Letter to the Editor

A note on the mapping and quantification of the human brain corticospinal tract

ARTICLE INFO

Keywords:
Diffusion tensor imaging
Tractography
Human brain
Motor pathways
Corticospinal tract
Medulla oblangata
Pons

ABSTRACT

Several diffusion tensor imaging tractography (DTT) have been adopted to construct the living human brain corticospinal tract. In this Note, we applied method "A" as recently described and used by "Lin CC, Tsai MY, Lo YC, et al. Reproducibility of corticospinal diffusion tensor tractography innormal subjects and hemiparetic stroke patients. Eur J Radiol 2013;82: e610–6." We compared the results obtained with method "A" with those obtained using an anatomy-guided method "B" on two healthy adults. We also quantified the results using tract volume, and corresponding fractional anisotropy, mean, and radial diffusivities. We demonstrate that accurate mapping and quantification of CST requires at least two regions of interest one at the level of the medulla oblongata, a second at the level of pons, this assures termination at the motor spine and contamination with cerebellar and sensory pathways.

Dear Editor,

We read with interest a recent study published in this Journal [1] in which the corticospinal tracts (CST) of healthy controls and chronic hemiparetic stroke patients was constructed using diffusion tensor tractography (DTT). Lin et al. [1] concluded that the fiber number derived from CST is less accurate than the corresponding mean diffusivity (MD) and fractional anisotropy (FA) which is consistent with previous reports [2]. They also showed that infarcted tracts are less reproducible in stroke patients compared to healthy subjects. There are some important issues related to the CST and its *in vivo* DTT that are worth emphasizing in view of this timely study [1].

First, over one half of the CST fibers originate from the primary motor cortex and the remainder arises from the premotor, supplementary motor areas and parietal cortices [3]. The CST then enters corona radiata merging with other corticofugal pathways such as corticobulbar, and corticopontine tracts [2–7]. The corticofugal pathways merge in the "posterior" limb of the internal capsule and continue into the midbrain cerebral peduncles whose ventral portion contains white matter called basis pedunculi [3,5]. The middle third of basis pedunculi contains CST and corticobulbar fibers together (see Fig. 1a). The CST fibers next descend through ventral pons, where they form scattered fascicles with other corticofugal pathways [3,5]. The CST fibers merge together on the ventral surface of the medulla, where corticopontine and corticobulbar pathways have already left the brainstem, to form medullary pyramids [2–8].

Currently, these fibers are not distinguishable on DTT acquired using 1–4 mm spatial resolution. The spatial resolution of the middle third of the basis pedunculi from the rest where the corticopontine fibers travel down is challenging [4,8]. Lin et al. [1] defined CST fibers as those passing both pons [9,10] at the level of superior cerebellar peduncle (Fig. 1b) and the cerebral peduncle at the level of the optic tracts (Fig. 1c), for which the region-of-interests (ROI) were chosen (1). The CST is obviously contaminated with other corticofugal pathways until forming medullary pyramids. This contamination can be prevented by seeding ROI in the medullary level (see Fig. 1d–f and i) [4,8,11,12].

Second, the number of fibers reported is misleading as it does not specify volume of the tracts and it does not help researchers in reproducing the results. The volume of the tract may also relate to brain size and hence tract volume along with intracranial vault volume (ICV) needs to be reported. It is noteworthy to mention that there are different methods that have been used previously and when the tract volume is not reported making comparisons between reports difficult [1,9–12].

To illustrate and compare different strategies as used by Lin et al. [1] or recommended previously [2] (see Fig. 1b and c), we acquired DTI data on two right handed healthy subjects (one male, 26 years of age, one female and 28 years of age) and (see Fig. 1h and i) compared the method used by Lin et al. [1] to the method with the approach we described above (see Fig. 1d–f and g) using CST volumes and corresponding FA, mean and radial diffusivities (see Table 1). Data were acquired at 3 T with voxel size of 1 mm × 1 mm × 2 mm as described elsewhere [13]. FA and angle threshold were chosen 0.2 and 45° respectively as in previous works [1,2].

Lin et al. reported that fiber number derived from tracking the CST shows lower precision than MD or FA [1]. We believe the low reproducibility of fiber numbers might be due to fiber contamination and lack of precise definition of the CST mapping in itself. In our experience [4,8] and comparison of the two strategies, there

http://dx.doi.org/10.1016/j.ejrad.2014.05.022

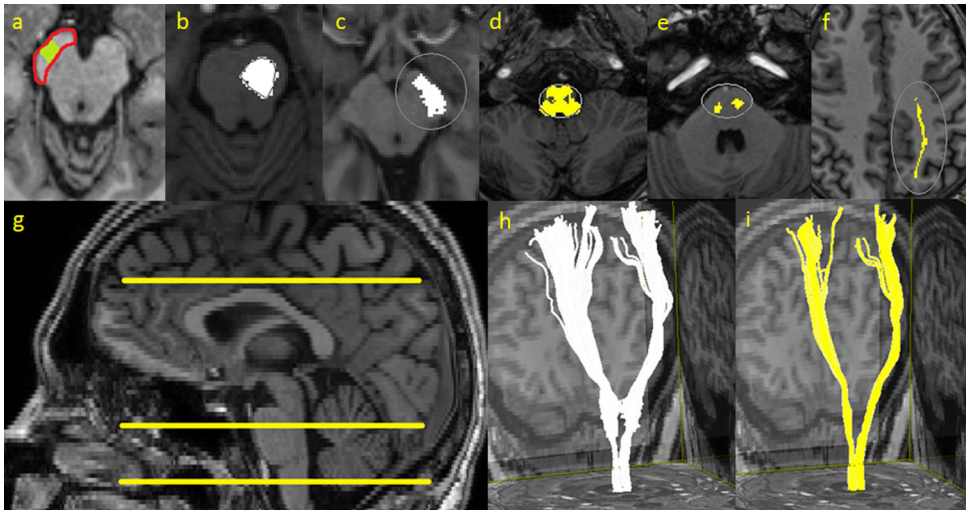

Fig. 1. The basis pedunculi and CST and corticobulbar fibers together in the middle third of basis pedunculi (a) ROI seeded in the pons at the level of superior cerebellar peduncle (b) and the cerebral peduncle at the level of optic tract (c) in the previous paper (1). The medullary level (d), the pons level (e), the cortical level (f) were chosen as ROIs with the method we described above (g). Fiber tracking of corticospinal tract with previous (h), and with the method we described (i).

Table 1
Quantitative comparison of volume, fractional anisotropy and diffusivities between methods used for CST DTT-based tracing (Method "a" described in Lin et al. [1] and method "b" is described above.

	Left CST				Right CST				
	VOL	FA	MD	RD	VOL	FA	MD	RD	ICV
Subject 1 26 years (M)									
Method a	10.81	0.63 ± 0.15	0.74	0.42	9.47	0.63 ± 0.16	0.73	0.42	1954
Method b	5.23	0.64 ± 0.15	0.78	0.423	3.58	0.65 ± 0.15	0.74	0.41	
Subject 2 28 years (F)									
Method a	5.80	0.62 ± 0.15	0.72	0.42	5.89	0.62 ± 0.15	0.69	0.40	1618
Method b	3.98	0.63 ± 0.15	0.72	0.42	3.07	0.63 ± 0.15	0.70	0.41	

Abbreviations: FA: Fractional Anisotropy; MD: Mean diffusivity (in units of 10^{-3} mm^2 s); RD; Radial diffusivity ($\times 10^{-3}$ mm^2 s^{-1}); VOL: volume of CST tract in mL or cm × cm × cm; ICV: Intracranial vault volume in mL or cm × cm × cm; M: Male; F: Female.

are striking differences in CST volumes that relate to contamination with other corticofugal pathways.

The virtual construction of white matter pathways using DTT has become popular in clinical studies to reveal distinct patterns of injury underlying the central nervous system (CNS) diseases. On the other hand, the peri-operative use of DTT in the brain and spine surgeries requires very well established fiber tracking strategies guided by accurate brain atlases to avoid post-surgical deficits.

In conclusion, neuroanatomy-guided fiber tracking strategies are needed to reveal better the pathologies of CNS diseases and to have better outcomes in the neurosurgical operations performed with the help of non-invasive imaging methods such as DTI.

Conflict of interest

None declared.

Acknowledgements

This study was supported by grants from Mission Connect/TIRR Foundation Department of Physical Medicine and Rehabilitation of UTHealth and Dunn Research Foundation.

References

[1] Lin CC, Tsai MY, Lo YC, et al. Reproducibility of corticospinal diffusion tensor tractography innormal subjects and hemiparetic stroke patients. Eur J Radiol 2013;82:e610–6.
[2] Wakana S, Caprihan A, Panzenboeck MM, et al. Reproducibility of quantitative tractography methods applied to cerebral white matter. Neuroimage 2007;36:630–44.
[3] Blumenfield H. Neuroanatomy through clinical cases. Sunderland: Sinauer Associates; 2011.
[4] Kamali A, Kramer LA, Frye RE, et al. Diffusion tensor tractography of the human brain cortico-ponto-cerebellar pathways: a quantitative preliminary study. J Magn Reson Imaging 2010;32:809–17.
[5] Snell RS. Clinical neuroanatomy. Philadelphia: Lippincott Williams & Wilkins, Wolters Kluwer; 2010.
[6] Kandel ER, Schwartz JH, Jessell TM, et al. Principles of neural science. United States of America: The McGraw Hill; 2013.
[7] Oishi K, Faria AV, van Zijl PCM, et al. MRI Atlas of Human White Matter. Amsterdam: Elsevier; 2011.
[8] Kamali A, Hasan KM. The importance of using a proper technique and accurate seeding of regions-of-interest in diffusion tensor tractography. J Neurol Sci 2014;339:235–6, http://dx.doi.org/10.1016/j.jns.2014.01.016.
[9] Yasmin H, Aoki S, Abe O, et al. Tract-specific analysis of white matter pathways in healthy subjects: a pilot study using diffusion tensor MRI. Neuroradiology 2009;51:831–40.
[10] Akter M, Hirai T, Sasao A, et al. Multi-tensor tractography of the motor pathway at 3T: a volunteer study. Magn Reson Med Sci 2011;10:59–63.
[11] Hong JH, Son SM, Jang SH. Somatotopic location of corticospinal tract at pons in human brain: a diffusion tensor tractography study. Neuroimage 2010;5:1952–5.
[12] Yu C, Shu N, Li J, et al. Plasticity of the corticospinal tract in early blindness revealed by quantitative analysis of fractional anisotropy based on diffusion tensor tractography. Neuroimage 2007;36:411–7.

[13] Hasan KM, Ali H, Shad MU. Atlas-based and DTI-guided quantification of human brain cerebral blood flow: feasibility, quality assurance, spatial heterogeneity and age effects. Magn Reson Imaging 2013;31:1445–52.

Z. Keser
N. Yozbatiran
G.E. Francisco
Department of Physical Medicine and Rehabilitation and TIRR Memorial Hermann NeuroRecovery Research Center, United States

K.M. Hasan*
Department of Diagnostic and Interventional Imaging, University of Texas Health Science Center at Houston, Houston, TX, United States

Corresponding author at: Department of Diagnostic and Interventional Imaging, University of Texas Health Science Center at Houston, 6431 Fannin Street, MSB 2.100, Houston, TX 77030, United States. Tel.: +1 713 500 7690; fax: +1 713 500 7684.
E-mail address: Khader.M.Hasan@uth.tmc.edu (K.M. Hasan)

17 March 2014