Upper extremity neural and vascular imaging with UHF 7T MRI

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Target audience: Researchers who are interested in ultra-high field (UHF) nerve and vessel imaging of extremities.

Purpose: UHF MRI of extremities is a valuable non-invasive modality with high sensitivity and superior tissue signal/contrast [1]. Musculoskeletal MRI is widely used to evaluate soft tissues for space-occupying lesions, infection, atrophy, or fibrotic scarring. In upper extremity (UE) imaging, MRI can provide contextual analysis of muscles, nerves, ligaments, tendons, vasculature and osseous structures. 7T MRI can comprehensively explore nerve (diffusion imaging) and vessel (non-contrast enhanced MR Angiography imaging and vessel segmentation) via homogeneous excitation. Our goal was to compare the signal to noise ratio (SNR) and contrast to noise ratio (CNR) findings of 3T vs. 7T UE MRI imaging with specific emphasis on peripheral nerve [1] and vasculature [2].

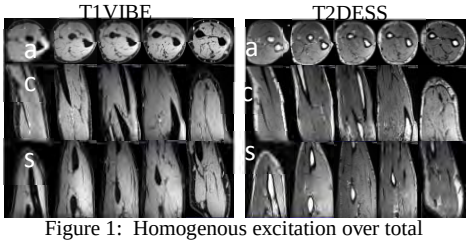

Figure 1: Homogenous excitation over total forearm with TEM Tx coil and 8-ch Rx insert (**a**: Axial, **c**: Coronal, **s**: Sagittal)

Methods: ATEM resonator designed and built in-house and actively detuned with an 8-ch receive array was developed exclusively for UE UHF imaging. Diffusion sequences utilizing higher water diffusional anisotropy (as compared to surrounding structures) were optimized for the high SNR at 7T to enhance nerve signals. Images were compared and verified with 3T diffusion tensor imaging (DTI) data. Forearm DTI and diffusion spectrum imaging (DSI) data was post processed using DSI studio (CMU, PA). Non-contrast enhanced MRA techniques were implemented at 7T to map digital vessels in UE applications. The time of flight (TOF) sequences had a longer T1 relaxation constant that enabled excellent 1) suppression of static spins contrasted against a dark background, and 2) bright delineation of flow in digital vessels. We needed to balance optimal RF power against a minimal specific absorption rate (SAR) while keeping scan times low. All the MR imaging parameters are shown in table 1.

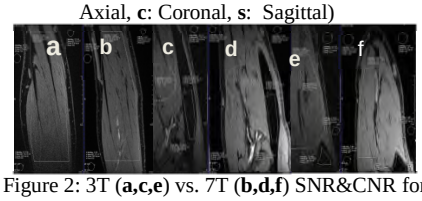

Figure 2: 3T (**a,c,e**) vs. 7T (**b,d,f**) SNR&CNR for complete volume of Forearm on the same subject

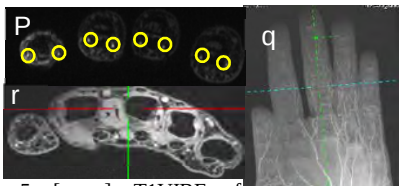

Figure 5: [**p,q,r**]: T1VIBE of proper palmer digital arteries; [**q**]: Non-contrast enhanced MRA image of the PPD arteries

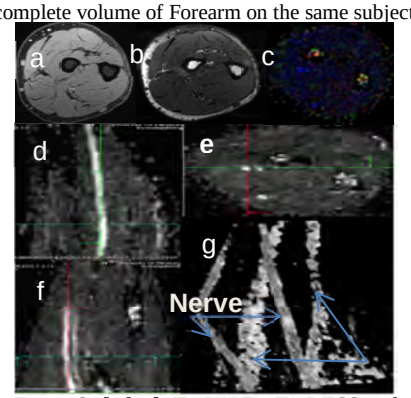

Figure 3: [**a,b,c**]: T1 VIBE , T2 DESS and DTI showing median and ulanar nerves , [**d,e,f**] showing UN, MN; [**g**]: 3D view of both nerves.

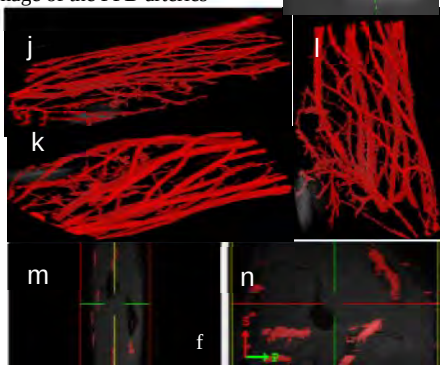

Figure 6 [**j, k, l**]: Vessel segmentation, [**m, n**]: Slice showing Paint grow method.

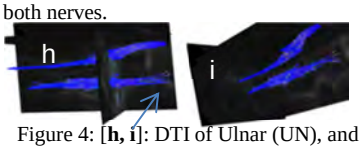

Figure 4: [**h, i**]: DTI of Ulnar (UN), and Median (MN) nerve

Results and Conclusions: The SNR (central slice) was 44, while the CNR was 33 for in-vivo coronal images at 7T. These values were consistently double that of equivalent scans at 3T across the volume of the arm and wrist in high resolution scans (Figures 1 and 2). Figure 3 [a, b, c] shows T1VIBE, T2DESS and DTI (color-map showing median (MN) and ulnar (UN) nerves). Figure 3 [d, e, f] shows sagittal, axial, and coronal views of DTI. Figure 3 [g] shows both nerves on minimal intensity projection. Figure 4 [h, i] shows DSI post processed data using DSI studio. The mean fiber anisotropy (FA) values were 0.83 for MN and 0.48 for UN. In Figure 5 [p, q, r], a physician interpreter was able to identify not only first and second order arteries (palmar arch) but also smaller proper palmar digital (PPD arteries). To our knowledge, this the first successful imaging of these UE vascular structures on a non-contrast sequence at 7T. T1W VIBE images were exported in DICOM format to MIPAV (NIH, MD). Masks were created manually using paint grow segmentation (rather than semi or automatic) to avoid errors in identifying structures (without skeletonization or dilation to preserve vessel anatomy). Figure 6 [j, k, l, m, n] shows forearm vasculature (deep and superficial arterial and venous structures including venae comitantes). Our ongoing clinical trial focuses on vascular and neuronal imaging with 7T in normals, trauma, and hand transplant patients focusing on nerve regeneration and vessel imaging (wall, luminal and flow changes) in forearm and hand. Taken together, this is the first demonstration of the potential utility and relevance of UHF 7T MRI in UE applications such as vascular and nerve imaging. 7T MRI is a non-invasive imaging modality that offers new insights into temporal changes in neurovascular structures of UE in relevant disease indications including superior, sensitive and specific, high resolution delineation of 3 D contextual anatomy compared to state of the art techniques (such as 3T).

Table 1: 7T Musculoskeletal imaging protocol

Sequences	FOV(mm)	TR/TE	Slices
B_1^+ field map	100 x 100	1500/1.8	112
T1 VIBE(304x512)	95 x 160	12/4.5	288
DTI (D:32, b=1300)	700 x 620	7000/83	65
DSI (b=0 to 2000)	700 x 620	8000/80	65
TOF(236x640)	85 x 208	12/4.5	-

References: [1] Vaughan JT et al, 7T vs. 4T: RF power, homogeneity, and signal-to-noise comparison in head images. Magn Res Med. 2001; 46:24–30. [2] Jambawalikar S, et al., Diffusion tensor imaging of peripheral nerves. Skeletal Radiol 2010; 39:1073–1079