Magnetic resonance tractography of the lumbosacral plexus
Step-by-step
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Abstract
MR tractography of the lumbosacral plexus (LSP) is challenging due to the difficulty of acquiring high quality data and accurately estimating the neuronal tracts. We proposed an algorithm for an accurate visualization and assessment of the major LSP bundles using the segmentation of the cauda equina as seed points for the initial starting area for the fiber tracking algorithm.

Twenty-six healthy volunteers underwent MRI examinations on a 3T MR scanner using the phased array coils with optimized measurement protocols for diffusion-weighted images and coronal T2 weighted 3D short-term inversion recovery sampling perfection with application optimized contrast using varying flip angle evaluation sequences used for LSP fiber reconstruction and MR neurography (MRN).

The fiber bundles reconstruction was optimized in terms of eliminating the muscle fibers contamination using the segmentation of cauda equina, the effects of the normalized quantitative anisotropy (NQA) and angular threshold on reconstruction of the LSP. In this study, the NQA parameter has been used for fiber tracking instead of fractional anisotropy (FA) and the regions of interest positioning was precisely adjusted bilaterally and symmetrically in each individual subject.

The diffusion data were processed in individual L3-S2 nerve fibers using the generalized Q-sampling imaging algorithm. Data (mean FA, mean diffusivity, axial diffusivity and radial diffusivity, and normalized quantitative anisotropy) were statistically analyzed using the linear mixed-effects model. The MR neurography was performed in MedINRIA and post-processed using the maximum intensity projection method to demonstrate LSP tracts in multiple planes.

FA values significantly decreased towards the sacral region (P < .001); by contrast, mean diffusivity, axial diffusivity, radial diffusivity and NQA values significantly increased towards the sacral region (P < .001).

Fiber tractography of the LSP was feasible in all examined subjects and closely corresponded with the nerves visible in the maximum intensity projection images of MR neurography. Usage of NQA instead of FA in the proposed algorithm enabled better separation of muscle and nerve fibers.

The presented algorithm yields a high quality reconstruction of the LSP bundles that may be helpful both in research and clinical practice.

Abbreviations: AD = axial diffusivity, CE = cauda equina, DTI = diffusion tensor imaging, DWI = diffusion-weighted imaging, FA = fractional anisotropy, LSP = lumbosacral plexus, MD = mean diffusivity, MIP = maximum intensity projection, MRN = MR neurography, MRT = MR tractography, NQA = normalized quantitative anisotropy, PNS = peripheral nervous system, RD = radial diffusivity, ROI = region of avoidance, ROI = region of interest, SDF = spin distribution function, STIR = short-term inversion recovery, λ1, λ2, and λ3 = eigenvalues.

Keywords: cauda equina, diffusion tensor imaging, lumbosacral plexus, MR neurography, MR tractography, peripheral nerves...
1. Introduction

Although conventional techniques of magnetic resonance imaging (MRI) play a crucial role in examining the peripheral nervous system (PNS), they are not capable of providing any information about functional properties of the peripheral nerve tracts and the orientation and localization of axons. However, other MR methods, such as diffusion-weighted imaging (DWI), diffusion tensor imaging (DTI), MR tractography (MRT) and MR neurography (MRN),[11-4] may enable the evaluation of these functional and structural properties. DWI is based on the diffusion of water molecules in tissues. DTI is a form of DWI, which models diffusion by tensor, mathematically described as a symmetric 3 × 3 matrix that characterizes diffusion in 3D space (measured in 6 or more different directions) and graphically represented by an ellipsoid or an orientation distribution function (ODF). Diffusion tensor can be described by its eigenvectors and eigenvalues (λ1, λ2, and λ3) from which the currently used diffusion indices are derived.[15]

Both DWI and MR tractography are promising methods that can be used to assess the microstructure of axonal bundles and to depict axonal integrity and the degeneration and regeneration of both normal and pathological peripheral nerves based on diffusion properties of the PNS tissue. The PNS pathological changes can modify the integrity of axonal tracts leading to diffusion-detectable changes.[8] These changes in the PNS microstructural environment lead to changes of diffusion indices such as fractional anisotropy (FA), mean diffusivity (MD), axial diffusivity (AD), and radial diffusivity (RD).[9] FA is the most commonly used parameter derived from DTI data, ranges from 0 (isotropic diffusion, e.g., cerebrospinal fluid) to 1 (maximum anisotropy). For tissues with high spatial diffusion anisotropy (neuronal or muscle fibers), FA can be a proxy of a microstructural integrity of the structure. Mean diffusivity is the average of the λ1, λ2, and λ3 (MD = (λ1 + λ2 + λ3) / 3) and is related to the amount of molecular diffusion in the extracellular space. Axial (parallel) diffusivity (also known as principal direction of diffusion PDD) is equal to the major λ1 (AD = λ1) and measures water diffusion along the main axis of the diffusion ellipsoid. Radial (perpendicular) diffusivity is the average of the 2 minor λ2 and λ3 (RD = λ2 + λ3) / 2.

MRN is another method providing an accurate assessment of 3D anatomy of the PNS bundles. Acquired 3D images can be post-processed using the maximum intensity projection method (MIP) to highlight the imaging abnormality (e.g., peripheral nerve entrapment neuropathy or muscle denervation syndromes) and to demonstrate PNS tracts in multiple planes. MRN techniques provide a better depiction of peripheral nerve anatomy using high resolution 2D and 3D imaging sequences due to optimized contrast between the nerves and surrounding tissues.[10]

MR tractography has been established in the brain imaging and found its widespread use in various brain studies.[11,12] MRT is an advanced MRI technique using DWI data to quantitatively evaluate and visually represent neuronal fibers (e.g., psoas major muscle, PMM) as both structures have similar fractional anisotropy values.[17,18] As a consequence, muscles often contaminate calculated peripheral nerve fibers that, in turn, exhibit as rather thick bundles. Different factors such as lower signal-to-noise ratio, lack of fat and blood suppression, spatial resolution, movement of the subject under examination, inappropriate choice of coils are involved in the quality of the acquired data. Furthermore, there is no gold standard for post-processing data and MRT reconstruction techniques in this area.

One of the interesting targets for PNS imaging is the lumbosacral plexus (LSP). Lumbosacral neuropathies are very frequent. Different etiologies such as compression, inflammation, tumours and other factors may be involved in the development of the LPS neuropathies.[19,20] The patients could benefit from a detailed visualization and characterization of the course of LSP bundles in 2 ways. Firstly, the understanding of the detailed configuration of bundles in the affected regions would help in presurgical planning; secondly, the follow-up examinations could help assess the healing process. The latter is of significant interest mainly for the research of the operative or conservative approaches to LSP defects treatment.

Published results suggest significant differences of diffusion parameters between healthy and impaired nerve bundles as well as mild differences between individual healthy nerves (L4-S2).[21,22] Therefore, in order to assess the fiber integrity a comparison of the evaluated diffusion parameters with the corresponding parameters evaluated in the contra-lateral side is usually performed.

The aim of this study is to propose an algorithm for an accurate assessment of the major LSP bundles using the segmentation of the CE as seed points along with an iterative placement of 2 regions of interest (ROIs) and 1 regions of avoidance (ROA). In this study, the normalized quantitative anisotropy (NQA) parameter has been used for fiber tracking instead of FA. Quantitative anisotropy (QA) is measuring the density of anisotropic diffusing water along a fiber pathway and is robust to partial volume of crossing fibers.[23,24] The fiber bundles reconstruction was optimized in terms of eliminating the muscle fibers contamination using the segmented CE as seed points, the effects of the normalized quantitative anisotropy (NQA) and angular threshold on reconstruction of the fiber bundles.

This study presents the visualization of LSP structures in healthy controls using MR tractography combined with high-resolution 3T MR neurography.

2. Materials and methods

2.1. MRI data acquisition

Twenty six healthy volunteers [(11 females, 15 males, mean age of 33.8 ± 9.5 years (range 19–50 years)] underwent MRI examinations in the supine position on a 3T MR scanner (Siemens Trio TIM, Erlangen, Germany) using 2 12-channel phased-array body coils with the following optimized measurement protocol for:

1) Diffusion-weighted images using the single-shot echo-planar imaging sequence used for PNS fiber reconstruction, and 2) Coronal T2 weighted 3D STIR (short-term inversion recovery) (sampling perfection with application optimized contrast using varying flip angle evaluation) sequence used for high-resolution MR neurography. All sequence parameters are summarized in Table 1. All volunteers were asymptomatic with no relevant
medical history. MR data were checked by 2 radiologists to exclude any pathology. All participants were informed about the purpose of the study and signed their written consent prior to the examination. The objective and protocol of the study were approved by the local ethical committee of the Institute for Clinical and Experimental Medicine and Thomayer Hospital (G-16-06-08).

2.2. Data processing

The DWI data were firstly corrected for distortions and eddy current effects using an eddy tool (a part of FSL - https://www.ncbi.nlm.nih.gov/pubmed/26481672). Afterwards, the data were reconstructed using the DSI studio (http://dsi-studio.labsolver.org/) with the Generalized Q-sampling imaging - Q-sampling imaging algorithm[23] The Q-sampling imaging method is a model-free reconstruction that can be applied to any diffusion sampling scheme (single-shell or multiple-shell), and provides a quantitative anisotropy parameter, which is based on the spin distribution function (SDF) of diffusing water at different orientations. SDF is a kind of diffusion orientation distribution function and is the density of diffusion of water in different orientations, provided by the high order models which are able to correctly evaluate voxels with multiple fiber populations[25] (Fig. 1).

The fiber bundles reconstruction was optimized in terms of eliminating the muscle fibers contamination. The effects of the normalized quantitative anisotropy (NQA) and angular thresh-

| Parameters of a coronal T2 weighted 3D short-term inversion recovery (3D STIR SPACE) sequence used for high-resolution MR neurography, and diffusion-weighted single-shot echo-planar imaging (ss-EPI) sequence used for PNS fiber reconstruction. |
|---------------------------------|-----------------|
|                                | 3D STIR SPACE   | ss-EPI          |
| Repetition time [ms]           | 1500            | 11100           |
| Echo time [ms]                 | 100             | 79              |
| Inversion time [ms]            | 200             | NA              |
| b-value [s/mm²]                | NA              | 0/700           |
| Slice thickness [mm]            | 1               | 3               |
| In-plane resolution, [mm²]     | 1 × 1           | 3 × 3           |
| orientation                    | Coronal         | Transversal     |
| No. slices                     | 160             | 100             |
| Bandwidth [Hz/Px]              | 592             | 3002            |
| Acceleration factor of PAT (GRAPPA) | 2               | 2               |
| Field of view [mm²]            | 384 × 384       | 384 × 264       |
| Echo spacing [ms]              | 3.58            | 0.69            |
| Number of gradient directions  | NA              | 30              |
| Number of signal averages      | 1               | 2               |
| Total scan time [min]          | 10:00           | 12:03           |

Figure 1. The diffusion orientation distribution function (ODF) obtained from Q-sampling imaging. The ODF map (A) and details of zoomed voxels with multiple fiber population and with ODF shape (B) to give the reader estimation of the diffusion modeling along the lumbar roots.
old on reconstruction of the fiber bundles are shown in Figure 2. The resulting algorithm is described below step by step and it is also illustrated and complemented by a flowchart (Figs. 3 and 4). All regions of interest were manually selected based on anatomical knowledge of the PNS and muscles using a normalized quantitative anisotropy map.

Firstly, the CE was segmented from the b = 0 images using the ITK-SNAP Medical Image Segmentation Tool (http://sourceforge.net/projects/itk-snap/). Thereafter, the segmented CE was used as a set of seed points to reconstruct the major pathway roots of lumbosacral bundles. To reduce the contamination by the main muscle fibers to a minimum, the deterministic streamline fiber tracking algorithm was performed with the following tracking parameters: NQA was set to 0.1 (1–2 times greater than the initial NQA default value in the DSI studio), the angular threshold of 30°, the step size of 1 mm, and the primary orientation and subvoxel seeding (a total of 1,000,000 seeds at random subvoxel positions) were set in order to visualize the major fiber roots (Figs. 3A to C).

Secondly, for reconstruction of L3 nerves, 2 additional ROIs and one ROA were used. One region was placed proximally (ROI-1) at the level of the L3/L4 intervertebral disk and one region (ROI-2) was placed distally along the L3 nerve. The ROA was always placed under the subsequent intervertebral level to eliminate the nerve bundles originating in the lower level roots (i.e., when reconstructing L3 roots, the ROA was placed under the L3/L4 disk, Fig. 3D to G). Finally, fiber tracking was performed with the decreased NQA threshold set down to 0.02 and the angular set to the value of 45 degrees (Figs. 3D to H). It should be noted that the finally selected parameters are constant across subjects.

The above steps were repeated for the reconstruction of the remaining lumbosacral plexus bundles. The result of LSP reconstruction is shown in Figure 3I (for details, see Supplemental Digital Content with a video, http://links.lww.com/MD/F641) and can be visually compared with 3D MIP-STIR neurography (Figs. 5A-C).

The time required to generate a full tractogram is about 30 to 40 minutes.

MR neurography images have been reconstructed in Med-INRIA (http://med.inria.fr/) and enhanced using MIP projection. Mean values of FA, MD, AD, RD, and NQA of the studied nerve bundles were calculated in each subject for each bundle (L3-S2, referred to as locality below) and both sides (left and right, referred to as laterality below).

2.3. Statistical analysis

To evaluate the dependency of diffusion indices on locality and laterality, while accounting for age and sex, the data were statistically analyzed by the linear mixed-effects model using the R framework with the package nlme. Separate models for dependent variables NQA, FA, MD, AD, and RD were computed. Each model contained following explanatory variables: locality, laterality, interaction of locality and laterality, age, and sex. The character of the data (multiple data points per 1 subject) implies internal correlation in the data. This repeated-measures character of the data violates basic assumptions for statistical modelling. To remedy this, subject-specific offset was modelled as a random effect and linear mixed-effects model was used for analysis. To fulfill assumptions of statistical models (normal distribution of errors), the residuals of the models were inspected and checked. When needed, dependent variables were transformed to improve normality of model residuals. A Box-
Cox transformation\textsuperscript{[28]} for data transformation was used. Standard method of model simplification (sequential removing of non-significant terms in the model until all remained terms are significant), a method commonly used in context of statistical modeling, was applied.

3. Results

The optimized measurement protocol proved to be robust and the quality of diffusion and neurography data was sufficient for the reconstruction of lumbosacral bundles in all examined subjects. This is illustrated in Figure 5, where representative diffusion and neurography images acquired in the healthy subject are shown. The proposed algorithm efficiently tracked L3–S2 nerves in all subjects.

The mean FA, MD, AD, RD, and NQA values calculated in individual L3-S2 nerve fibers in all examined volunteers in the left and right hand side with their standard deviations are shown in Table 2.

Figure 5. The individual steps (A to I) of the reconstructed fiber bundles L3-S2 in detail in a 19-year-old healthy woman. NQA (A): normalized quantitative anisotropy map, ROI: region of interest, ROA: region of avoidance. L indicates left, R, right. A: Segmented cauda equina (SCE) was used as seed points for the initial starting area for the fiber tracking algorithm within these seeding regions at subvoxel resolution. A to C: Reconstruction of the major pathway roots of the lumbosacral plexus (LSP) using the SCE with NQA of 0.1 and angular thresholding of 30°. D to H: Reconstruction of the L3 nerves using additional 2 ROIs (1 placed proximally (ROI-1) at the level of the L3/L4 intervertebral disk (above the root of L3) and 1 distally (ROI-2)) along the pathway of the nerve and 1 ROA under the root of L3 with decreasing NQA threshold to the 0.02. I: The above steps were repeated for the reconstruction of the remaining fiber bundles (L4-S2). For details, see Supplemental Digital Content, http://links.lww.com/MD/F641.

The results of the linear mixed-effects model are depicted in the graphical form in Figure 7. Plots with observed values versus locality together with prediction curves computed for the fixed average age are presented. The results show that the FA values significantly decrease towards the sacral region ($P < .001$). By contrast, the MD, AD, RD and NQA values significantly increase towards the sacral region ($P < .001$). For NQA/location dependence the linear slope with a significance level of below 0.001 was identified. The effect of laterality, interaction of laterality and locality, age and sex were not significant.

4. Discussion

Previous MR tractography studies of the lumbosacral plexus used several regions of interest along the nerve pathway and fiber tracking was performed with the FA threshold\textsuperscript{[29–31]} However, due to the direct proximity of skeletal muscles and peripheral nerves and the similar FA values of both tissues,\textsuperscript{[17,18,32]} there is a high contamination risk from muscle fibers when MR tractog-
raphy of the LSP bundles is performed. It also relies on spatial resolution and algorithm type that separation of 2 structures becomes difficult. The muscle contamination turns out to be the greatest issue in reconstructing PNS in the lumbar region. Indeed, several performed studies present reconstructed LSP bundles that may show muscle contamination.\[31,33,34\] This may be attributed to the lower signal-to-noise ratio or different processing methodology leading to suboptimal visualization quality of the reconstructed bundles. In our study, we propose an innovative approach to minimize the impact of muscle fibers on LSP reconstruction. To the best of our knowledge, this is the first work reporting on how to reconstruct step by step the LSP bundles using the segmentation of the cauda equina as seed points and the effects of the normalized quantitative anisotropy (NQA) and angular threshold on reconstruction of the fiber bundles. As is apparent from the resulting reconstructed fibers in Figure 2 and Figure 3, the presented method enables clear reconstruction of LSP bundles. Moreover, by inspecting the course of the reconstructed nerves in the MR neurography and 3D T2 STIR images it was confirmed that the reconstructed nerves closely correspond with the nerves visible in the MIP images and that no significant muscle contamination is present (see Fig. 5). However, when assessing the quality of the fiber tracts compared to the nerve geometry in the 3D T2 STIR images it should be noted that the quality of diffusion data is a crucial determinant of the success. Diffusion data quality depends on different factors such as signal-to-noise ratio, spatial resolution; eddy currents induced geometric distortions and motion artifacts, pulsation artifacts, sequence parameters and choice of used coils.\[35,36\] During the optimization of the algorithm it turned out that the proper combination of the cauda equina as seed points along with an iterative placement of 2 ROIs and 1 ROA, and angular threshold setting as described in the method section are crucial for the exact fiber pathway estimation.

In this study, the NQA parameter has been used for fiber tracking instead of FA. The motivation was the outcome of the study that showed that QA-aided tractography had better resolution (lower sensitivity to partial volume effects) than the FA-aided tractography.\[24\] Also normalization of QA can help stabilize the spin density measurement across subjects. However, the presented algorithm can be applied in other extensively used fiber tracking routines with the FA threshold.

Assessment of the peripheral nerve degeneration and regeneration is important in clinical research of various peripheral nerve disorders including traumas and neuropathies.\[37\] The early determination of the potential for the nerve to regenerate

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**Figure 4.** A flowchart describing the proposed algorithm for MR tractography of the lumbosacral plexus. CE = cauda equina, NQA = normalized quantitative anisotropy.

**Figure 5.** The diffusion orientation distribution function obtained from the Q-sampling imaging (A), and 3D STIR image (B) fused with the MR tractography image. Images (A) and (B) show the architectural configuration of the reconstructed fiber bundles (L3-S1). The image (C) shows the corresponding results of MR neurography reconstruction from a coronal 3D dataset in 19-year old healthy woman.
spontaneously is crucial for planning possible surgical intervention. Although clinical examinations and electromyography measurements may aid in evaluating the nerve functional status they suffer from various shortcomings such as pure localization of the injured nerves. Conversely, the visualization of the PNS using 3D MR neurography offers high spatial resolution; however, it lacks the possibility of evaluating the nerve tracts integrity quantitatively. An excellent MRN neurogram can be obtained using a contrast agent[38] however; it cannot be used in patients with kidney or liver disorders.

The calculated FA, MD, AD, RD, and NQA values given in Table 2 are in line with the published results. The observed significant decrease of the FA values and an increase of the MD values towards the sacral region (P < .001) confirm the results published by the former study.[18] In the studied region, the dependence appears approximately linear. Although the observed decrease of the FA values has been reported by several studies, no explanation for this behavior has been afforded. The variable diffusion properties in nerve bundles with different locality may be attributed to the increasing average diameter of nerve roots from L1 to S1.[39,40] Contrary to the FA values, a significant increase of the NQA values was observed towards the sacral region. This finding may be explained by the different physical meaning of both FA and QA.[25] Fractional anisotropy is based on the diffusivity (a measure of how fast water diffuses, defined for each voxel) in the diffusion tensor model, whereas QA is based on the SDF and quantifies spin population which undergoes diffusion in specific direction and hence has a very different meaning.

It should be noted that already the first step of the presented evaluation algorithm - using the cauda equina as seed points-provides a superior depiction of spinal nerve roots. The measurement and evaluation of the peripheral nerves bundles is challenging due to movement and blood pulsation artifacts.

Table 2

| subjects (n = 26) | FA_L  | MD_L (mm²/s × 10⁻³) | AD_L (mm²/s × 10⁻³) | RD_L (mm²/s × 10⁻³) | NQA_L |
|------------------|-------|---------------------|---------------------|---------------------|-------|
|                  | mean ± SD | mean ± SD | mean ± SD | mean ± SD | mean ± SD |
| L3               | 0.27 ± 0.05 | 1.47 ± 0.19 | 1.83 ± 0.20 | 1.28 ± 0.20 | 0.07 ± 0.02 |
| L4               | 0.24 ± 0.04 | 1.82 ± 0.28 | 2.21 ± 0.31 | 1.63 ± 0.27 | 0.09 ± 0.04 |
| L5               | 0.23 ± 0.04 | 1.96 ± 0.35 | 2.35 ± 0.39 | 1.77 ± 0.33 | 0.20 ± 0.04 |
| S1               | 0.21 ± 0.04 | 2.16 ± 0.33 | 2.56 ± 0.34 | 1.96 ± 0.33 | 0.13 ± 0.04 |
| S2               | 0.22 ± 0.05 | 2.10 ± 0.56 | 2.46 ± 0.62 | 1.91 ± 0.53 | 0.12 ± 0.06 |
| L3-S2 merged     | 0.23 ± 0.04 | 2.05 ± 0.32 | 2.45 ± 0.34 | 1.85 ± 0.31 | 0.11 ± 0.04 |
| FA_R            |       | MD_R               | AD_R               | RD_R               | NQA_R |
| L3               | 0.28 ± 0.06 | 1.41 ± 0.19 | 1.80 ± 0.21 | 1.22 ± 0.20 | 0.07 ± 0.03 |
| L4               | 0.26 ± 0.05 | 1.61 ± 0.27 | 2.00 ± 0.30 | 1.42 ± 0.26 | 0.08 ± 0.03 |
| L5               | 0.23 ± 0.04 | 2.00 ± 0.29 | 2.40 ± 0.32 | 1.80 ± 0.29 | 0.11 ± 0.04 |
| S1               | 0.21 ± 0.04 | 2.11 ± 0.31 | 2.52 ± 0.34 | 1.91 ± 0.30 | 0.13 ± 0.06 |
| S2               | 0.21 ± 0.04 | 2.07 ± 0.50 | 2.45 ± 0.55 | 1.88 ± 0.48 | 0.12 ± 0.05 |
| L3-S2 merged     | 0.23 ± 0.04 | 1.99 ± 0.30 | 2.40 ± 0.33 | 1.78 ± 0.29 | 0.11 ± 0.04 |

Mean fractional anisotropy (FA), mean diffusivity (MD), axial diffusivity (AD), radial diffusivity (RD) and normalized quantitative anisotropy (NQA) values with their standard deviations (SD) calculated in individual nerve bundles (L3-S2) in 26 examined healthy volunteers in the left (L) and right (R) side.

Figure 6. Quantitative anisotropy images (A, B). The ROIs (ROI-2) were placed bilaterally and symmetrically in each individual subject (e.g., for reconstruction L3 nerves. 2 additional regions of interest (ROI-1, ROI-2), and 1 region of avoidance (ROA) were used. The ROA was always placed under the subsequent intervertebral level to eliminate the nerve bundles originating in the lower level roots. SCE: segmented cauda equina.
however, this study shows that the identification of the LSP in superior quality is possible. The quality of the acquired diffusion data could be further improved using MR sequences with short acquisition time such as simultaneous multi-slice imaging.\textsuperscript{[41–44]}

In any case, we believe that the presented algorithm yields high quality reconstruction of the neuronal bundles in the lumbo-sacral plexus that may be helpful both in research and clinical practice. However, our study had several limitations. The main limitation

Figure 7. Scatterplots showing observed values of fractional anisotropy (FA), mean diffusivity (MD), axial diffusivity (AD), radial diffusivity (RD), and normalized quantitative anisotropy (NQA) plotted as a function of locality. Prediction curves computed for fixed average age and separately for the left and right side are shown as solid lines. L indicates left, R-right, m-males, f-female. MD, AD, and RD expressed in units mm\textsuperscript{2}/s × 10\textsuperscript{-3}.
of our study is the lack of correlation between MR tractography and electromyography. The demonstration of a correlation between MR tractography and electromyography would reinforce the clinical relevance and the objective importance of the proposed method. Another limitation is the missing patient group in this study. Also, multiple b-values should be used to improve the accuracy of the DWI-derived parameters.

To conclude, we improved an algorithm for fiber tractography of the LSP and tested it in vivo. Reconstructed tracts correspond with the nerves visible in the MIP images of MR neurography. The proposed algorithm represents a robust method for evaluation of LSP tracts.

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Author contributions
Ibrahim Ibrahim: designed the study and wrote the paper, Antonín Škoch: performed a statistical analysis of the diffusion data, reviewed the manuscript, Vit Herynek: reviewed the manuscript, Filip Jíru: reviewed the content, and Jaroslav Tintěra contributed to the acquisition of MRI.

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