Robust diffusion-prepared neurography of the complete brachial plexus facilitated by an optimized shimming strategy.

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Introduction: Diagnosis of treatable immune-mediated diseases affecting peripheral nerves such as multifocal motor neuropathy (MMN) commonly relies on the specific abnormalities on nerve conduction studies such as a conduction block. However, conduction studies cannot properly assess the roots and the most proximal parts of the plexus brachialis, so that the diagnosis may be missed. New imaging methods for qualitative and quantitative imaging of the brachial plexus may be useful for diagnosing and monitoring patients with immune-mediated neuropathies [1,2]. In this study, we utilized the 3D diffusion prepared iMSDE sequence suggested by Yoneyama et al. [3] and optimized it to include the full brachial plexus and shoulders. Although the sequence gives excellent contrast of the nerves, image quality is often compromised by poor fat-suppression and a poor signal to noise ratio (SNR). The origin of these artifacts may be found in poor homogeneity of the magnetic field (B_0) and inhomogeneous distribution of the RF-signal (B_1). Both B_0 and B_1 can be improved by respective shimming methods. However when multiple tissue-air transitions are present -as is the case in the neck- shimming can become unreliable. The **aim** of this work was therefore to develop the optimal (combination of) methods to overcome problems with fat suppression and low SNR of brachial plexus imaging. To improve the B_0 and B_1 homogeneity we used a neck-pillow filled with pineapple juice (Pillow) for susceptibility matching. The pillow provides a large susceptibility-matched volume which facilitates improved shimming [4,5], but at the same time has low signal on T2-weighted imaging due to the paramagnetic effect of manganese in the pineapple juice [6]. Next we compared image based (IB) shimming to volume shimming. IB-shimming uses a 2nd order shim based on an automatic segmentation which follows the contours of the anatomy [7].

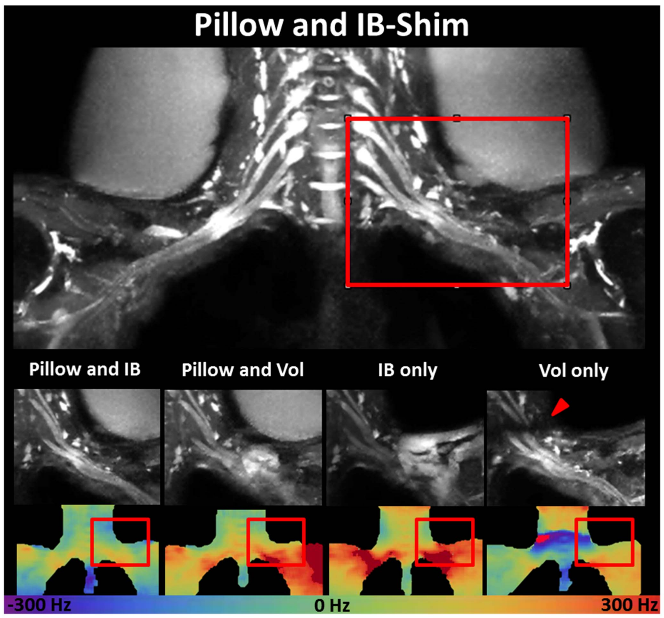

Figure 1: Maximum intensity projection (MIP) of the whole neck area using Pillow and IB-shimming (top). Magnifications of the infraclavicular space for different set-ups (middle row), corresponding B_0 maps in Hz in a mid-coronal plane (lower row). Strong inhomogeneities in B_0 resulted in poor fat-suppression or low SNR in the anatomical images (red arrow).

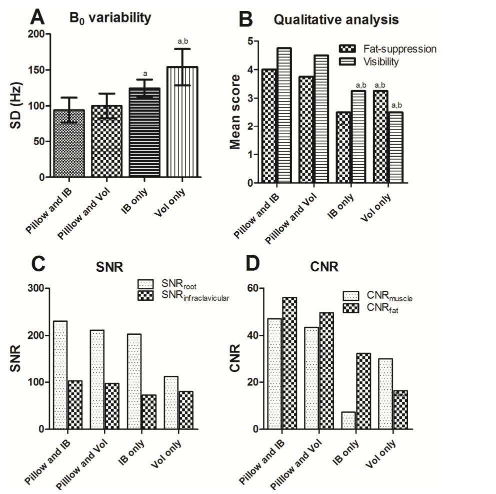

Figure 2: (A) Variability of the B_0 field in Hz; (B) mean score on fat-suppression and visibility; (C) SNR of the nerve at the root and in the infraclavicular space; D) CNR of the nerves (a = significant difference to Pillow and IB, b = significant difference to Pillow and Vol ($p < 0.05$)).

Methods: 4 healthy volunteers (3 male, 1 female, age 25-30) were positioned supine with the pillow placed anteriorly. Scanning was performed in the following order: pillow with IB-shim (Pillow and IB), pillow with volume shim (Pillow and IB), IB-shim only (IB only) and volume shim (Vol only). The study was performed on a 3 Tesla Philips Ingenia MRI-scanner (Best, The Netherlands). iMSDE: coronal TSE acquisition with RARE readout; FOV: 300x450 mm2; TEeff/TR 61/2500 ms; TSE factor: 100; echo spacing: 4.0 ms; voxel size: 1.1×1.1×1.1 mm3; fat suppression: SPAIR; duration of 7 min 13 s; SENSE 3.5 in right-left (RL) direction and 1.5 in the anterior-posterior (AP) direction. For B_0 and B_1 measurements the FOV; shim settings and SENSE factor were kept identical. B_1: 3D FFE; TR/TE; 20/2.2 ms; voxel size 4x4x4 mm3 and a duration of 2 min 27 s [8]. B_0: 3D FFE; TR/TE$_1$/TE$_2$; 3.6/1.23/2.3 ms; voxel size 2x2x2 mm3; flipangle of 10° and a duration of 15 s. We masked the nerves and its surroundings and calculated the variability of the B_0 and B_1. Scoring was performed for nerve visibility over the whole image (1=not visible, 2=visible but not suitable for analysis, 3=visible and suitable for analysis, 4=good visibility and 5=excellent visibility) and fat-suppression (1=poor and in area of interest, 2=poor, however not in area of interest but hindering analysis, 3=incomplete but not hindering analysis, 4=some incomplete fat-suppression but overall good, and 5=excellent). SNR was calculated for the nerves of the brachial plexus at the roots and at the infraclavicular space. For contrast to noise (CNR) evaluation we concentrated on the infraclavicular spaces in which image quality was most hindered by poor fat-suppression and low SNR. We compared the signal of the nerve with the surrounding fat (CNR_{fat}) in the infraclavicular space, but also with the deltoid muscle (CNR_{muscle}).

Results & discussion: The pillow significantly ($p < 0.05$) improved the B_0-homogeneity over the area around the nerves (Figure 2) and resolved the strong feet to head gradient (Figure 1). B_1-maps did not reveal significant differences for the different set-ups. The B_0-inhomogeneity produced drops in SNR and poor fat-suppression (red triangle in Figure 1). With the pillow, both IB and Vol shim provided good to excellent visibility of the nerves over the whole image from the myelum to the shoulders in all subjects. For all of the measured outcomes, there were no significant differences between 'Pillow and IB' and 'Pillow and Vol'. Nevertheless, 'pillow and IB' scored higher on all measures and therefore we consider this the best option.

Conclusion: The use of the pillow filled with pineapple juice in combination with IB-shimming resulted in the best overall visibility of the brachial plexus with minor to no artifacts. Furthermore, the application of the pillow, may find application for other sequences (e.g. diffusion tensor imaging) and for other anatomical areas where B_0-homogeneity is required.

References: [1] Chhabra et al. Am J Neuroradiol 34 (2013) 486-497; [2] Van Schaik et al. J Peripher Nerv Syst. 15 (2010) 295-301; [3] Yoneyama et al. Magn Reson Med Sci 12 (2013) 111-114; [4] Cox et al. Am J Neuroradiol 16 (1995) 1367–1369; [5] Maeharaet al. Magn Reson Imaging 32 (2014) 440–445; [6] Riordan et al. Br J Radiol 77 (2004) 991–999; [7] Schär et al. Magn Reson Med 51(2004) 799; [8] Yarnykh et al. Magn Reson Med 57 (2007) 192-200.