Localising unilateral lumbosacral radicular pain through Diffusion Tensor Imaging: an experimental study

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Main category: **Quality, Quantitation, and Validation**

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Introduction (1292 chars)

Unilateral lumbosacral radicular pain is common, but accurately diagnosing it remains difficult [1]. Conventional macroscopic anatomical MRI (T1- and T2-weighted sagittal and axial sequences) produce a notable number of false positives or false negatives, resulting in discrepancies between MRI findings and patient symptoms [2-7]. In contrast, microstructural MRI, such as Diffusion Tensor Imaging (DTI), can reveal pathological changes in the form of reduced fractional anisotropy (FA) in the affected lumbosacral nerve, even in the absence of overt nerve compression [6-12]. However, there is no consensus yet on the optimal DTI protocol for reliably identifying symptomatic nerve roots [13].

In this experimental study, we aim to identify the most reliable DTI acquisition strategy for the robust visualization and segmentation of the lumbosacral nerve roots (LNR) (L3–S1), with the ultimate goal of enabling quantification of the extent of unilateral damage associated with radicular pain. We scanned healthy controls using multiple spinal cord DTI protocols and evaluated how well each protocol preserved anatomical normality. Additionally, we examined the effect of two distinct DTI processing pipelines to assess the relative impact of pipeline's strategies on tractography results.

Materials & Methods

Seven healthy volunteers were scanned on a 3T Siemens Prisma system at the GIGA *In Vivo* Imaging platform, GIGA Institute, University of Liège, Belgium. Three different DTI protocols were considered (Table 1). ZOOMit showed higher anatomical detail but longer scan time (~35 min), while Coronal was fastest (~7 min). Due to time constraints, only two protocols were applied per subject, with each tested in four volunteers (Table 2).

Table 1: DTI Acquisition Parameters Across Protocols

Parameter	**Standard axial DTI**	**ZOOMit axial DTI**	**Coronal DTI**
Acquisition Type	Axial	Axial (reduced FOV)	Coronal
Spatial Resolution (mm^3)	$2 \times 2 \times 2$	$2.5 \times 2.5 \times 2.5$	$2.5 \times 2.5 \times 2.5$
FOV (mm^2)	200×200	217×174	320×320
Matrix Size	100×100	124×87	128×128
TR / TE (ms)	9800 / 55	10900 / 74	4400 / 48
b-values (s/mm^2)	0, 600	0, 800	0, 800
b-directions (#)	30	30	30
Duration (minutes)	15	35	7

Table 2: Scanned Healthy Controls

Healthy Control	**Standard axial DTI**	**ZOOMit axial DTI**	**Coronal DTI**
HC 1	Yes	No	No
HC 2	Yes	No	Yes
HC 3	No	Yes	Yes
HC 4	No	No	Yes
HC 5	Yes	Yes	No
HC 6	Yes	Yes	No
HC 7	No	Yes	Yes
Total	4	4	4

Two different DTI pipelines were examined to evaluate the impact of preprocessing on tractography: “SCT” and “our”. The former uses the MOCO algorithm [17], while the latter consists of denoising [19], correction for Gibbs ringing artifacts [20], correction of distortions due to susceptibility, head motion, and eddy currents [21]. “None” refers to a baseline case with no preprocessing. Tractography was performed using MRtrix3's tckgen algorithm [22]. We estimated FA using DTIFIT in FSL with weighted linear least squares [23]. The FA symmetry score was computed by multiplying the FA map and tract density map voxel-wise, then summing the weighted values separately for the left and right hemispheres (Figure 1).

Results & Discussion

Figure 1 shows left–right FA symmetry for the L3 to S1 nerve roots. Results are grouped by DTI protocol (*Standard axial, ZOOMit axial, Coronal*) and preprocessing pipeline (*none, SCT, our*). Substantial differences are observed across both protocols and pipelines. The combination of *ZOOMit* and *our* pipeline provided on average the highest FA symmetries for L3, L4, and L5. However, the *Coronal DTI* protocol combined with the *our* pipeline provided the highest FA symmetries for S1.

Figure 2 shows representative tractography results of the lumbosacral nerve roots using the three examined DTI protocols. Notable differences in streamline density and anatomical coherence are observed across protocols, with ZOOMit axial DTI yielding the highest coverage but also more spurious tracts.

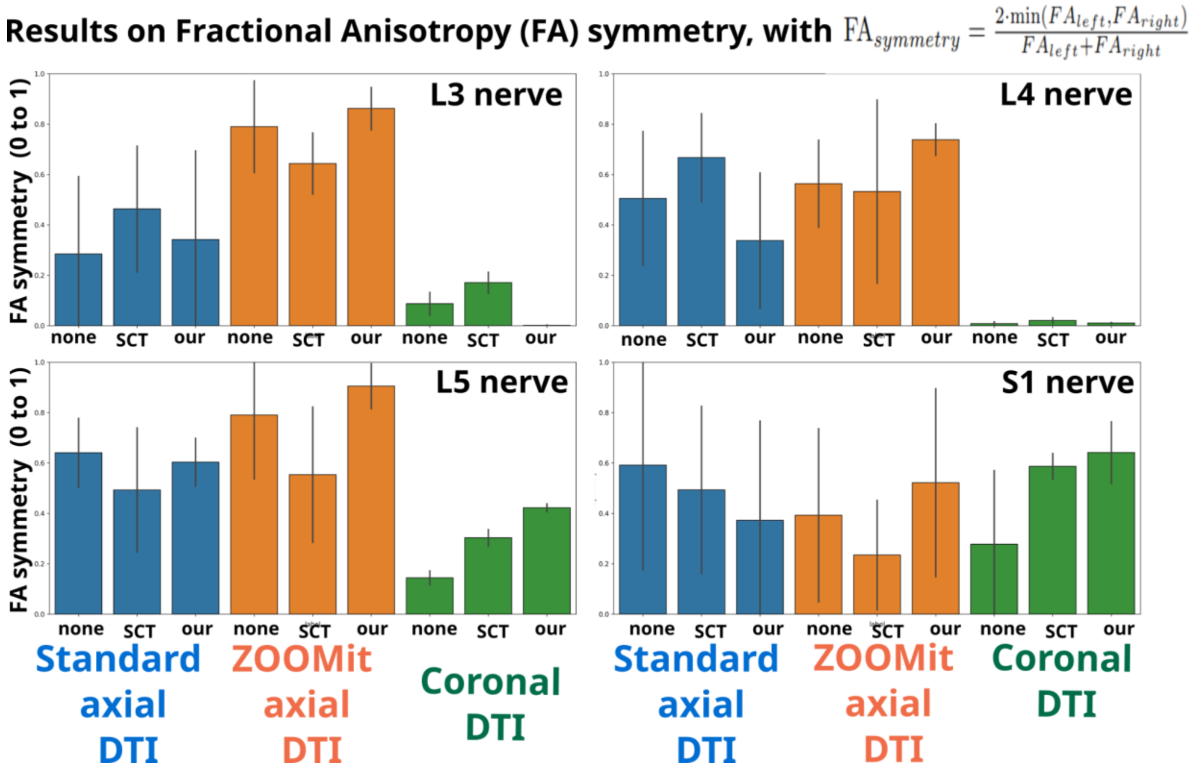

Figure 1.

Left–right FA symmetry across DTI protocols and pipelines for L3–S1 nerves, highlighting protocol- and pipeline-dependent variability.

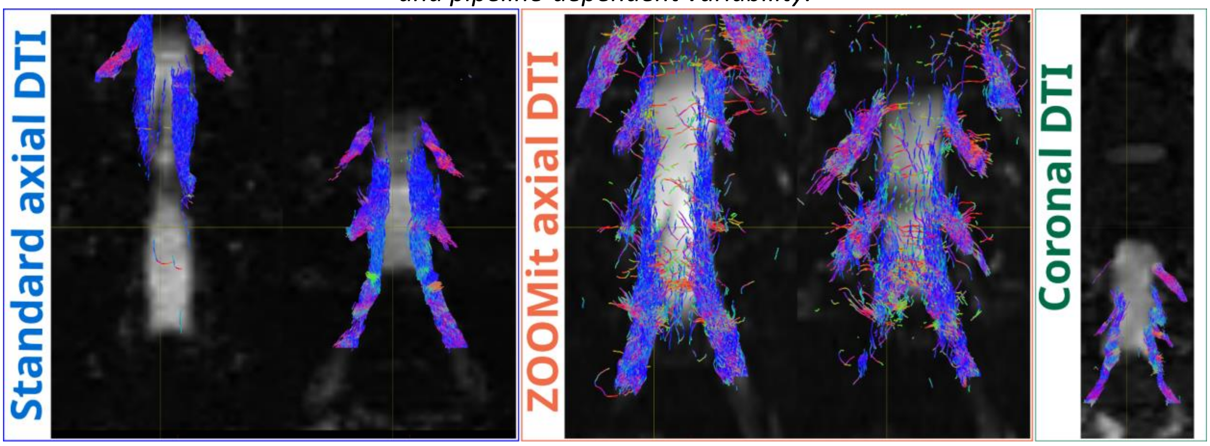

Figure 2.

Exemplar tractography results in a coronal view across DTI protocols.

Discussion

This study shows that the choice of DTI acquisition protocol has a substantial impact on tractography outcomes and left–right FA symmetry. The visibility and reconstruction quality of specific lumbosacral nerves varied across protocols: the ZOOMit axial DTI provided the most consistent and detailed tractography for the L3 nerve, while both the ZOOMit and Standard axial protocols performed comparably well for L4 and L5. In contrast, the S1 nerve was reconstructed with similar reliability across all three protocols. Notably, the ZOOMit protocol exhibited increased sensitivity to spurious streamlines, emphasizing the need for careful parameter tuning to minimize false positives. Between the two preprocessing pipelines evaluated, our in-house method yielded slightly better performance than the SCT pipeline. While this experimental analysis was conducted on a limited number of subjects, it offers a practical framework for optimizing DTI-based imaging of the lumbosacral nerve roots. Future studies involving larger cohorts are warranted to validate these findings and to further refine protocol selection for clinical and research applications.

Conclusion

In conclusion, our findings highlight that the choice of DTI acquisition protocol has a more significant impact on tractography and FA symmetry of the lumbosacral nerve roots than the choice of processing pipeline. ZOOMit provided the best anatomical detail for L3–L5, while all protocols performed similarly for S1. Careful tuning of tractography parameters and thoughtful pipeline selection remain essential.

Data and Code Availability Statement

The datasets generated and/or analyzed during the current study are not publicly available, but are available from the corresponding author upon reasonable request. The custom code used for diffusion MRI preprocessing and tractography is based on publicly available packages (e.g., MRtrix3, FSL, SCT) with additional scripts developed in-house. These scripts are available upon reasonable request and will be made publicly accessible on [e.g., GitHub] upon publication.

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