Metal Artifact Reduction Sequence (MARS) Magnetic Resonance Neurography (MRN) Evaluation of the Lumbosacral Plexus in Patients with Metallic Implants

Shivani Ahlawat, M.D.; Jan Fritz, M.D., P.D., D.A.B.R.

Johns Hopkins University School of Medicine, Baltimore, MD, USA

Abstract

Magnetic resonance neurography (MRN) is a reliable and accurate modality in the assessment of patients with peripheral neuropathy, which can be useful for distinguishing intrinsic and extrinsic etiologies of neuropathy following surgery. However, MRN surrounding metal implants[1] can be challenging to both perform and interpret. The diagnosis of abnormal peripheral nerves often heavily relies on fluid sensitive MR pulse sequences, but the presence of metal in the field of view introduces image artifacts, distortion and interferes with fat suppression. Conventional turbo spin echo pulse sequences with optimization for metal artifact reduction[1] are best suited for nerve imaging as advanced multi-spectral, and multi-spatial pulse sequences introduce a degree of blur that obscure nerve details. As such, metal artifact reduction sequence (MARS) techniques[1] can be applied to improve the image quality of MRN in patients with pelvic metallic implants, when compared with standard fast spin echo sequences. We describe a high-resolution MARS MRN protocol that yields high image quality and validated diagnostic accuracy for the assessment of lumbosacral neuropathies in patients with metallic implants of the pelvis and hips.

	Intermediate-weighted Turbo Spin Echo	STIR Turbo Spin Echo
Orientation	transversal	transversal
Repetition time [ms]	5700	3660
Time to echo [ms]	38	6.9
Inversion time [ms]	-	150
Echo train length	16	16
Slice thickness/gap [mm]	4.5/0.45	5/0.5
Pixel size [mm^2]	0.5 x 0.5	0.7 x 0.7
Bandwidth [Hz/px]	560	545
Flip angle [degree]	150	130
Number of slices	2 x 35	2 x 27
Number of excitations	1.5	2
In-plane frequency encoding direction	Right to left	Right to left
Total acquisition time [min:sec]	8:42	13:36

Table 1:
Detailed MARS MR imaging protocol optimized for the evaluation of lumbosacral plexus and pelvic nerves in patients with metallic implants[1].

Introduction

Traumatic nerve palsy in the setting of previous pelvic instrumentation and hip arthroplasty is a rare but serious complication [1–9]. Diverse mechanisms of peripheral nerve injury have been described including lesions intrinsic and extrinsic to the affected peripheral nerve. Intrinsic causes of peripheral neuropathy in the postoperative setting include stretch injury, nerve lacerations, and vascular compromise. Extrinsic causes of peripheral neuropathy in the postoperative setting include mass effect by implant components, heterotopic ossification, fluid collections such as hematoma, distended peri-articular bursae, and abscesses, and adverse local tissue reactions. The current standard of care for the detection and characterization of peripheral neuropathy is clinical examination and electrodiagnostic testing. However, evaluation of sensory and deep intra-pelvic nerves can be challenging, representing a gap in the clinical management of patients with a pelvic peripheral nerve injury in the post-operative setting.

[1] The MRI restrictions (if any) of the metal implant must be considered prior to patient undergoing MRI exam. MR imaging of patients with metallic implants brings specific risks. However, certain implants are approved by the governing regulatory bodies to be MR conditionally safe. For such implants, the previously mentioned warning may not be applicable. Please contact the implant manufacturer for the specific conditional information. The conditions for MR safety are the responsibility of the implant manufacturer, not of Siemens.

Magnetic resonance neurography (MRN) is a reliable and accurate modality for the assessment of patients with peripheral neuropathy that can be useful for identifying intrinsic or extrinsic etiologies of neuropathy. However, the presence of metal in the field-of-view generates local magnetic field heterogeneity and results in image artifacts including signal voids, failure of fat suppression, and spatial misregistration [10]. As such, MR imaging surrounding metal implants, including arthroplasty and osteosynthesis implants, can be challenging to interpret [10]. Metal artifact reduction strategies include the use of lower magnetic field strength, such as 1.5 instead of 3 Tesla, turbo spin echo (TSE) rather than gradient echo based sequences, high receiver bandwidth, and inversion recovery rather than frequency-selective fat suppression [10–19]. The application of such metal artifact reduction sequence (MARS) techniques results in substantially improved image quality when compared with standard TSE pulse sequences [12].

TSE pulse sequences with optimization for metal artifact reduction are ideal for peripheral nerve imaging as advanced multi-spectral and multi-spatial pulse sequences, such as Multi-acquisition Variable-resonance Image Combination (MAVRIC, GE Healthcare, Wauwatosa, WI, USA) and Slice Encoding for Metal Artifact Correction (SEMAC) introduce a degree of blurring that can obscure the fine architecture of peripheral nerves [12, 1]. We describe a validated, high-resolution MARS MRN protocol that yields high image quality and accuracy for the diagnosis of lumbosacral neuropathies in patients with metallic implants of the pelvis and hips [20].

MARS MRN acquisition

At our institution, we perform MARS MRN of the lumbosacral plexus for the evaluation of patients with metallic implants on a 1.5 Tesla MR imaging system (MAGNETOM Aera, Siemens Healthcare, Erlangen, Germany) with 48 radio-frequency receive channels, 45 mT/m maximum gradient field amplitude and 200 T/m/s slew rate [20]. Patients are positioned supine, and imaging is acquired using two 18-channel receive-only body matrix surface coils (Siemens Healthcare) and 12 elements of a spine matrix coil in 'sandwich configuration' to cover the lower lumbar spine, pelvis and proximal thighs. Table 1 describes the imaging protocol in detail (Fig. 1). The short tau inversion recovery (STIR)

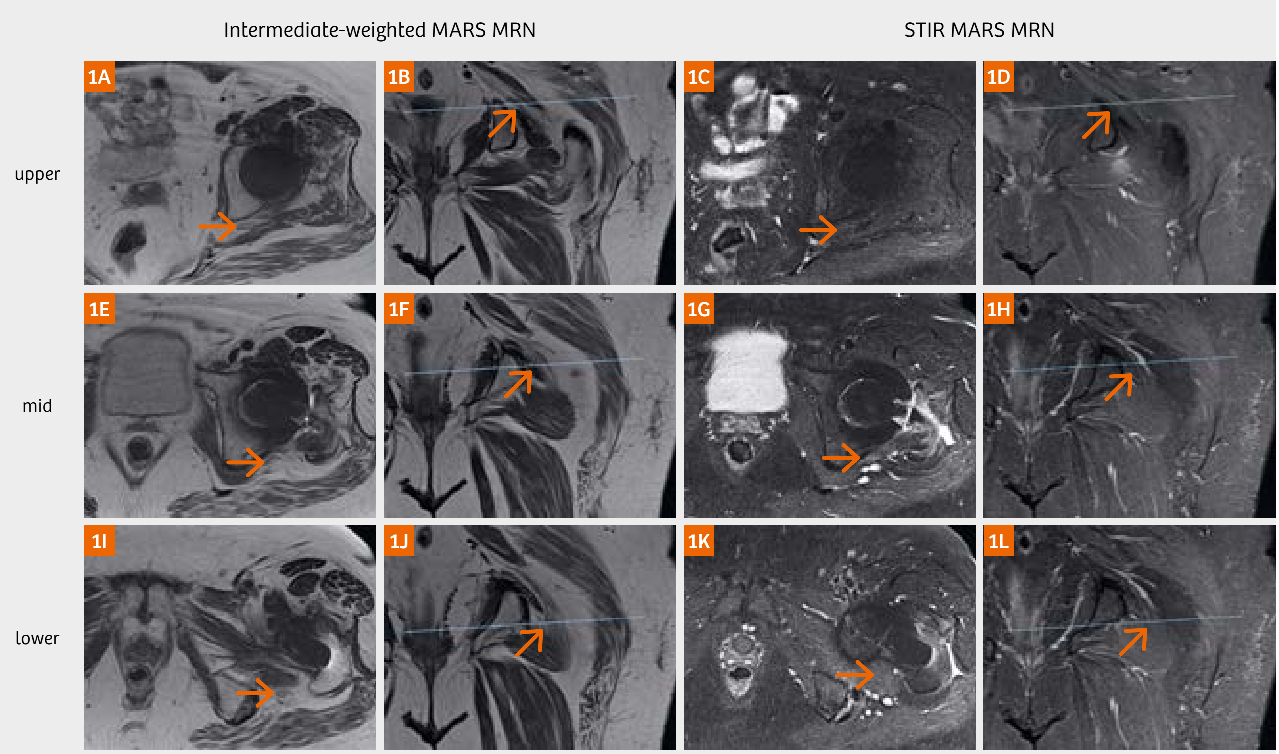


Figure 1:
Metal Artifact Reduction Magnetic Resonance Neurography in a patient with left hip arthroplasty implants demonstrates a normal appearing sciatic nerve (arrows) at the upper, mid and lower levels (reference lines) of the hip replacement without obscuration by implant-induced artifacts and with solid fat suppression.

TSE pulse sequence employs a radio-frequency pulse that matches the high receiver bandwidth [16]. Because the field-of-view extends from the L5 vertebral body to the ischial tuberosity, contiguous stacks of axial intermediate-weighted and STIR TSE pulse sequences are obtained. Intravenous contrast material administration is typically not required. The total acquisition time of the axial pulse sequences of this particular MARS MRN protocol is approximately 25 minutes, predominantly due to the long acquisition time necessary for high-quality STIR images. Optional coronal or sagittal pulse sequences can be helpful to identify landmarks for surgical interventions. The length of this protocol may be difficult to tolerate for acutely ill patients, but is similar to other investigations [14, 15, 20].

MARS MRN Interpretation

There is a paucity of literature of MRN in the setting of metal implants [19–21]. Our validated MARS MRN protocol offers high diagnostic quality, inter-rater agreement and overall high diagnostic accuracy for the presence of MR features of neuropathy [20]. With this MARS MRN protocol, both primary and secondary features of peripheral neuropathy can be visualized at the level of many metallic implants.

Primary features of peripheral neuropathy include abnormal course, caliber, signal intensity, and architecture (Fig. 2). Secondary features of peripheral neuropathy include skeletal muscle denervation. Of note, elevated

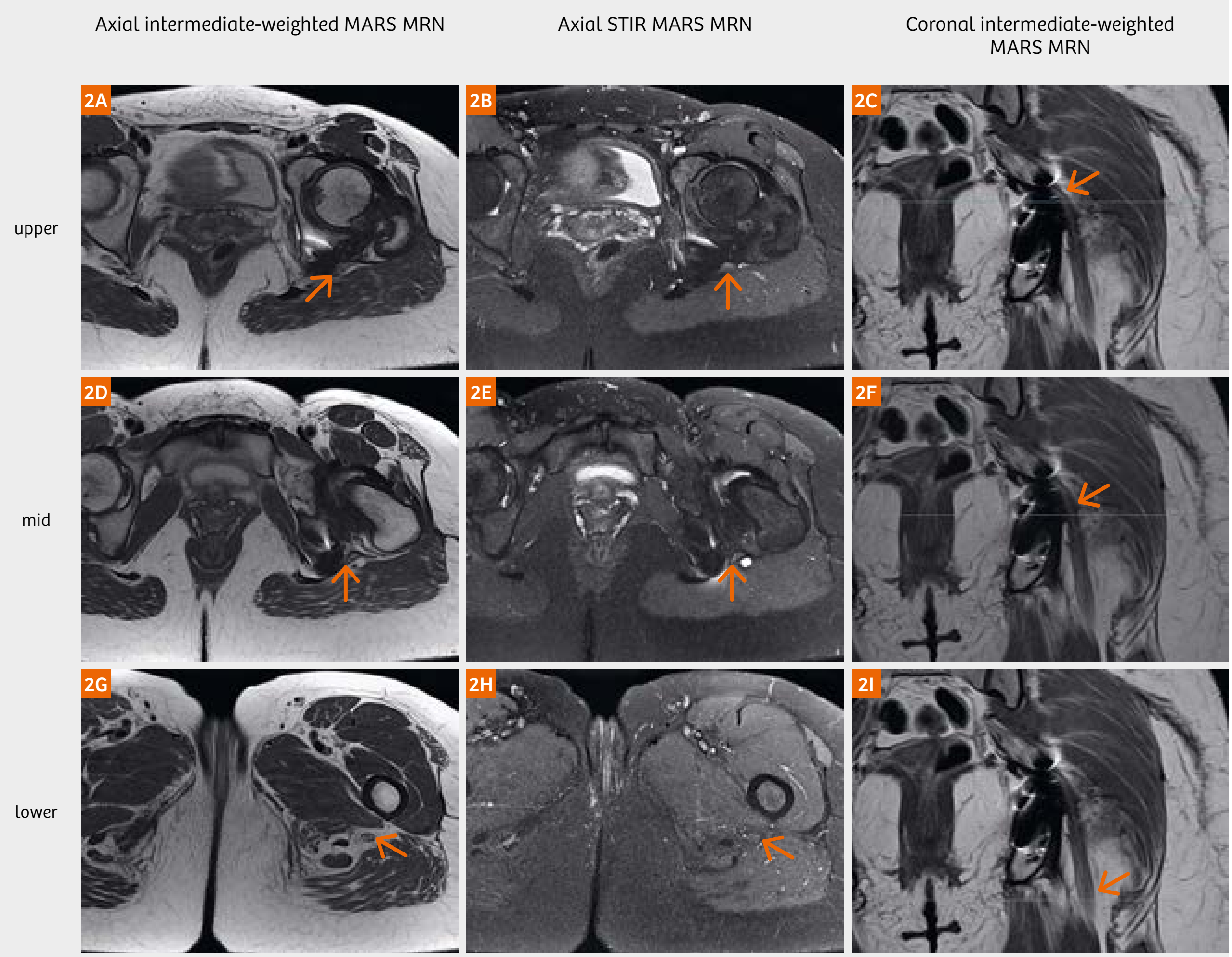


Figure 2:
Metal Artifact Reduction Magnetic Resonance Neurography in a patient with prior pelvic osteosynthesis and metallic implants of the left posterior acetabulum and ischium demonstrates unilateral, abnormal signal hyperintensity of the left sciatic nerve (arrow, **2A–C**), indicating neuropathy. At the mid level, there is unilateral left perineural scarring and tethering of the sciatic nerve (arrows, **2D–F**) to the metallic implants, as well as abnormal signal hyperintensity of the nerve. At the lower level, below of the site of surgical instrumentation, the sciatic nerve (arrow, **2G–I**) is normal in morphology and signal intensity.

peripheral nerve signal on fluid sensitive sequences alone is common, but not necessarily a reliable finding, that can result in high sensitivity but low specificity, when used in isolation, [22, 23]. The presence of additional imaging features such as abnormal nerve caliber including flattening and enlargement can add specificity [23]. Bulbous enlargement and architectural distortion in otherwise longitudinally intact nerves may suggest the presence of a traumatic neuroma-in-continuity [9]. Lastly, nerve discontinuity can serve as a marker for a high-grade peripheral nerve injury or nerve laceration, which are rare causes of neuropathy in the postoperative setting [9].

Concerning secondary features of peripheral neuropathy, MARS MRN can detect and characterize the extent of skeletal muscle denervation, if the muscles of interest are included, which may require adding additional stacks of images. MRN features of skeletal muscle denervation include intramuscular edema-like signal, fatty replacement, and loss of muscle bulk. Skeletal muscle atrophy and fatty replacement have been described in patients following hip arthroplasty and can be present in asymptomatic patients [21]. Hence, it is important to interpret MARS MRN in the individual clinical context rather than in isolation.

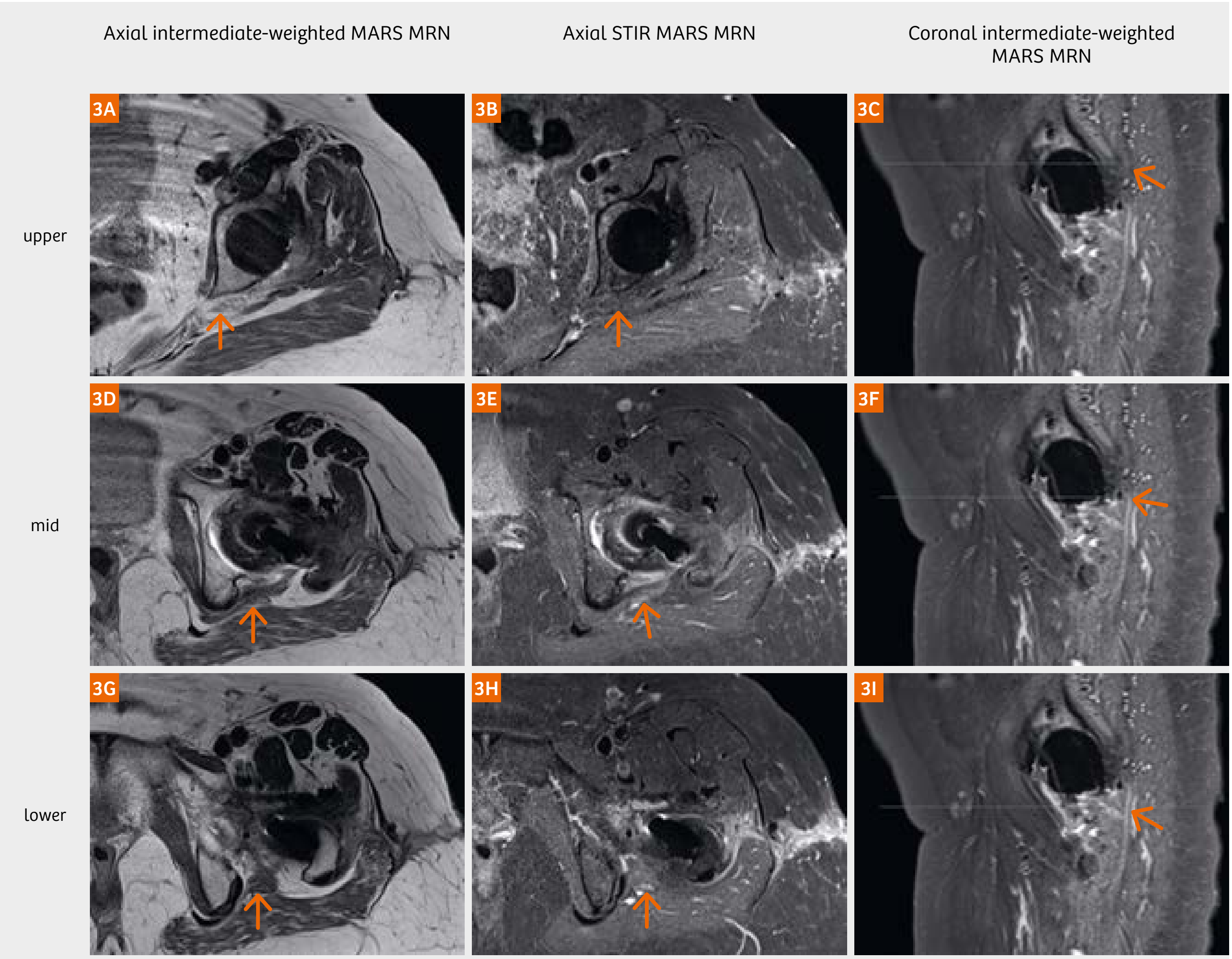


Figure 3:
Metal Artifact Reduction Magnetic Resonance Neurography in a patient with new-onset foot extension and flexion weakness following recent left hip arthroplasty demonstrates normal morphology and signal hyperintensity of the left sciatic nerve (arrow, **3A–C**) at the upper level. At the mid level, there is abnormal signal hyperintensity of the sciatic nerve (arrows, **3D–F**) in the subgluteal space. At the lower level, there is perineural scarring of the sciatic nerve and abnormal signal intensity of the sciatic nerve (arrow, **3G–I**), indicative of neuropathy.

Lastly, MARS MRN also demonstrates the soft tissues surrounding the pelvic nerves, including perineural fibrosis (Fig. 3), collections causing course deviations and mass effect, which can provide added value to electrodiagnostic testing and the clinical management of these patients.

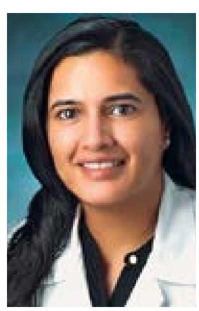
Conclusion

MARS MRN provides high image quality of the pelvic peripheral nerves and lumbosacral plexus with validated accuracy for the diagnosis of lumbosacral plexopathy in patients with metallic pelvic implants.

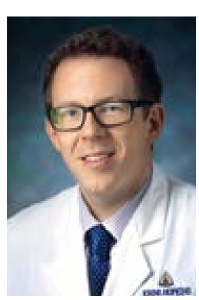
References

1 Burge AJ, Gold SL, Kuong S, Potter HG. High-resolution magnetic resonance imaging of the lower extremity nerves. Neuroimaging Clin N Am. 2014;24(1):151-70.
2 Brown GD, Swanson EA, Nercessian OA. Neurologic injuries after total hip arthroplasty. Am J Orthop 2008;374:191-197.
3 Farrell CM, Springer BD, Haidukewych Gj, Morrey BF Motor nerve palsy following primary total hip arthroplasty. J Bone Joint Surg Am 2005; 87(12):2619-2625.
4 Navarro RA, Schmalzried TO, Amstutz HC, Dorey FJ Surgical approach and nerve palsy in total hip arthroplasty. J Arthroplasty 1995; 10:1-5.
5 Zappe B, Glauser PM, Majewski M, Stöckli HR, Ochsner PE. Long-term prognosis of nerve palsy after total hip arthroplasty: results of two-year-follow-ups and long-term results after a mean time of 8 years. Arch Orthop Trauma Surg. 2014;134:1477-82.
6 Schmalzried TP, Amstutz HC, Dorey FJ. Nerve palsy associated with total hip replacement. Risk factors and prognosis. J Bone Joint Surg Am. 1991;73:1074-80.
7 Melamed NB, Satya-Murti. S. Obturator neuropathy after total hip replacement. Ann Neurol. 1983;13:578-9.
8 Weber ER, Daube JR, Coventry MF. Peripheral neuropathies associated with total hip arthroplasty. J Bone Joint Surg [Am] 1976;58:66-69.
9 BN Edwards, Tullos HS, Noble PC. Contributory factors and etiology of sciatic nerve palsy in total hip arthroplasty. Clin Orthop 1987; 218:136.
10 Fritz J, Lurie B, Miller TT, Potter HG. MR Imaging of Hip Arthroplasty Implants. Radiographics. 2014; 34(4): E106-132.
11 Potter HG, Nestor BJ, Sofka CM, Ho ST, Peters LE, Salvati EA. Magnetic resonance imaging after total hip arthroplasty: evaluation of periprosthetic soft tissue. J Bone Joint Surg Am; 2004(86):1947–1954.
12 Hayter CL, Koff MF, Shah P, Koch KM, Miller TT, Potter HG. MRI after arthroplasty: comparison of MAVRIC and conventional fast spin-echo techniques. AJR Am J Roentgenol 2011;197: W405–W411.
13 Hayter CL, Koff MF, Potter HG. Magnetic resonance imaging of the postoperative hip. J Magn Reson Imaging 2012;35:1013–1025
14 Fritz J, Ahlawat S, Demehri S, Thawait GK, Raithel E, Gilson WD, Nittka M.Compressed Sensing SEMAC: 8-fold Accelerated High Resolution Metal Artifact Reduction MRI of Cobalt-Chromium Knee Arthroplasty Implants. Invest Radiol. 2016;51(10):666-76.
15 Fritz J, Fritz B, Thawait GK, Raithel E, Gilson WD, Nittka M, Mont MA. Advanced metal artifact reduction MRI of metal-on-metal hip resurfacing arthroplasty implants: compressed sensing acceleration enables the time-neutral use of SEMAC. Skeletal Radiol. 2016 Oct;45(10):1345-56.
16 Ulbrich EJ, Sutter R, Aguiar RF, Nittka M, Pfirrmann CW. STIR sequence with increased receiver bandwidth of the inversion pulse for reduction of metallic artifacts. AJR Am J Roentgenol. 2012 Dec;199(6):W735-42.
17 Sutter R, Ulbrich EJ, Jellus V, Nittka M, Pfirrmann CW. Reduction of metal artifacts in patients with total hip arthroplasty with slice-encoding metal artifact correction and view-angle tilting MR imaging. Radiology 2012;265:204–214.
18 Muller GM, Lundin B, von Schewelov T, Muller MF, Ekberg O, Mansson S. Evaluation of metal artifacts in clinical MR images of patients with total hip arthroplasty using different metal artifact reducing sequences. Skeletal Radiol. 2015:44:353-09.
19 Wolf M, Bäumer P, Pedro M, Dombert T, Staub F, et al. Sciatic Nerve Injury Related to Hip Replacement Surgery: Imaging Detection by MR Neurography Despite Susceptibility Artifacts. PLoS ONE 2014;92: e89154.
20 Ahlawat S, Stern SE, Belzberg AJ, Fritz J. High-resolution metal artifact reduction MR imaging of the lumbosacral plexus in patients with metallic implants. Skeletal Radiol. 2017 Jul;46(7):897-908.
21 Pfirrmann CW, Notzli HP, Dora C, Hodler J, Zanetti M. Abductor tendons and muscles assessed at MR imaging after total hip arthroplasty in asymptomatic and symptomatic patients. Radiology 2005;235:969–976.
22 Chhabra A, Chalian M, Soldatos T, Andreisek G, Faridian-Aragh N, Williams E, Belzberg AJ, Carrino JA. 3-T high-resolution MR neurography of sciatic neuropathy. AJR Am J Roentgenol. 2012;1984:W357-64.
23 Kwee RM, Chhabra A, Wang KC, Marker DR, Carrino JA. Accuracy of MRI in diagnosing peripheral nerve disease: a systematic review of the literature. AJR Am J Roentgenol. 2014;203:1303-9.
24 Ahlawat S, Belzberg AJ, Montgomery EA, Fayad LM. MRI features of peripheral traumatic neuromas. Eur Radiol. 2016;26:1204-12.

Contact



Shivani Ahlawat, M.D.
Director MSK Fellowship
Assistant Professor of Radiology and Radiological Sciences
Johns Hopkins University School of Medicine
Russell H. Morgan Department of Radiology and Radiological Science
Musculoskeletal Radiology
601 N. Caroline Street
Baltimore, MD 21287, USA
sahlawa1@jhmi.edu



Jan Fritz, M.D., P.D., D.A.B.R.
Director of Interventional MR Imaging
Associate Director MSK Fellowship
Assistant Professor of Radiology and Radiological Sciences
Johns Hopkins University School of Medicine
Russell H. Morgan Department of Radiology and Radiological Science
Musculoskeletal Radiology
601 N. Caroline Street, JHOC 3140A
Baltimore, MD 21287, USA
jfritz9@jhmi.edu