Fiber architecture of the female pelvic floor: An exploratory investigation using different diffusion MRI tractography algorithms

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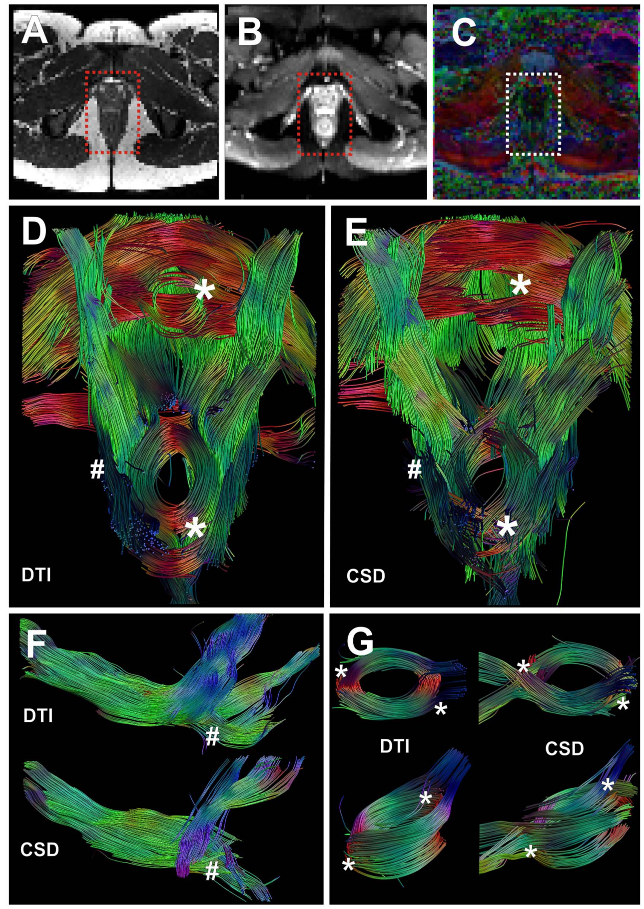
Introduction: Detailed subject specific knowledge and visualization of the female pelvic anatomy greatly aids the diagnostics of pelvic floor dysfunction. Diffusion tensor imaging (DTI) based fiber tractography can be used to visualize such skeletal muscle tissue in vivo in the human body[1]. However, the major limitation of this technique is that it assumes the presence of only one fiber orientation in a single voxel. Other models have been proposed to overcome this limitation, like the constrained spherical deconvolution (CSD) approach[2]. In general, skeletal muscle does not exhibit crossing fibers and DTI should be sufficient to describe the tissue characteristics. However, for muscles in the femal pelvic floor this might not be the case. Since here, multiple very thin sheetlike muscles together with sphincter muscles occupy a very small volume. This 'partial volume effect' leads to voxels with highly curved muscles or containing several muscle fiber bundels of different orientations, which can pose a problem for fiber tractography. In this study, we explored both DTI and CSD based tractography algorithms to invesitgate the female pelvic floor muscle anatomy in vivo.

Methods: The pelvic floor of one healthy female volunteer was imaged using a 16 channel coil on a 3T Philips Intera scanner. Diffusion weighted SE-EPI images were aquired with 60 evenly spaced gradient directions[3]. Other parameters were: FOV: 240x240 mm^2, matrix size: 80x80, voxel size: 3x3x3 mm^3, 30 slices, TR/TE: 8000/44 ms, NSA: 2, b=400 s/mm^2, fat suppression: SPAIR, scan time: 14:38 min. The data was processed with *ExploreDTI*[4]. First, the diffusion weighted images were corrected for motion and eddy currents induced geometric distortions accompanied with the appropriate b-matrix reorientation[5]. Next, a volume of 6x9x6 cm^3 was selected containing the pelvic floor musculature and whole volume DTI and CSD fiber tractography was performed[6]. Seed points were spaced evenly with a 2mm isotropic resolution, the minimum tract length was 25mm, and tracts were stopped at a curvature greater than 25 degrees per 1mm integration step. For DTI, fiber tracts continued for a FA range between 0.1 and 0.5, which equals the mean value ± 2 times the standard deviation of pelvic muscle FA preventing tracking of tendons and connective tissue outside this FA range. For the CSD approach, the harmonic degree of the estimated fiber orientation distribution function was limited to 8. The response function was simulated using DTI based diffusion properties derived from well-known single fiber population data.

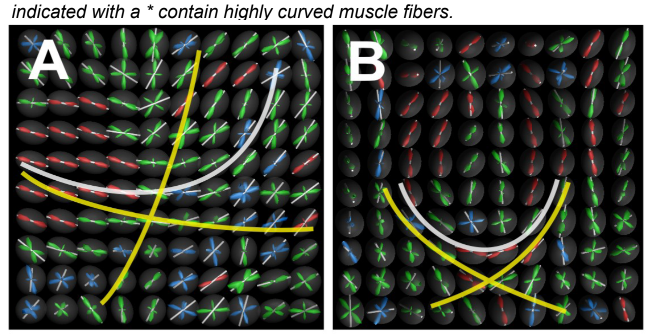
Results and Discussion: Figure 1 shows tractography results for both DTI and CSD of the whole pelvic floor as well as isolated muscle groups. Although both methods suffice for the global description of the anatomy they show subtle differences. Figure 2 illustrates these differences in more detail by visualizing the main diffusion directions based on DTI and CSD using glyphs. In regions with a single fiber direction, both methods find similar principal diffusion directions. This is shown in figure 2 where the red CSD glyphs nicely coincide with the white tubes, which depict the principal tensor eigenvector. However, in regions which are known to contain multiple fiber directions (indicated in figure 1 with "hash"), the DTI tubes represent fiber directions, which are a combination of the two or more directions derived from the CSD model (figure 2A). This fiber configuration explains the different tractography results of, for instance, the iliococcygeus and pubococcygeus, as depicted with a "hash" in figure 1F. Another difference between the two approaches can be seen in regions with high curvature (indicated in the figure 1 with an "asterisk"). Figure 2B show that the CSD model will interpret voxels containing high curvature as crossings (green and blue glyphs) resulting in inaccurate tractography of for instance the anal sphincter as indicated with an "asterisk" in figure 1G.

Conclusion: We have shown that both DTI and CSD can adequately describe the global architecture of the female pelvic floor. However, in regions with complex structures they show different results. DTI seems to follow highly curved fiber orientations more easily, but it cannot resolve multiple fiber orientations. For CSD, the opposite has been observed.

References: [1]*Froeling et al. MRM 2010; 64(4): 1182-90.* [2]*Tournier et al. Neuroimage 2008; 42(2): 617-25* , [3]*Jones et al. MRM 199; 42(3) 515-25,* [4]*www.exploredti.com,* [5]*Leemans et al. MRM 2009; 61(6): 1336-49,* [6]*Jeurissen et al. HBM 2010; DOI: 10.1002/hbm.21032*



^ Fig 1: *A) T2 weighted image. B) Non-weighted diffusion image. C) Color coded FA map. D) DTI based tractography. E) CSD based tractography F) Fiber tractography of the left part of the iliococcygeus and the pubococcygeus; top panel: DTI; bottom panel: CSD. G) Fiber tractography of the anal sphincter; left two panels: DTI; right two panels: CSD. The rectangles in A, B, and C represent the region tracked in D and E. The regions indicated with a # show "kissing" muscle fibers and the regions indicated with a * contain highly curved muscle fibers.*



^ Fig 2: *Glyphs showing the fiber orientation the DTI and CSD models. DTI ellipsoids are shown in transparent white, with the primary diffusion direction represented by a white tube. The red, green and blue CSD glyphs represent voxels containing 1, 2, and 3 diffusion directions, respectively. The lines schematically represent the DTI (white) and CSD (yellow) reconstructed tracts. A) Sagital view of the region where the iliococcygeus and the pubococcygeus cross. B) Axial view of the anal sphincter. Notice that the highly curved regions typically show CSD glyps with 2 or more diffusion directions.*