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

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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 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 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 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.

Introduction
Traumatic nerve palsy in the setting of previous pelvic instrumentation and hip arthroplasty is a rare but serious complication. 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.

Table 1:
<table>
<thead>
<tr>
<th>Orientation</th>
<th>Intermediate-weighted Turbo Spin Echo</th>
<th>STIR Turbo Spin Echo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repetition time [ms]</td>
<td>5700</td>
<td>3660</td>
</tr>
<tr>
<td>Time to echo [ms]</td>
<td>38</td>
<td>6.9</td>
</tr>
<tr>
<td>Inversion time [ms]</td>
<td>-</td>
<td>150</td>
</tr>
<tr>
<td>Echo train length</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Slice thickness/gap [mm]</td>
<td>4.5/0.45</td>
<td>5/0.5</td>
</tr>
<tr>
<td>Pixel size [mm²]</td>
<td>0.5 x 0.5</td>
<td>0.7 x 0.7</td>
</tr>
<tr>
<td>Bandwidth [Hz/px]</td>
<td>560</td>
<td>545</td>
</tr>
<tr>
<td>Flip angle [degree]</td>
<td>150</td>
<td>130</td>
</tr>
<tr>
<td>Number of slices</td>
<td>2 x 35</td>
<td>2 x 27</td>
</tr>
<tr>
<td>Number of excitations</td>
<td>1.5</td>
<td>2</td>
</tr>
<tr>
<td>In-plane frequency encoding direction</td>
<td>Right to left</td>
<td>Right to left</td>
</tr>
<tr>
<td>Total acquisition time [min:sec]</td>
<td>8:42</td>
<td>13:36</td>
</tr>
</tbody>
</table>

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)
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

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**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**