IN VIVO RECONSTRUCTION OF LUMBAR SPINAL MUSCLE ARCHITECTURE USING DT-MRI

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INTRODUCTION
Diffusion Tensor MRI (DT-MRI) enables three-dimensional *in vivo* reconstruction of muscle architecture. Previous studies on human skeletal muscle reconstruction using DT-MRI focused on lower limb and forearm musculature [1-4]. Aim of the present study was to explore the ability to reconstruct the human lumbar spinal muscles from in vivo DT-MRI measurements and to compare the results with actual anatomy.

METHODS
The lumbar spine of one healthy male volunteer (age 29 years) was scanned in supine position. All measurements were performed on a 3.0 Tesla Philips Intera clinical MRI scanner. Scan range reached from the level of the second sacral to the twelfth thoracic vertebra. Data collection and post-processing were performed according to the protocol developed by Froeling et al.[5]. MRI data acquisition consisted of three parts: (1) High resolution T1w turbo spin echo (TSE) for anatomical reference. Slice thickness 5 mm; number of slices 60; reconstructed voxel dimensions 0.5x0.5x5.0 mm$^3$; TR/TE=550/12ms; NSA=2. (2) DTI for fiber tract reconstruction (DW-SE-EPI). Number of slices 60; reconstructed voxel dimensions 2x2x5 mm$^3$; FOV 224x224mm$^2$; acquisition matrix 112x112; 15 gradient directions; TR/TE=1100/41ms; NSA=2; b=0, or 400 s/mm$^2$. (3) A dual echo gradient echo sequence (GE) to allow correction for field inhomogeneities. Number of slices 60; reconstructed voxel dimensions 2x2x5 mm$^3$; TR/TE/TE$_2$=12/4.6/9.6 ms; NSA=2. After processing, DT-MRI data were exported to a custom built software program for fiber tractography[6]. Fiber trajectories were ended on basis of anisotropy and/or curvature. The resulting reconstructions were anatomically validated by comparison with bilateral dissections of two cadaver specimens.

RESULTS AND DISCUSSION
The multifidus (MF) and four parts of the lumbar erector spinae (ES) (thoracic part of iliocostalis lumborum (TIL), lumbar part of iliocostalis lumborum (LIL), thoracic part of longissimus thoracis (TLT) and lumbar part of longissimus thoracis (LLT)) were successfully reconstructed. Within these muscles, many fascicles with separate origins and insertions could be differentiated. Beside some artifacts, the DTI trajectories were in agreement with anatomical descriptions from literature and with findings in systematically dissected cadaver specimens. Figures 1B and C, as an example, show the DTI reconstruction of TIL. Diffusivity was lower in the erector spinae aponeuroses (ESA, pink in fig. 1B/C) than in the muscle bellies (red in fig. 1B/C). Figures 1A shows confirmation by comparable anatomical topography. Figure 2 shows a close-up of two fascicles of LLT, illustrating acceptable reconstruction of muscle bellies, while accuracy at the sites of attachment was lower.

![Figure 1](image1.png)

Figure 1. DTI fiber tracking results for TIL with anatomical reference. Fig. A shows topographical overview in dissection, dorsal right side. Medial and lateral borders of TLT are indicated by red (dotted) lines. The part surrounded by solid red lines corresponds with the reconstruction shown in 1B: cranial tendons marked by red * are out of scan and reconstruction range. Green #---# marks TLT tendons contributing to ESA; red # marks TIL tendons contributing to ESA.

![Figure 2](image2.png)

Figure 2. Close-up (dorsal view) of reconstructed fiber trajectories of L2 and L3 LLT fascicles. White lines indicate muscle line of action.
DT-MRI enables adequate reconstruction of complex muscle geometry, like in the lumbar spine. Most muscles could be separated, but for reliable reconstruction of the smallest fascicles and attachments a smaller voxel size is needed. Furthermore, the scan range did not include the entire length of ES; stitching of two or more image stacks is needed to cover ES as a whole. DT-MRI reconstructions were found to correspond with cadaver dissections, except for inevitable differences due to age and conservation. Most reconstructed fiber trajectories consist both of a fleshy and a tendinous part. Fiber trajectory length is thus not equal to muscle fiber length. Currently we are implementing software for manual selection of individual fibers and interactive determination of the endpoints of the fleshy part of selected fiber trajectories. These fiber lengths and muscle volumes can be used as input in individualized biomechanical modeling.

CONCLUSIONS
Successful reconstruction of spinal muscle architecture is possible using DT-MRI. In the near future it will be possible to determine architectural parameters from such reconstructions, both in lower back, arm and leg muscles.

REFERENCES