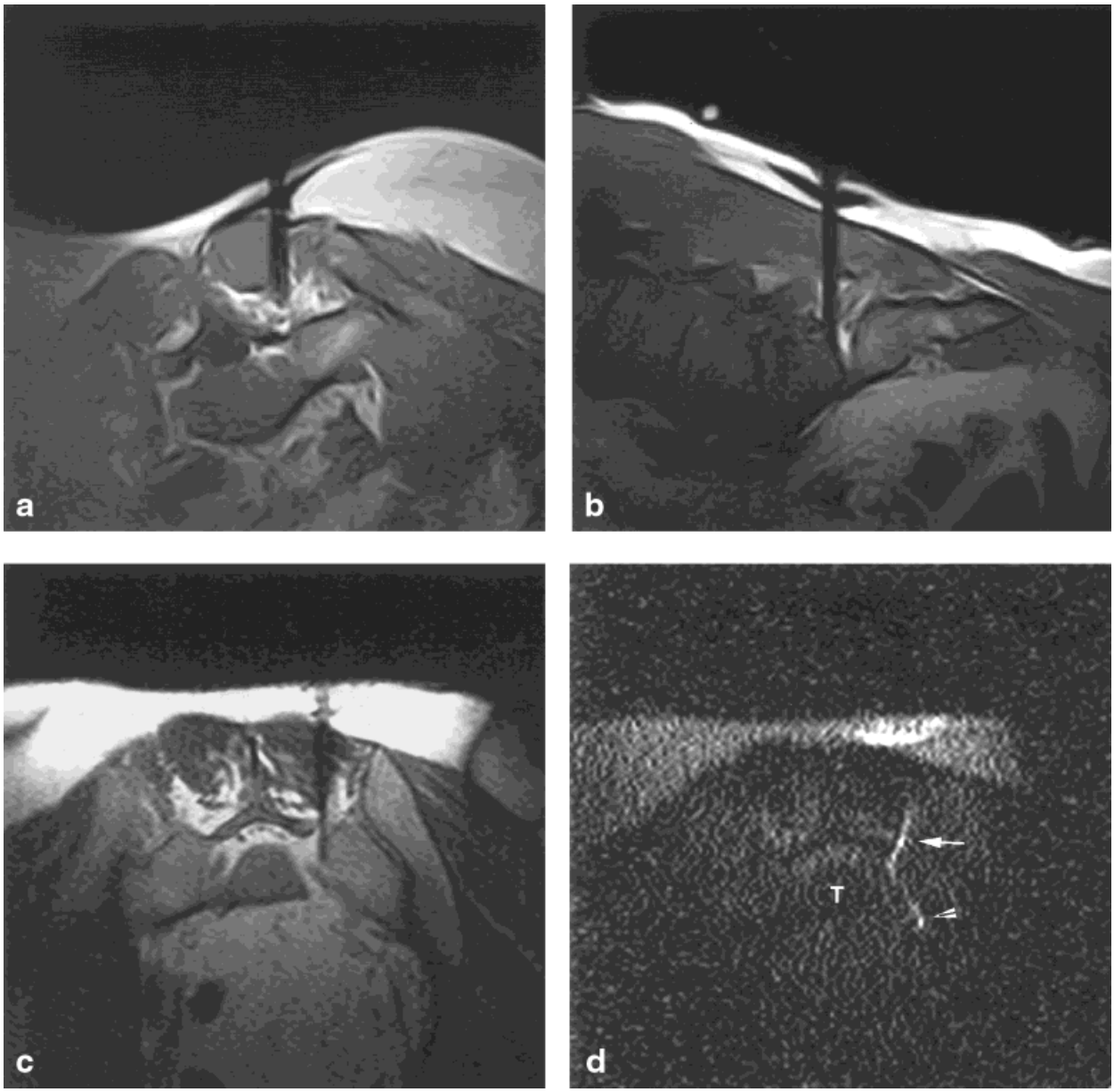


Figure 4. Infiltration of the first sacral root. **A:** The needle was inserted through the muscle layer and is seen as the black artifact in a T1 field echo (gradient-echo) sequence. This sequence was used to monitor the progress of the procedure; TA was 20 seconds for three slices and 34 seconds for five slices. Axial view in the plane of the needle. **B, C:** Final position of the needle: sagittal (B) and axial (C) views in the plane of the needle. Same imaging sequence as in A. **D:** Injected saline solution appears bright in the nerve sheath in axial SSFSE image. The projection is the same as in C. arrow = dorsal ramus of the first sacral nerve, arrowhead = ventral (main) ramus of the first sacral nerve, T = thecal sac.

After the three infiltrations done with bupivacaine alone, the patients had a temporary good to excellent outcome. The outcome of all infiltrations is shown in Table 1.

Saline solution served as the contrast agent for heavily T2-weighted SSFSE imaging sequences in the 29 last infiltrations. For all of these the contrast-to-noise ratio was sufficient to confirm correct needle placement. Fluoroscopy confirmation of the needle tip position was not needed since we obtained the SSFSE sequences.

Table 1
Outcome of MR-Guided Infiltration of First Sacral Root*

Radicular pain	No. of procedures	%
Complete relief	18	51.4
Temporary (1–4 weeks) relief	12[a]	34.4
No relief	4	11.4
Worsening[b]	1	2.8
Total	35	100.0

*Outcome was evaluated as the effect on radicular pain 1–6 months after the procedure (mean 2.2 months).
[a]Methylprednisolone/bupivacaine solution was used for nine infiltrations and bupivacaine alone for three infitrations.
[b]Temporary worsening of pain for 2 weeks.

DISCUSSION

Low back disorders are extremely prevalent in all societies, and the rate of disability, as well as the costs have increased, independently of the disease prevalence, over recent decades (9). It is obvious that we cannot solve this dilemma with increasing surgical interventions. Minimally invasive interventional procedures are an option to relieve pain and minimize the risk of disability. MR-guided procedures have been developed since the mid-1980s, first with conventional closed-bore MR systems (10–13), and subsequently with a great number of new applications (14–18). Nerve root infiltration is particularly suited for MRI-guided interventions, as the root sheath forms an easily detectable structure for the injected contrast agent (19).

Open-configuration magnets allow greater patient access and monitoring than their conventional closed-bore counterparts, as well as more rapid temporal resolution and the option of interactive guidance of image acquisition (13,20). Lee et al (21) have reported good results in 33 MRI-guided procedures in a variety of locations with a C-arm open-configuration system. Furthermore, Lewin et al (17) concluded from 106 biopsies and aspirations that a modified clinical C-arm system is feasible, with relatively rapid needle placement.

There are several different methods for real-time tracking of the needle (22–24). One of these is optical tracking (13,25), whereby the instrument is located with a stereovision camera. The advantages of optical tracking are real-time operation and ease of use, the disadvantages being the need for line-of-sight and insensitivity to needle bending. The most critical phase of performing minimally invasive procedures is the accurate and safe positioning of the needle. The aforementioned bending must be taken into account, as the correct position should be ascertained unambiguously. In practice this means confirmatory images in which the needle artifact or injected contrast agent are clearly visible. In MRI-guided first sacral root infiltration, needle bending is not a problem. In the present study saline solution proved to be a sufficient contrast agent for confirming correct needle placement. Gadolinium compounds with T1-weighted sequences have been used for this purpose (26). To date, these compounds have not been accepted for intrathecal use, and using saline as contrast agent makes it possible to avoid the possible side effects of intrathecal or epidural gadolinium infiltration.

This is the first study to demonstrate the usefulness of MRI guidance in deep neural tissue injections. To our knowledge this is the first study to evaluate only the first sacral root infiltration. Other studies (3,4,7,27) evaluated the outcome of first sacral root and lumbar root infiltrations together. In our C-arm MRI guidance system, we were able to infiltrate the treatment agent directly into the main, ventral ramus sheath of the first sacral root. Since 1995 over 1400 nerve root infiltrations have been performed with fluoroscopy guidance in our institution, and in our experience this method allows the needle to be placed only into the dorsal root canal or dorsal root sheath of the first sacral root; the depth is difficult to estimate. The technical difficulties with S1 root infiltration have been confirmed by Viton et al (7). Compared with CT guidance, MRI allows better three-dimensional imaging capability and produces no radiation.

In our study the length of the procedures decreased from 34 minutes to 23 minutes 30 seconds. These nerve root infiltrations were the first procedures performed in our interventional MR unit, and three interventional radiologists were trained for interventional MR during this study. The procedures can be performed in a normal imaging room with an interventional hardware and software package.

In a study of CT-guided lumbar nerve root infiltrations (27), 55% of patients were free of symptoms or had had some improvement when evaluated approximately 4 months after the treatment; 30% reported temporary improvement, and in 15% there was no change compared with the pretreatment symptoms. In the study of Seibel et al (26), only 15% of the failed back surgery patients had relief of symptoms after a single CT- or MRI-guided nerve root infiltration, and after four treatments 72% of the patients were symptom free. In our study, 6 of 10 patients with irritation after failed back surgery had good to excellent outcome. Lutz et al (3) reported that 75.4% of patients with radicular leg pain had a successful long-term outcome after lumbar transforaminal epidural steroid injection. Twenty-two of the 28 patients with lumbar disc herniation had considerable and sustained relief from their symptoms in another study (4). The outcome was not evaluated separately for lumbar and sacral nerve roots in these studies. In our series the outcome of the first sacral root infiltration was in accordance with these other studies of lumbosacral roots using fluoroscopy or CT guidance (3,4,7,27). Our unpublished controlled trial is in accordance with these earlier studies (28).

On the basis of the present study, guided placement of the needle by MRI is an accurate procedure and may be used to substitute conventional techniques for first sacral root infiltration. It is a radiation-free procedure and allows fast three-dimensional imaging for needle guiding.

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