Optimizing Brachial Plexus Magnetic Resonance Neurography at 3 Tesla

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Introduction

At the Hospital for Special Surgery (HSS), ongoing efforts are made to improve image quality in magnetic resonance neurography (MRN). MRN comprises a specialized set of techniques focused on imaging peripheral nerves, which can be challenging given their small size and non-linear course throughout the body. When utilized in parallel with electrodiagnostic testing, MRN not only facilitates accurate localization of nerve injuries but also offers a comprehensive assessment of both the injured nerve and the end-organ muscle. MRN of the brachial plexus (BP) presents unique challenges due to inherent field inhomogeneities related to the neck/shoulder curvature and proximity to the lungs [1]. In 2021, the first Siemens Healthineers system was installed at our institution – a MAGNETOM Vida 3T. In this article, we share our experience in optimizing imaging quality for BP imaging on the MAGNETOM Vida.

Three-coil setup:
20-channel HNU +
18-channel UltraFlex +
posterior Spine Coil

Two-coil setup:
18-channel UltraFlex
(anterior: small,
posterior: large)

1 Comparison of coil types for unilateral, left brachial plexus MRN. **(1A)** Imaging with the neck at isocenter and the brachial plexus off isocenter using a combination of a 20-channel neurovascular array for the neck region, an 18-channel UltraFlex flexible coil array, and posterior spine elements. The BioMatrix Respiratory Sensor may be used for respiratory gating. **(1B)** An alternative setup with the left brachial plexus at isocenter, using two 18-channel UltraFlex arrays; the smaller coil is placed anteriorly while the larger coil is placed posteriorly (under the subject). An additional strap may be needed to deploy the respiratory pillow.

Sequence	2D IW-TSE	2D T2w-TSE	SPACE STIR	2D T2w-TSE
Deep Resolve Boost	Y	Y (Prototype)[1]	Y (Prototype)[1]	Y (Prototype)[1]
Orientation	Axial	Coronal	Double oblique-coronal	Oblique sagittal
Field of view, cm	28	32	30	16
TR/TE, ms	4000–6500/35	3000–9000/85	3000/161 (apparent TE = 60)	3000–6000/85
TI, ms	–	–	250	–
Matrix size (frequency × phase)	512 × 410	320 × 240	304 × 168	320 × 240
Pixel resolution (frequency × phase), mm^2	0.5 × 0.7	1.0 × 1.3	1.0 × 1.0	0.5 × 0.7
Slice thickness, mm (no spacing)	3.5	4.0	1.0	2.5
Slices	60	40–50	100–120	24–40
Bandwidth, Hz/Pixel	296	240	382	240
Turbo factor	14	14	130	14
Total acceleration factor (GRAPPA / CAIPIRINHA)	2	2	4	2
Gadolinium contrast	none	none	optional	none
Fat suppression	none	Dixon	STIR	Dixon/Fat saturation
Scan time, min:sec	2:00	3:45	4:40	4:00, variable with respiratory gating

Table 1: Unilateral brachial plexus protocol on MAGNETOM Vida 3T.
IW indicates intermediate-weighted; TSE: turbo spin echo; T2w: T2-weighted; TR: repetition time; TE: echo time; TI: inversion time; GRAPPA: generalized autocalibrating partial parallel acquisition; CAIPIRINHA: controlled aliasing in parallel imaging results in higher acceleration

[1] *Work in progress. The product is still under development and not commercially available. Its future availability cannot be ensured.*

Coil configuration

To maximize signal-to-noise ratio (SNR) for BP MRN, it is vital to use multichannel receiver arrays that cover the large anatomical regions of the neck, shoulder, and axilla, while also minimizing the distance between coil elements and the targeted anatomy [2]. At HSS, the BP is typically imaged unilaterally, rather than bilaterally, to optimize spatial resolution and coverage; if bilateral coverage is required, two unilateral scans are typically acquired. On the MAGNETOM Vida 3T, the preferred three-coil setup includes a combination of either a 20-channel neurovascular array for the neck region, an 18-channel UltraFlex flexible coil array (small or large, depending on coverage needed) over the chest wall/upper arm, and the posterior spine array (Fig. 1). Alternatively, two 18-channel UltraFlex arrays, the smaller version placed anteriorly and the larger placed posteriorly, can be placed (Fig. 1). The three-coil setup is easier to configure, in our experience, but the two-coil setup provides flexibility for positioning the targeted BP closer to magnet isocenter.

BP protocol – overview and rationale

Our current, unilateral BP protocol comprises acquisitions both longitudinal and orthogonal relative to the course of the nerve segments (Fig. 2). Following localizer scans, a two-dimensional (2D) axial intermediate-weighted (IW)-TSE is acquired to guide plotting of subsequent scans. Next, a large field of view 2D coronal T2-weighted Dixon TSE is acquired to assess the regional musculature. These two TSE sequences are used to plot the remaining nerve-sensitive scans: two, 2D oblique sagittal T2-weighted Dixon acquisitions for orthogonal, high in-plane resolution and a single, coronal T2-weighted three-dimensional (3D) SPACE-STIR sequence for high through-plane resolution. For the SPACE-STIR, coverage is best optimized with a 'double oblique' prescription, which is first aligned parallel to the clavicle and includes cephalocaudal coverage from the C4 superior endplate to the axilla and anterior-posterior coverage from the chest wall to the posterior scapula. This is followed by a second alignment step, made off the 2D coronal T2-weighted Dixon TSE, from C4 to the axillary region.

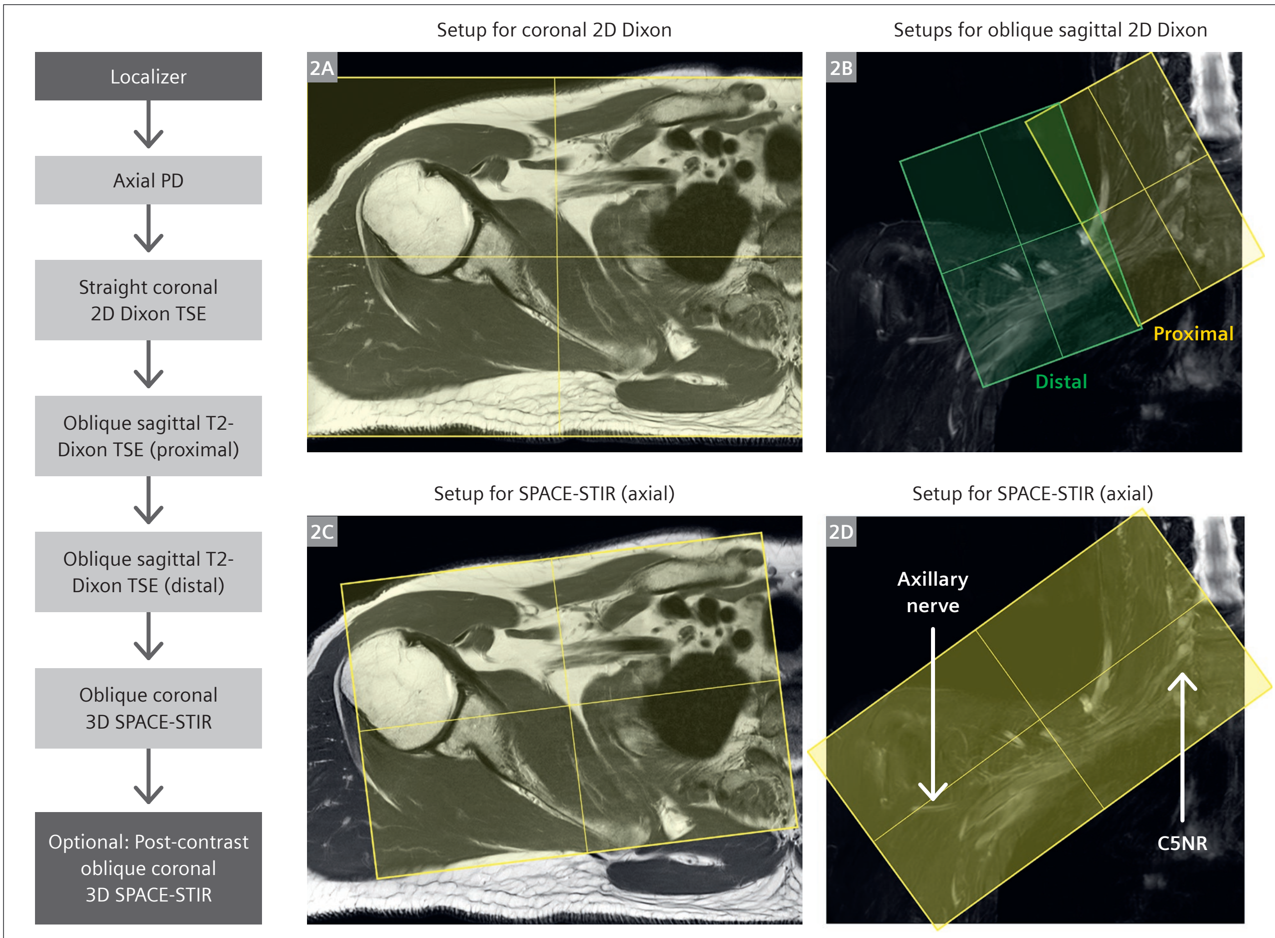
Optimized 3D SPACE STIR

The SPACE sequence offers a significant advantage, compared to 2D imaging, by enabling higher through-plane spatial resolution (0.8–1.0 mm isotropic) and facilitating evaluation in any arbitrary plane without distortion, either using oblique or curved multiplanar reformations. We use a prototype SPACE-STIR sequence[1] with optimizations to improve B_0 and B_1+ robustness. These improvements include:

1. C-shaped frequency offset corrected inversion (C-FOCI) pulse for uniform fat suppression [3, 4],
2. variable flip angle train tailored with consideration of the B_1+ inhomogeneity and
3. deep-learning-based 3D reconstruction algorithm tailored for CAIPIRINHA sampling pattern for high-quality reconstruction.

In particular, 3D deep-learning reconstruction now facilitates acquisitions at 0.8 mm resolution, as compared to our default 1.0 mm-isotropic prescription (Fig. 3).

[1]*Work in progress. The product is still under development and not commercially available. Its future availability cannot be ensured.*



2 Suggested protocol for unilateral BP MRI, and illustration of prescription boxes. From the unilateral axial intermediate-weighted image **(2A)**, the straight coronal Dixon is plotted to cover 'skin-to-skin' (anterior to posterior) at the level of the subclavian vessels. Then two, 2D oblique sagittal T2-weighted Dixon scans are plotted off the coronal Dixon water image for proximal (yellow) and distal (green) coverages **(2B)**; two scans are needed to ensure the images are orthogonal to the BP. Finally, a double-oblique coronal 3D SPACE-STIR is plotted off the axial IW image, parallel to the clavicle **(2C)** and off the coronal Dixon, to include from the C5 nerve root to the axillary region (yellow box as shown in **2D**).

A SPACE-STIR sequence is sometimes acquired following intravenous gadolinium administration to improve vascular suppression, and to visualize small branch nerves of the plexus that may otherwise be obscured by venous contamination (Fig. 4) [5]. Gadolinium shortens the T1 of blood, thus bringing the blood T1 closer to that of fat, and reduces T2 transverse magnetization.

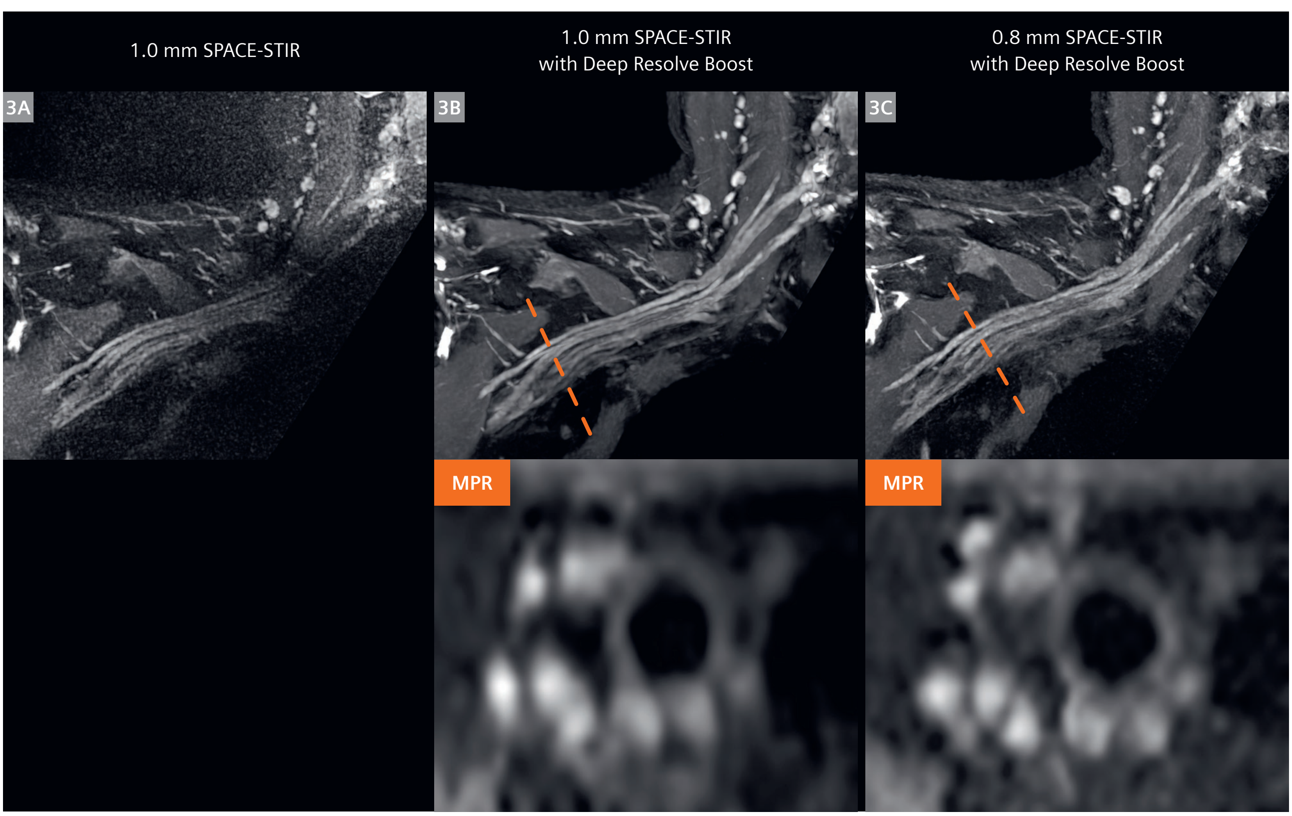
2D MRN

Orthogonal 2D MRN imaging typically provides higher in-plane spatial resolution, compared to 3D sequences, to better evaluate fascicular architecture [6]. However, achieving high in-plane spatial resolution (< 0.5 mm) within a clinically reasonable scan time (to mitigate respiratory motion artifact) while also maintaining adequate SNR poses a significant challenge. The Siemens Healthineers Deep Resolve Boost reconstruction algorithm helps mitigate these challenges by reducing noise amplification or blurring [7], when applying parallel imaging acceleration or partial Fourier acquisition.

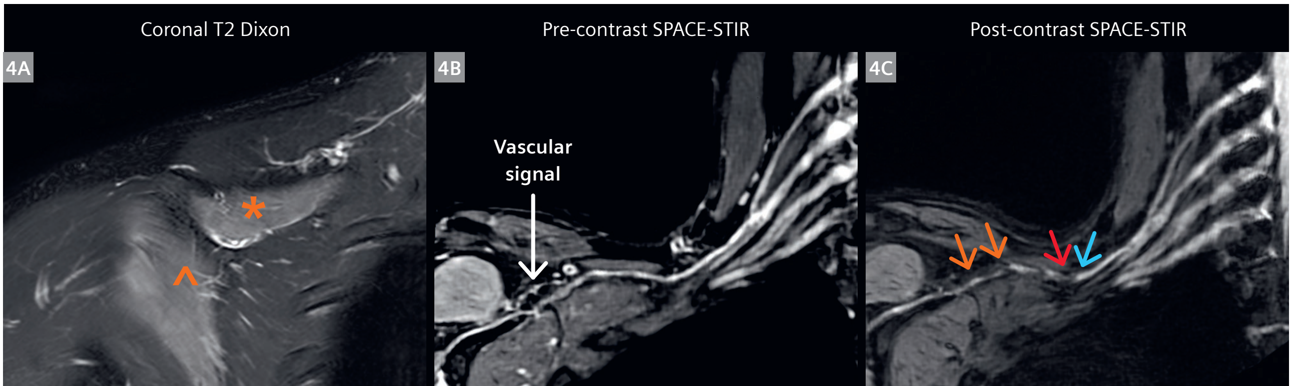
Applying fat suppression techniques is also crucial in 2D MRN to enhance the contrast ratio between the peripheral nerves and surrounding fat. We typically employ the Dixon method in this context due to its ability to simultaneously provide homogenous fat suppression (despite field inhomogeneities) and high SNR efficiency. This is particularly important in the neck-shoulder region, which has high B_0-variation. For the 2D Dixon sequence on the MAGNETOM Vida system, one can choose between 'strong' and 'weak' fat suppression modes to modulate the degree to which the fat signal contributes to the MR images. Our preference is the 'strong' option to optimize nerve/muscle and nerve/fat contrast.

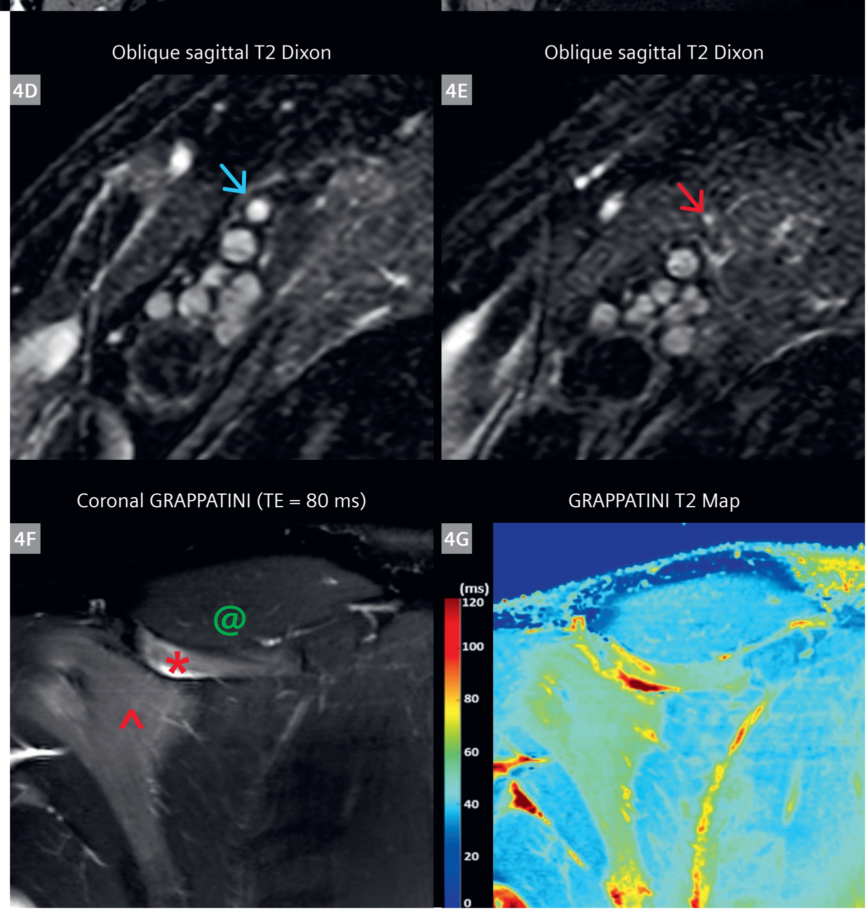
Respiratory triggering

Orthogonal imaging planes, particularly those through the infraclavicular segments of the BP, are prone to aliasing from respiratory motion due to the proximity of such segments to the lung apex. Respiratory motion artifacts are sometimes severe and may render the exam uninterpretable. Use of prospective respiratory



3 Comparison of SPACE-STIR acquired with standard reconstruction and with Deep Resolve (DR) Boost reconstruction. The top row images are all coronal SPACE-STIR images with 10 mm maximal intensity projection (MIP). **(3A)** Standard reconstruction of a 1.0 mm isotropic acquisition exhibits poor conspicuity of the brachial plexus. **(3B)** With DR Boost, improved conspicuity of the nerves is observed. **(3C)** DR Boost with 0.8 mm acquisition is feasible, providing sharper nerve definition, especially in the oblique-axial multiplanar reformation orthogonal to the brachial plexus at the level of the dashed lines (bottom row).



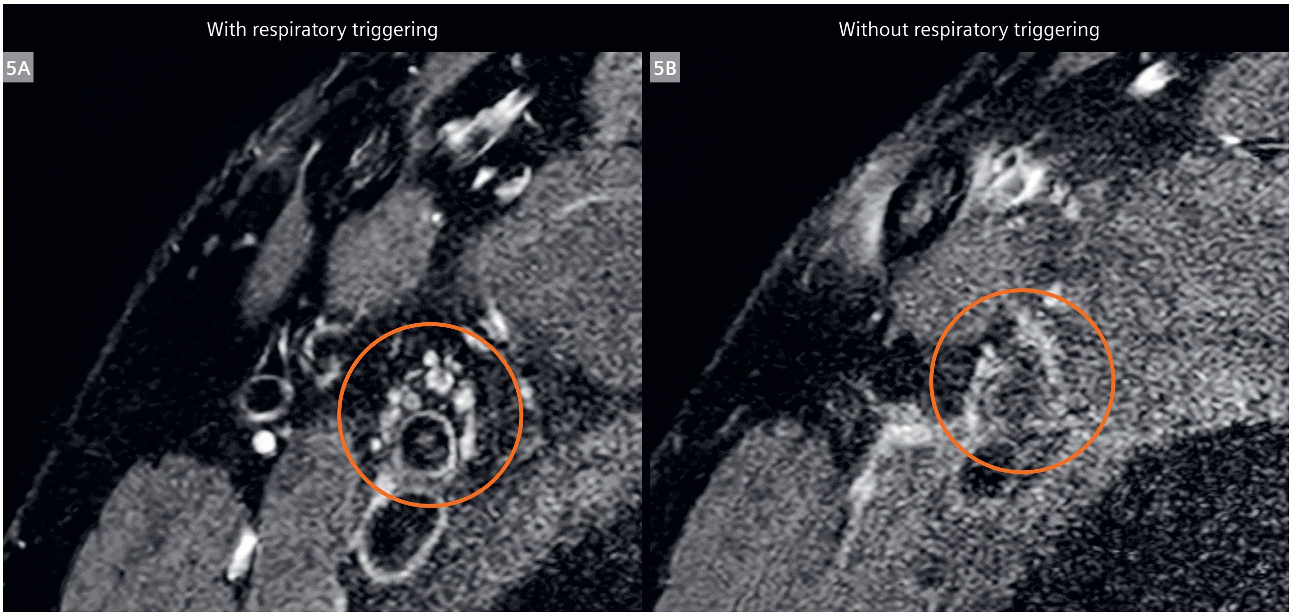


4 34-year-old man with Parsonage-Turner syndrome (PTS) involving the suprascapular nerve. **(4A)** Coronal T2-weighted Dixon illustrates muscle edema patterns in the supraspinatus (*) and infraspinatus (^) muscles, reflecting denervation secondary to a spontaneous suprascapular neuropathy. **(4B)** Pre-contrast SPACE-STIR image shows vascular signal in the vicinity of the suprascapular nerve (arrow). **(4C)** Post-gadolinium contrast SPACE-STIR image provides improved vascular suppression and conspicuity of the constrictions (orange and red arrows) in the suprascapular nerve associated with PTS. **(4D, 4E)** Oblique sagittal T2-weighted Dixon images at the corresponding positions indicated by the blue and red arrows in **4C**, demonstrate enlargement (**4D**, blue arrow) of the suprascapular nerve, just proximal to one of the constriction sites (**4E**, red arrow). **(4F, 4G)** Straight coronal GRAPPATINI with morphological image **(4F)** generated at TE = 80 ms and the corresponding T2 maps **(4G)** show signal hyperintensity **(4F)** and high T2 values **(4G)** in both the supraspinatus (*) and infraspinatus (^) muscles, relative to the unaffected trapezius (@).

triggering via bellows to enable acquisitions during maximal end-expiration has been shown to improve interobserver agreement and nerve conspicuity [8].
On the MAGNETOM Vida, prospective respiratory gating uses the BioMatrix Respiratory Sensor embedded into the posterior spine array. These sensors automatically detect and record respiratory and head movements once the patient is positioned on the table. This feature enhances workflow efficiency by enabling technologists to perform respiratory-triggered scans without incurring additional setup time (Fig. 5). Alternatively, the respiratory signal may also be obtained using the respiratory cushion complete with belt setup where an additional posterior phased-array coil is placed between the patient and the table in the two-coil setup.

Future directions

Quantitative MRI techniques, including T2 mapping, perfusion, and diffusion-weighted or diffusion tensor imaging (DWI/DTI), carry the potential to supplement qualitative BP assessment. A study of patients with chronic inflammatory demyelinating polyneuropathy found that not only were nerve root sizes enlarged but also demonstrated elevated



5 Oblique sagittal T2 Dixon imaging through the infraclavicular plexus (distal acquisition), demonstrates improved conspicuity of the cords with prospective respiratory gating (**5A**, using the imbedded BioMatrix Sensors) compared to the non-gated respiratory acquisition **(5B)**. Note that the gated scan requires approximately two minutes longer to acquire.

T2 relaxation times [9]. A quantitative Siemens Healthineers MRI prototype sequence, generalized autocalibrating partially parallel acquisition with the model-based accelerated relaxometry by iterative nonlinear inversion (GRAPPATINI)[1], can provide accurate T2 estimations and synthetic morphologic images [10, 11]. This technique may enable simultaneous qualitative and quantitative evaluation of both nerves and muscles in MR neurography, thereby shortening overall scan time and reducing registration errors between two separate acquisitions (Fig. 4F–G).

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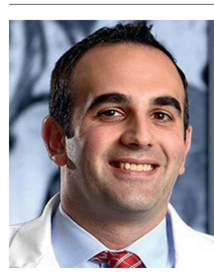

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