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CLINICAL INVESTIGATION NON-VASCULAR INTERVENTIONS

Outcome Study of Real-time MR-guided Cervical Periradicular Injection Therapy in an Open 1.0 Tesla MRI System

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Abstract
Purpose To evaluate the accuracy, safety, and efficacy of cervical nerve root injection therapy using magnetic resonance guidance in an open 1.0 T MRI system.
Methods Between September 2009 and April 2012, a total of 21 patients (9 men, 12 women; mean age 47.1 ± 11.1 years) underwent MR-guided cervical periradicular injection for cervical radicular pain in an open 1.0 T system. An interactive proton density-weighted turbo spin echo (PDw TSE) sequence was used for real-time guidance of the MR-compatible 20-gauge injection needle. Clinical outcome was evaluated on a verbal numeric rating scale (VNRS) before injection therapy (baseline) and at 1 week and 1, 3, and 6 months during follow-up.
Results All procedures were technically successful and there were no major complications. The mean preinterventional VNRS score was 7.42 and exhibited a statistically significant decrease ($P < 0.001$) at all follow-up time points: 3.86 ± 1.53 at 1 week, 3.21 ± 2.19 at 1 month, 2.58 ± 2.54 at 3 months, and 2.76 ± 2.63 at 6 months. At 6 months, 14.3 % of the patients reported complete resolution of radicular pain and 38.1 % each had either significant (4–8 VNRS score points) or mild (1–3 VNRS score points) relief of pain; 9.5 % experienced no pain relief.
Conclusion Magnetic resonance fluoroscopy-guided periradicular cervical spine injection is an accurate, safe, and efficacious treatment option for patients with cervical radicular pain. The technique may be a promising alternative to fluoroscopy- or CT-guided injections of the cervical spine, especially in young patients and in patients requiring repeat injections.

Keywords Spine/nervous system · Pain management · Radiation protection · Open MRI · Interventional MRI · Cervical nerve root injection · Clinical outcome

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Introduction

Cervical pain syndrome and cervical radicular pain are very common conditions and have considerable economic impact. Cervical pain is typically caused by disc herniation or degenerative changes of the cervical spine [1]. In many patients, adequate symptom control is achieved by conservative treatment consisting of oral pain medication and physical therapy. In patients who do not achieve adequate pain relief with conservative measures, good results are obtained with minimally invasive periradicular nerve root

injection of corticosteroids and anesthetics [2, 3]. Most interventionists perform injection treatment using conventional fluoroscopy or computed tomography (CT) fluoroscopy for guidance to ensure proper positioning of the injection needle and to minimize the risk of some very rare but potentially fatal complications such as vascular dissection and spinal or cerebellar infarction [4, 5]. A disadvantage of these two imaging techniques is that they expose patients and staff to ionizing radiation. Especially patients who require repeat injections may thus be exposed to potentially harmful doses [6, 7]. Moreover, there is a slight risk of allergic reactions to the contrast agent used to visualize the distribution of the injected solution and thus ensure that the subsequently injected therapeutic agent reaches the nerve roots. Magnetic resonance imaging (MRI) has recently been established as an alternative to these techniques for fluoroscopic guidance of nerve root injection for the lumbar spine [8–11]. MRI-based fluoroscopy does not involve radiation exposure and needs no contrast medium injection. Technical developments of MRI hardware and software have advanced to a stage where MR fluoroscopy allows near-real time imaging and ensures a smooth workflow. Open MRI systems facilitate the interventionist's access to the patient and meet with wide patient acceptance [12]. Although the clinical benefit of periradicular infiltration treatment using conventional or CT fluoroscopy for guiding the intervention has been demonstrated in several studies, scientific evidence for a similar benefit of MR fluoroscopy is still lacking [13, 14]. We therefore conducted a study to evaluate the technical feasibility and clinical efficacy of MR-fluoroscopy-guided nerve root injection in the cervical spine in an open 1.0 T MRI system.

Materials and Methods

Patients

In a prospective study setting, a total of 21 patients (9 men, 12 women; mean age, 47.1 ± 11.1 years; range, 32–77 years) underwent cervical nerve root injection with MRI guidance within a time period between September 2009 and April 2012. The patients were referred to our department by their orthopedic or spine surgeons for treatment of radiating cervical radicular pain. The pain did not respond to a conservative treatment regimen, including analgetics and physiotherapy for more than 6 months, and there was no absolute indication for a surgical intervention. For all patients, preinterventional MRI of the cervical spine was available, revealing a compression of a cervical nerve root as a result of disc herniation or disc protrusion with coinciding ligamentous or osseous facet joint hypertrophy (degenerative neuroforaminal stenosis). Patients with known allergy to anesthetics or corticosteroids, spinal infection, coagulopathy, or indications for emergency surgery were excluded. All patients gave written informed consent after comprehensive explanation of the intervention, possible complications, and alternative treatment options. MRI-guided periradicular infiltration treatment was approved by the local ethics committee.

Technique of Nerve Root Injection with MRI Fluoroscopy

Two interventionists with at least 4 years of experience in CT-guided cervical periradicular injection treatment performed all interventions in an open 1.0 T MRI system (Panorama, HFO, Philips, Best, Netherlands) with a vertically oriented magnetic field [8]. The MRI system has a 26 mT/m gradient system for fast image acquisition and an in-room monitor with a wireless MR-compatible mouse for interactive multiplanar navigation. For the intervention, the patient was positioned in lateral position on the side opposite the side to be treated with the cervical spine in the isocenter of the magnet. The interventional radiologist had nearly 360° access to the patient. A flexible single loop Multipurpose L^{TM} surface coil (Philips Healthcare, Best, Netherlands) with an inner diameter of 21 cm was positioned above the target region orthogonal to the main magnetic field, B0, to maximize MR signal readout. T1- and T2-weighted fast spin-echo (FSE) sequences were acquired for preinterventional planning and anatomic localization of the target region. After skin disinfection and sterile draping, subcutaneous local anesthesia was applied using 2 ml of 1 % Xylonest (lidocaine and 1 % epinephrine, AstraZeneca, Wedel, Germany). The interventions were performed via a posterolateral access through the cervical soft tissues using an MR-compatible 20-Gauge injection cannula (MReye, Cook Medical, Limerick, Ireland). The injection needle was guided using an interactive proton-density (PD) FSE sequence (TE/TR, 10/600; acquisition time, 2 s) (Table 1). Using images acquired in near-real time, the tip of the injection cannula was positioned posterior to and contiguous with the nerve root to be treated and lateral to the adjacent facet joint (Fig. 1). Once the correct needle position has been assured, a mixture of 1 ml triamcinolone acetonide (40 mg, Triam, Winthrop Arzneimittel GmbH, Mühlheim, Germany) and 2 ml of Carbostesin (0.5 % bupivacaine hydrochloride, AstraZeneca, Wedel, Germany) was injected into the periradicular region. Proper distribution of the injected solution was monitored with a fat-saturated, strongly T2-weighted FSE sequence (SPIR, Spectral Presaturation with Inversion Recovery) in the axial plane. After the intervention, all patients were monitored for at least 30 min. If there was no

Table 1 Imaging protocol for preprocedural diagnostic evaluations, real-time needle guidance, and postinterventional control in an open 1.0-T MRI system

Characteristic	Description	Settings
Diagnostic imaging	T2-w FSE (sagittal/axial)	TR/TE, 3000/120 ms; FOV, 240 mm; matrix, 304 × 210 mm; SL, 3 mm
	T1-w FSE (sagittal)	TR/TE, 463/10 ms; FOV, 180/240 mm; matrix, 300 × 215 mm; SL 3 mm
Real-time guidance of the needle	Interactive PD-w FSE (multiplanar)	TR/TE, 600/10 ms; DRIVE pulse; FOV 200 × 157 mm; matrix, 224 × 72 mm; SL, 5 mm
Postinterventional control	Fat-saturated (SPIR) T2-w FSE (axial)	TR/TE, 1500/100 ms; FOV, 200 × 200 mm; matrix, 224 × 216 mm, SL, 3 mm

TR repetition time, *TE* echo time, *FOV* field of view, *SL* slice thickness, *SPIR* spectral presaturation with inversion recovery

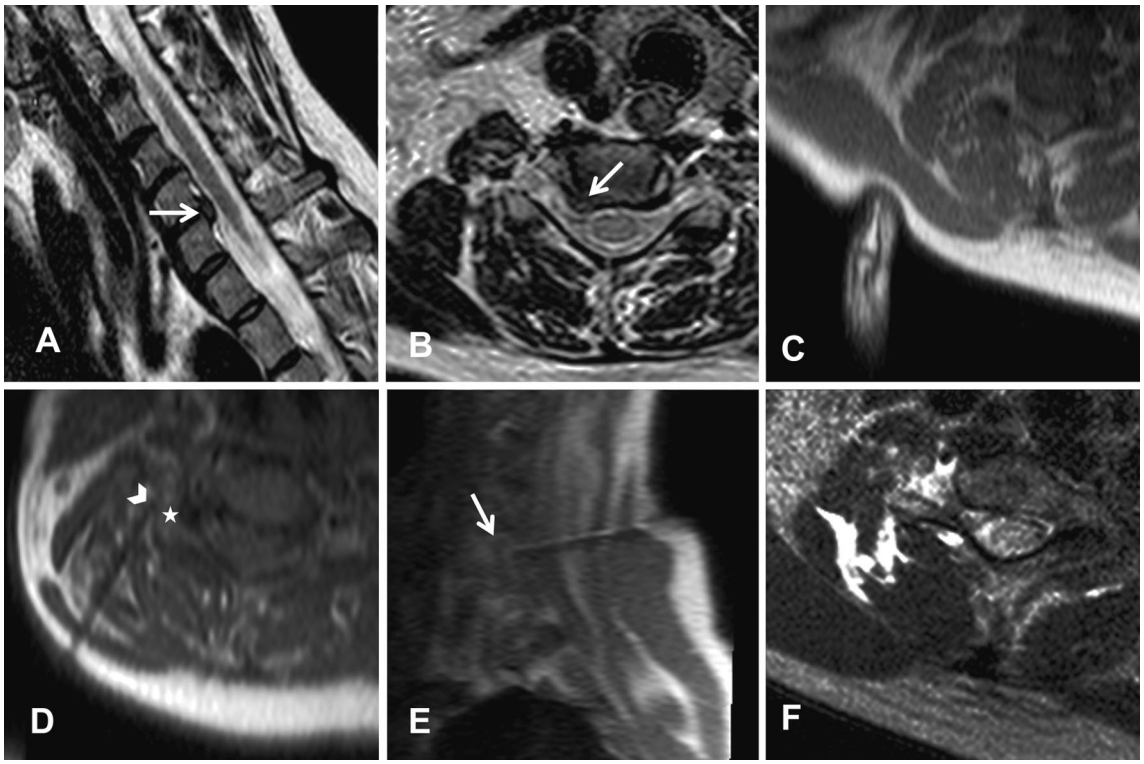

Fig. 1 Example of MR-guided periradicular injection treatment of the cervical spine in a 44-year-old woman with radicular pain due to protrusion of the C5/C6 intervertebral disc with impingement on the right C6 nerve root foraminally (*arrows,* **A** and **B**). The finger-pointing technique is used for identifying the skin entry site for posterior access to the right C6 nerve root (**C**). Interactive PD-w FSE images in axial (**D**) and sagittal (**E**) planes showing the tip of the injection cannula (*arrowhead*) positioned adjacent to the facet (*asterisk*) and directly posterior to the C6 nerve root (*arrow* in **E**). A strongly T2-weighted TSE SPIR sequence is used to check correct distribution of the injected solution, seen as a stripe of high signal intensity along the target nerve root. In addition, the sequence visualizes the local anesthetic in the access channel and the cervical soft tissues (**F**). The patient reported significant pain relief 6 months after the intervention (VNRS score of 1 vs. 9 at baseline)

evidence of possibly aggravated pain or unwellness, the patient was discharged.

Assessment of Technical and Medical Outcome

Technical success was assumed when the injected solution distributed as expected, i.e., around the nerve root (extra-foraminally but contiguous with the nerve root). For assessment of technical outcome, the MR fluoroscopy data set and the postinterventional T2-weighted SPIR sequences were analyzed by two radiologists in consensus.

Medical outcome was assessed by the patient's subjective pain sensation using an 11-point self-reporting verbal numeric rating scale (VNRS) from 0 to 10 (no pain to most severe pain) immediately before the intervention (baseline) as well as 1 week, 1 month, 3 months, and 6 months after the intervention. Pain assessment was obtained by the treating physician before the intervention

and by telephone during the 6-month postinterventional follow-up period. VNRS scores at the different time points in the follow-up period were compared to the base line, respectively.

Changes in pain severity after the intervention were classified as follows: complete relief of pain (drop of VNRS score to 0), strong relief (drop of 4–8 score points), mild relief (decrease of 1–3 on VNRS), and unchanged pain severity (no change in VNRS score). According to the guidelines of the American College of Radiology, major intervention-related complications were defined as events leading to hospitalization of an outpatient, treatment in the intensive care unit, a longer hospital stay of hospitalized patients, permanent damage, or death of the patient [15].

Statistical Analysis

Statistical analysis was performed using the SPSS software package (version 19.0). Baseline VNRS scores and postinterventional scores at 1 week, 1 month, 3 months, and 6 months were compared using the Mann–Whitney *U*-test. Statistical significance was assumed at $P < 0.001$. Microsoft Excel (version 2010) was used for visualization of VNRS scores over time.

Results

Magnetic resonance (MR) fluoroscopy using a PD-weighted FSE sequence allowed accurate positioning of the injection cannula posterior to the nerve root and lateral to the facet joint in all 21 patients. The T2-weighted TSE SPIR images acquired after the intervention confirmed correct extra- and partially transforaminal distribution of the injected solution with extension to the nerve root from the posteriorly placed needle (Fig. 1). This corresponds to a technical success rate of 100 %. The intervention was well tolerated by all patients, and no major complications were observed. There were no transient or persistent neurological deficits.

The following cervical nerve roots were treated: C6 in 10 patients, C7 in nine patients (bilateral in one patient), and C8 in one patient. One patient in whom the right C6 nerve root was treated underwent repeat injection at the same site as a result of persistent pain 1 month after the initial intervention. Two patients had cervical spine surgery in the 6-month follow-up period (patient 1: anterior discectomy, spinal canal revision and fusion of C6/C7; patient 2: sequestrectomy, spinal canal decompression, implantation of an intervertebral disc prosthesis). Therefore, these two patients were only included in the baseline rating and in the assessment of clinical outcome at 1-week follow-up but were excluded from the subsequent time points.

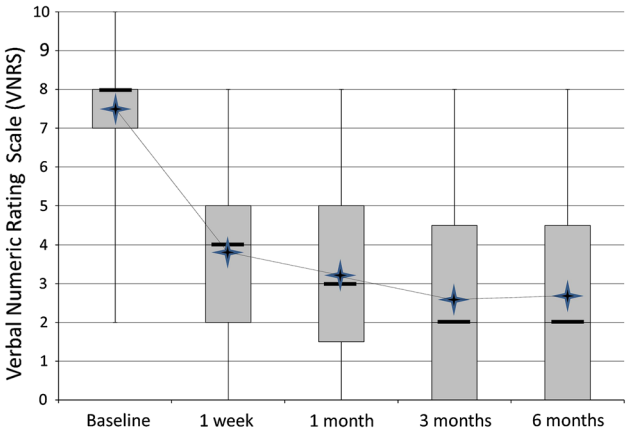

Fig. 2 Box plot of VNRS scores before the intervention (*baseline*) and at 1 week and 1, 3, and 6 months during follow-up. At all time points of the 6-month follow-up period, the average VNRS scores were significantly lower compared with the preinterventional baseline score ($P < 0.001$). *Stars* indicate mean VNRS scores for all patients included in a certain time point of evaluation

Table 2 Outcome of MR-guided periradicular injection in all patients ($n = 21$ at 1 week and $n = 19$ at 6 months)

Outcome	Mean %
Improvement at 1 week ($n = 21$)	
Complete (VNRS decrease to 0)	14.3 ($n = 3$)
Strong (VNRS decrease of 8–4)	38.1 ($n = 8$)
Mild (VNRS decrease of 3–1)	38.1 ($n = 8$)
No decrease	9.5 ($n = 2$)
Compared to baseline	$P < 0.001$*
Improvement at 6 months ($n = 19$)	
Complete (VNRS decrease to 0)	31.6 ($n = 6$)
Strong (VNRS decrease of 8–4)	36.8 ($n = 7$)
Mild (VNRS decrease of 3–1)	15.8 ($n = 3$)
No decrease	15.8 ($n = 3$)
Compared to baseline	$P < 0.001$*

VNRS verbal numeric rating scale

* Mann–Whitney *U*-test

The average VNRS score was 7.42 ± 1.67 before the intervention (baseline; median, 8; range, 2–10), 3.86 ± 1.53 (median, 4; range, 0–8) at 1 week, 3.21 ± 2.19 (median, 4; range, 0–8) at 1 month, 2.58 ± 2.54 (median, 2; range, 0–8) at 3 months, and 2.76 ± 2.63 (median, 2; range, 0–8) at the end of the 6-month follow-up period (Fig. 2). The average VNRS scores were significantly lower at all time points of the 6-month follow-up period compared with the preinterventional baseline score ($P < 0.001$).

One week after the intervention, 3 of 21 patients (14.3 %) had complete resolution of pain and 8 patients each (38.1 %) had strong or mild pain relief; 2 patients (9.5 %) reported unchanged pain. At 6 month-follow-up, 6 of 19 patients (31.6 %) reported complete resolution of

pain, 7 of 19 (36.8 %) had strong improvement and 3 of 19 each (15.8 %) had mild or no improvement (Table 2).

Discussion

Many studies have demonstrated that patients with radiating cervical radicular pain syndromes who do not achieve adequate pain control with conservative measures but are not candidates for surgery can benefit from minimally invasive periradicular injection treatment [13, 16]. Clinical outcome of radicular pain treatment in the cervical spine has been investigated for image guidance using conventional and CT fluoroscopy and ultrasound [5, 14, 17]. To the best of our knowledge, ours is the first study investigating clinical outcome of cervical nerve root injection using MR fluoroscopy for guiding the intervention. In our population of 21 patients, MR-guided injection had a technical success rate of 100 %, and average VNRS pain severity scores were significantly reduced at all four follow-up time points compared with baseline pain intensity before the intervention.

The pain relief reported by our patients is comparable to that achieved using other imaging modalities for guidance. For instance, Jee et al. [14] compared clinical outcome of periradicular cervical pain treatment using visual analogue scores (VAS) in a population of 110 patients in whom fluoroscopy or ultrasound was used for interventional guidance. The two groups (55 patients each) had preinterventional VAS scores of 6.06 (fluoroscopy group) and 6.15 (ultrasound group; our study: 7.42). Statistically significant reduction of average VAS scores was observed at 2 weeks (fluoroscopy: 3.17; ultrasound: 3.2; our study/at 1 week: 3.21) and 12 weeks (fluoroscopy: 2.61; ultrasound: 2.62; our study/at 3 months: 2.76). Wolter et al. [17] analyzed outcome in a group of 31 patients treated with use of CT fluoroscopy for guidance. The patients had an average preinterventional VAS score of 5.57, and the authors observed a reduction of the average score to 1.52 at 6 h in the subgroup of patients responding to treatment.

Although periradicular pain treatment in the cervical spine is a clinically established intervention with good clinical outcome in many cases, we must also bear in mind the possible complications associated with the intervention. The commonly chosen anterolateral access with positioning of the tip of the injection cannula directly in front of the facet joint of a cervical segment and posterior to the course of the nerve root bears the risk of inadvertent injury to nerves, the vertebral artery, and the nerve root itself. The complications reported range from vertebral artery dissection, to irreversible nerve damage, to spinal, cerebellar, or cerebral infarction [18–21]. In a survey of complications of cervical transforaminal epidural steroid injections in the USA, 287 pain physicians reported a total of 78 complications, including 16 vertebrobasilar brain infarcts and 12 cervical spinal cord infarcts [22]. These complications are assumed to be attributable to an embolic mechanism.

Established measures to reduce the risk of such complications include image guidance with CT fluoroscopy or ultrasound and the use of extension tubes that minimize manipulation of the injection cannula when the syringe is changed. Moreover, a posterior access route can be used to position the tip of the injection cannula lateral to the facet joint [23]. In a study of 1036 patients, the posterior access was found to be associated with fewer complications, probably because the risk of inadvertent intravascular injection is lower because the radicular artery typically courses anterior to the nerve root [24]. With a posterior access and a target region lateral to the facet joint, the distance between the cannula tip and the nerve root is slightly greater compared with the anterolateral approach, and the contrast medium tends not to distribute epidurally; nevertheless, it was demonstrated that the therapeutic effect on the nerve root or clinical outcome is not compromised [17, 25].

In our approach with MRI guidance, we used a posterior needle access for maximum patient safety with patients placed in lateral position in the open MR scanner. Technically, this is a favorable approach because optimal signal readout requires coil positioning orthogonal to the main magnetic field B0, and a large puncture angle ($\sim$70–90 degrees) relative to B0 for producing an adequate needle artifact. Moreover, we used an extension tube to minimize movement of the injection cannula during change of the syringe. MRI is the diagnostic method of first choice for spinal imaging, and the use of interactive MRI fluoroscopy for interventional guidance enables detailed visualization of spinal soft tissues, primarily of the nerve root, the neuroforamina, the spinal canal, and the vertebral artery. The multiplanar capabilities of MRI allow the interventionist to choose any imaging plane during the intervention with a simple mouse click inside the MR scanner room. This facilitates the intervention in patients with more complex anatomy, e.g., when dorsal osteophytes are present, and an angulated needle guidance may be necessary to enter the periradicular space.

The absence of radiation exposure is another advantage of MR fluoroscopy for both the patients and staff [6, 26, 27]. The radiation exposure of nerve root injections using CT fluoroscopy for guidance has mainly been investigated for the lumbar spine using phantom models. Schmid et al. [28] and Hoang et al. [29] reported effective doses of up to 0.45 mSv per patient and intervention with an additional dose of up to 2.9 mSv for a spiral scan for improved planning of the access route. An iodine-based contrast agent, with the risk of allergoid reactions, is commonly used in conventional and CT fluoroscopy to monitor

distribution of the injected solution. No contrast agent is necessary in MR fluoroscopy, where the correct distribution of the injected solution at the nerve root can be assessed with fat-saturated, strongly T2-weighted TSE sequences (see Fig. 1F) [30].

Our study has some limitations. In our study population, we achieved good clinical outcome with intervention guidance in an open MRI system. Outcome was found to be comparable to that achieved with established techniques of image guidance including conventional and CT fluoroscopy and ultrasound. However, our small patient population limits generalization of the results. A randomized controlled study is planned to prospectively compare the clinical outcome of patients undergoing either CT- or MR-guided spinal injections. In the context of the study design, the lack of a control group is another limitation. However, this is intrinsic to outcome studies; it seems to be unethical not to treat patients assigned to a control group who are suffering from inadequate pain relief with conservative measures.

As an outlook in the future, wider use of our method is precluded by the fact that open MRI systems are not yet generally available. However, more open MRI systems are expected to be available in the future, and several systems are on the market; this will improve workflow also for interventional techniques [8, 10]. In principle, it is also possible to perform periradicular pain treatment in the cervical spine in conventional MR tunnel systems. Here, robot systems and computer-assisted interventional guidance may be helpful [31, 32]. MR guidance was demonstrated to be approximately twice as expensive as CT fluoroscopy guidance [33]. Finally, the varying reimbursement in different countries will heavily influence the choice of the imaging techniques used for the intervention.

In conclusion, our results suggest that cervical nerve root injection treatment using an open 1.0-T MR system for interventional guidance is technically successful, safe, and efficacious. Medical outcome is comparable to that of injections using conventional and CT fluoroscopy. MR fluoroscopy offers the advantages of multiplanar imaging, the use of T2-weighted TSE sequences for monitoring the distribution of the injected solution, dispensing with the need for contrast medium, and the absence of radiation exposure, which is especially beneficial in young patients and those requiring serial interventions.

Conflict of interest The authors declare that they have no conflict of interest.

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