Improvements in DTI and muscle fiber tractography of the human forearm using Rician noise supression and B0-field corrections

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Introduction: DTI based fiber tractography is a promising non-invasive technique for revealing in vivo muscle architecture in high detail. The technique is troubled by a number of issues, related to deformations of the EPI images [1] and high SNR demand required to accurately perform fiber tractography [2]. For DTI based tractography to become clinically usable these problems have to be overcome without increasing the scan time.

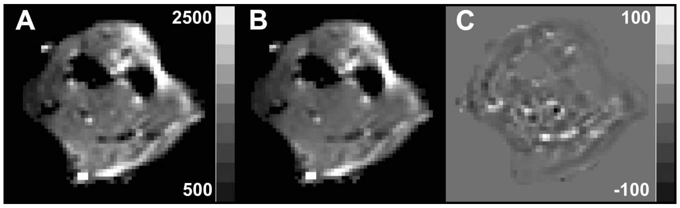
MRI: The right forearms of male healthy volunteers were measured using four flexible surface coils on a 3T Philips Intera scanner. Three acquisitions were performed with a total scan time of 13:57 min; T1 weighted imaging for anatomy, dual-echo gradient echo (GE) imaging to derive a B0-field inhomogeneity map and diffusion tensor imaging (DTI). Imaging parameters were; ***T1:*** TSE, FOV: 160x160 mm^2, voxel size: 0.5x0.5x5 mm^3, 60 slices, TR/TE: 550/12 ms, NSA: 2, scan time: 4:57 min; ***GE:*** 160x120 mm^2, matrix size: 80x60, voxel size: 2x2x5 mm^3, TR/TE$_1$/TE$_2$: 12/4.6/9.6 ms, NSA: 1, scan time: 42 s; ***DTI:*** SE-EPI, FOV: 160x120 mm^2, matrix size: 80x60, voxel size: 2x2x5 mm^3, 60 slices, 15 diffusion gradient directions, TR/TE: 8800/41 ms, NSA: 2, b=400 s/mm^2, fat suppression: SPAIR, scan time: 8:18 min.

Analysis: Diffusion-weighted images were registered to the b=0 image using the Philips scanner software. Further processing was done using *Wolfram Mathematica 7.0*. First, the diffusion-weighted images were filtered using a recursive linear minimum mean-square-error estimator as proposed by Aja-Fernandez et al. [3] to suppress Rician noise. Next the phase images from the dual-echo gradient echo data were unwrapped using a fast 2D algorithm proposed by Herraez et al. [4]. From these unwrapped images a B0-field map was calculated [5], which was used to correct field-inhomogeneity related deformations in the EPI images [6]. Fiber-tracking was performed using the DTI-tool developed in house. Fiber tracts continued bidirectional (0.1 voxel integration steps) from a single seeding ROI located in the middle of the muscle (see figure **4E**) until stopping criteria were satisfied (FA < 0.1 or angle change >5 degrees/integration step). The single seeding ROI was drawn in a T1-weighted image selecting the flexor digitorum profundus (FDP) muscle. Fiber tractography was compared to photographs of human cadaver muscle.

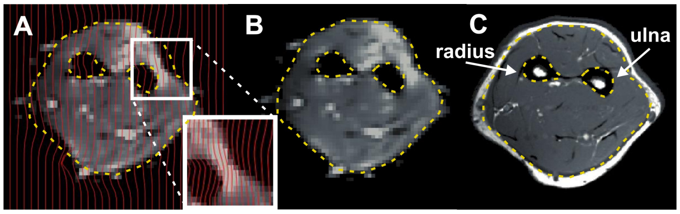
Results: Figure **1** shows the results of the Rician noise supression filter. Figure **1C** depicts the difference between the filtered **(B)** and original image **(A)**. Figure **2A** shows the deformation grid calculated from the B0-field map overlaid on an EPI image. Figure **2B** shows the corresponding corrected EPI image, which clearly demonstrates better anatomical agreement with the T1-weighted image in Figure **2C** indicated by the dashed yellow line. Figure **3** presents whole volume fiber tractography, made using the non-corrected (**A**) and corrected (**B**) DTI acquisitions. The fiber tracts of the corrected datasets cover the complete muscles and closely follow muscle boundaries, for example near tendons at the interfaces with subcutaneous fat, as indicated by the red arrows. Figure **4** shows detailed fiber tractography of the FDP muscle. There is excellent agreement with fibers observed on photographs of a FDP muscle, dissected from a human cadaver. Only a few erroneous tracts are observed that stray away from the muscle and many distinct features, such as attachments to tendons and bones, are clearly visible as indicated by the black dashed lines.

Conclusion: The proposed imaging protocol with a total examination time less than 15 min combined with post processing tools allows for accurate measurements of whole muscle architecture based on a single seeding ROI.

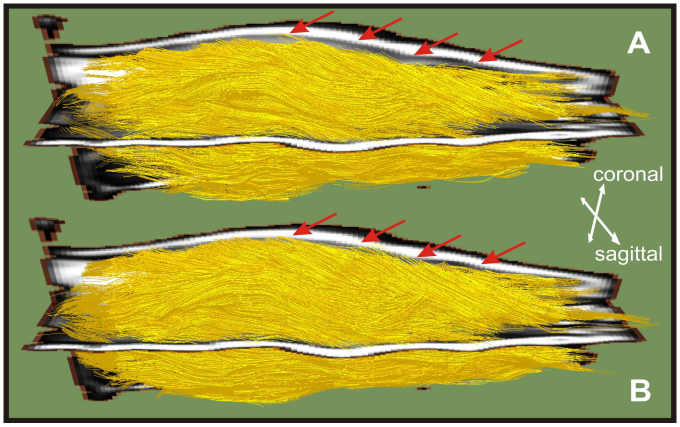
References: ***[1]*** Zeng et al. MRM 2002; 48(1): 137-146 ***[2]*** Damon et al. MRM 2008; 60(4): 934-944; ***[3]*** Aja-Fernandez et al. J IEEE 2008; 27(10): 1389-1403; ***[4]*** Herraez et al. Appl Opt 2002; 41(35): 7437-7444; ***[5]*** Chen et al. MRM 1999; 41(6):1206-1213; ***[6]*** Koch et al. Prog Nucl Mag Res Sp 2009; 54(2): 69-96



^ Figure 1: **A**) *Diffusion weighted EPI image;* ***B****) Same image after Rician noise supression;* ***C****) Difference between image* ***B*** *and* ***A***



^ Figure 2: **A**) *Deformed EPI image with deformation grid in red;* ***B****) Corrected EPI image;* ***C****) High Resolution T1 weighted image.*



^ Figure 3: *Whole volume fiber tractography of entire forearm overlaid on sagittal and coronal T1 cross sections.* ***A****) Original data;* ***B)*** *After post-processing. The red arrows in* ***A*** *illustrate regions with deformed fiber tracts, yielding imperfect coverage of the muscle volume. The post processing corrects these tracts, as shown in* ***B****, which now are accurately aligned to the subcutaneous fat.*

^ Figure 4: *Fiber tractography of the flexor digitorum profundus in comparison to photographs of human cadaver specimens. Views are:* ***A****,* ***B****) volar;* ***C****,* ***D****) radial to ulnar, also indicated by the red arrows in* ***E****.*