Diffusion tensor imaging of the lumbar and sacral plexus in post mortem subjects

Wieke Haakma[1,2], Michael Pedersen[3], Martijn Froeling[2], Lars Uhrenholt[4], Jeroen Hendrikse[2], Alexander Leemans[5], and Lene Warner Thorup Boel[4]
[1]*Department of Forensic Medicine & Comparative Medicine Lab, Aarhus University, Aarhus, Central Denmark, Denmark,* [2]*Department of Radiology, University Medical Center Utrecht, Utrecht, Utrecht, Netherlands,* [3]*Department of Comparative Medicine Lab - Clinical Institute, Aarhus University, Central Denmark, Denmark,* [4]*Department of Forensic Medicine, Aarhus University, Aarhus, Central Denmark, Denmark,* [5]*Image Sciences Institute, University Medical Center Utrecht, Utrecht, Netherlands*

Audience: Clinicians and researchers interested in the visualization of nerves with diffusion tensor imaging in post mortem subjects

Background and purpose: Diffusion tensor imaging (DTI) allows evaluation of microstructural properties of tissue and therefore is an emerging imaging technique to investigate post-mortem (PM) tissue. However DTI of PM nervous tissue remains challenging, particularly due to PM autolysis which is occurring shortly after death. Combined with bacterial degradation, which facilitates tissue decomposition, nervous tissue will quickly degrade.[1] Therefore, most PM DTI research has been performed on formaldehyde fixated tissue. However, fixation changes the diffusion characteristics and reduces proton density as well as T2.[2] Moreover, PM studies have mainly focused on brain research.[1] Whether DTI can be used in peripheral nervous tissue such as the lumbar and sacral nerves PM remains to be shown. This information is relevant as it can be helpful in the PM identification of death-related injuries. Furthermore, it is expected to be helpful to better understand peripheral nerve pathologies as it can be combined with histology. In this work we investigate the feasibility of DTI to examine the nerves in the lumbosacral plexus after death in PM non-fixated subjects and to identify trauma in one case.

Methods: Six non-fixated PM subjects with normal anatomy of the lower spine were included; 5 men and 1 women (1-8 days after death) with a mean age of 44 years (range 30–55 years). In addition a female PM subject (35 years) with a crushed lower lumbar vertebrae occurred during life was included. Subjects were scanned at the level of the lumbosacral plexus on a 1.5 Tesla MR system (Achieva; Philips Healthcare, Best, The Netherlands) using a 16-channel phased-array surface coil. DTI was performed with diffusion-weighted spin echo single-shot echo planar imaging (EPI) in the coronal plane with the following parameters; TE = 82 ms, TR = 13538 ms, SENSE factor 2, number of excitations = 8, FOV 384 × 216 mm², matrix size 128 × 72, 35 slices with thickness = 3.0 mm, resulting in a voxel size of 3.0 × 3.0 × 3.0 mm³, EPI factor: 35, SPIR fat suppression, b-values 0 en 2000 s/mm², and 15 gradient directions. The total acquisition time was 29:06 minutes. This protocol was repeated 4 times. For anatomical reference, a 3D Turbo Spin Echo (3D-TSE) scan was acquired according to the protocol described by van der Jagt et al[3]. The DTI scans were concatenated into one dataset. Fiber tractography (FT) was performed with the diffusion MRI-toolbox *ExploreDTI* to determine the fractional anisotropy (FA), mean diffusivity (MD), axial diffusivity (AD), and radial diffusivity (RD) of the lumbar and sacral nerves. As a reference, 6 healthy living controls with a mean age of 30 years (range 25-42 years), were scanned on a 3 Tesla Philips MRI scanner. Nerves at the level of L3 to S2 for FA, MD, AD, and RD were compared between PM subjects and healthy controls with the non-parametric Mann-Whitney U test.

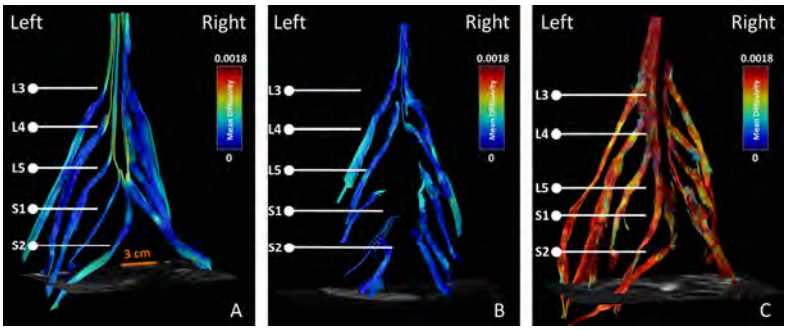

Figure 1: Lower lumbar and sacral nerves color coded with mean diffusivity, A) post-mortem, B) post-mortem subject with spinal cord injury with disorganization of spinal nerve roots, C) healthy living control

Results: This DTI study was able to reconstruct the 3D architecture of the lumbar and sacral plexus in all 7 PM bodies, detailing the individual pathway trajectories and the microstructural properties of L3-S2. The FT results were similar to in vivo measurements in healthy adults (see figure 1). In cases where the nerves and cauda equina were exposed during autopsy the FT results were similar in architecture found during autopsy (see figure 2).
Diffusion values showed a higher FA in PM cases ($p<0.05$). MD, AD and RD values were approximately 4 times lower than in vivo results (see table 1).
In one case disorganization of the nerves at the lower lumbar level was found (figure 1B). Here, the lower lumbar vertebrae was crushed due to trauma during life, years before death occured. Clinical background information of this case showed incontinence problems and less sensibility in the legs. This is comparable to the results found in spina bifida patients described by Haakma et al[4].

Table 1 Diffusion parameters (FA, MD, AD, and RD) of PM and in vivo healthy controls

Nerve	Diffusivity (mm^2/s) x 10^{-3}							
	FA		MD		AD		RD	
	In vivo	PM	In vivo	PM	In vivo	PM	In vivo	PM
L3**	0.27±0.05	0.33±0.07	1.47±0.16	0.35±0.05	1.90±0.17	0.48±0.05	1.25±0.16	0.29±0.05
L4**	0.27±0.04	0.33±0.07	1.43±0.17	0.36±0.05	1.84±0.18	0.49±0.05	1.22±0.17	0.29±0.05
L5**	0.29±0.03	0.35±0.06	1.41±0.17	0.36±0.03	1.87±0.19	0.51±0.04	1.18±0.16	0.29±0.03
S1**	0.26±0.04	0.31±0.06	1.47±0.17	0.38±0.05	1.89±0.16	0.51±0.05	1.26±0.17	0.31±0.06
S2**	0.25±0.03	0.29±0.06	1.49±0.10	0.38±0.06	1.88±0.12	0.50±0.07	1.29±0.10	0.31±0.06

** At all levels for each diffusion value in vivo vs PM: $p<0.05$

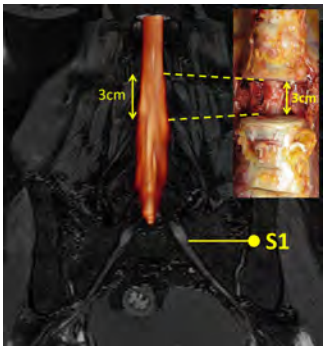

Figure 2: 3D TSE image with nerve tracts of the cauda equina found with FT (vertebrae not shown) and the matching images of the autopsy

Conclusion: This DTI study shows the feasibility of DTI to identify the architecture of the lumbar and sacral plexus in 7 PM bodies with DTI and FT. We demonstrate the difference in diffusion parameters between in vivo and PM nervous tissue. The architectural configuration of the nerves and cauda equina found on the DTI images was equivalent to the visual examination during autopsy. Disorganization of the nerves in the trauma case showed the potential of DTI and FT to be used to identify nerve injuries PM. The observed differences in MD, AD and RD are presumed to be caused by temperature difference[5] and PM changes of the nervous tissue. DTI PM allows the possibility to identify other peripheral nerve pathologies which can be helpful in the contribution of better understanding pathogenesis and disease progression as it can be compared with histology and other techniques. We expect that this technique can provide a valuable contribution to the identification of nerve injuries in complex PM trauma cases.

References:

[1] D'Arceuil et al. Neuroimage. 2007;36(1):64-8; [2] Miller et al. Neuroimage. 2011;57(1):167-81; [3] van der Jagt et al. Neuroimage. 2012;62(3):1792-9;
[4] Haakma et al. Journal of Urology. 2014; [5] D'Arceuil et al. Neuroimage. 2007;35(2):553-65