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EDUCATION & TRAINING

Advances in the Visualization and the Study of the Pyramidal Tract with Magnetic Resonance Tractography

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Abstract

Over the last several years, specific radiological techniques have been used for the analysis of the central nervous system pathways. They involve a magnetic resonance sequence called diffusion tensor imaging. In order to process the data provided by this sequence it is necessary to use software that can post-process the image and render three-dimensional images of the central nervous system pathways. Thanks to this sequence it has been possible to isolate over the years many nerve pathways that cross the brain tissue, particularly those which occupy a significant space. This sequence could have a large variety of uses, such as helping with the study of brain anatomy, assisting with surgery planning, or establishing a relationship between the nerve fibers and tumoral lesions. However, there has been an increasing number of cases that report a low reliability related to the tractographic representation of this technique. Our goal with this article is to analyse a specific nerve pathway, the piramidal tract, in order to assess the coherence between the images obtained and the anatomy that is already known from the perspective of the radiological image, and to compare this tract between different patients.

Keywords Tractography · Pyramidal tract · 3D imaging · Imaging analysis · Limitations

Introduction

The brain contains a lot of neurons whose axons are organized in tracts. Each of those tracts represents lots of neurons with similar functions which have a specific pathway in the brain and have been studied with different methods.

The Pyramidal Tract (PyT), also known as the corticospinal tract, belongs to a part of the descending spinal tract system that carries movement-related information from the layer of the brain called cortex to the spinal cord. At the cortex the tract is located in the precentral gyrus of the frontal lobe and goes through the corona radiata and then crosses the posterior limb of the internal capsule towards the base of the cerebral peduncle of the midbrain. Afterwards, it descends through the pons until it reaches the medulla oblongata to form the pyramid. In the junction between the medulla and the spinal cord, most neural fibres cross to the contralateral side within the spinal cord. The pyramidal tract descends through the spinal cord until it synapses with the neurons located in the grey matter of the spinal cord before leaving the spinal canal.

Nowadays we can isolate tracts in vivo and create a 3D image after post-processing with a sequence of magnetic resonance (MR) in order to have a visual representation [1–3]. The sequence is called Diffusion Tensor Imaging (DTI) and it analyse the diffusion of water in brain tissue and its anisotropy, which is higher in neural tracts. In spite of the amount of white matter tracts that the brain has, there are some parts in it that can be more easily to isolate through DTI than others. It is necessary to use an application in order to get the 3D image of neuronal tracts, the tractography.

With these new real images, it is easy to further understand what the brain contains, and they have also allowed health professionals to assess these neural tracts when there has been an abnormality in their development [4] or when there have

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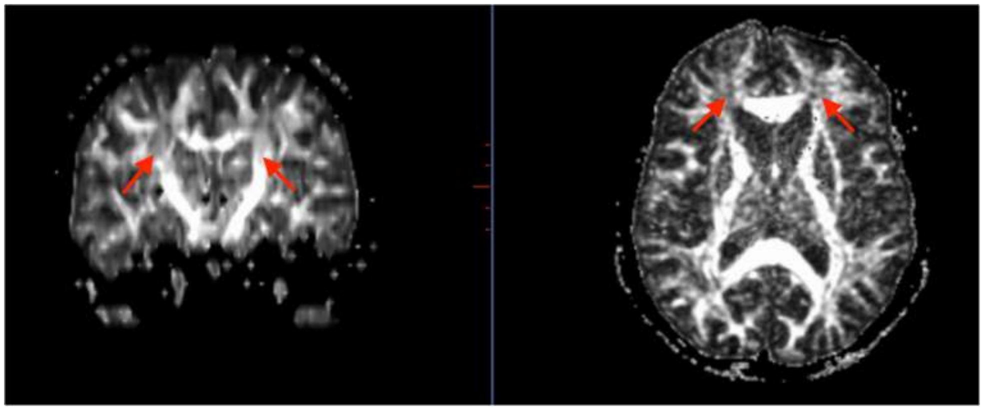


Fig. 1 Fractional anisotropy image on the coronal (left) and axial (right) axis that shows greyed sections of white matter that reveal areas with low anisotropy (red arrows)

been lesions that affect them [5]. More specifically, neurosurgeons rely on these images for the surgical management of brain tumours [6–8] with the help of post-processing software [9].

In spite of the functions that have been attributed to this sequence and of the 3D images that have been obtained from MR over the last years, the interpretation of the images is still a challenge, because some limitations have been described for tractographic images, particularly with regard to the real representation of the fibers in the surgical field [10–14]. In order to know more about limitations of the tractography and its reliability, we have chosen the pyramidal tract (PyT), so as to analyze its path and the representation in the tractography.

Methodology

We selected two patients, a women (45 years old) and a boy (24 years old) with symptoms of cephalalgia without other diseases that could imply significant alterations of the central nervous system (CNS). Patients with a personal history of neoplasms originating in the brain or in the rest of the body were ruled out due to the risk of a metastatic evolution that could affect the CNS. We also ruled out patients with demyelinating conditions and patients who had been subject to surgery of the CNS. The study did not include any patient with contraindications to magnetic resonance or patients who had magnetic material, claustrophobia or instability.

All the patients who underwent this study were informed about the procedure and were given an information brochure together with the informed consent form. The patients had to sign their informed consent forms prior to the study. Otherwise, the study would not be conducted, following the Declaration of Helsinki guidelines.

The radiological study was carried out with a General Electric SIGNA™ Voyager – 70 cm 1.5 T magnetic resonance scanner located in the Virgen Vega Hospital of the Healthcare Complex of Salamanca. The standard cerebral sequences were applied to verify the integrity of the cerebral anatomy, and after obtaining normal results, a single shot spin echo EPI (echo planar imaging) diffusion weighted sequence was performed for DTI acquisition with the following parameters: 26 cm FOV, 128 × 128 matrix size, one diffusion b 1000 smm^{-2}, TR: 748, TE: 26,9. We included the area from the edge of the brain to the second cervical vertebra. After the study was completed, the images were sent in DICOM format

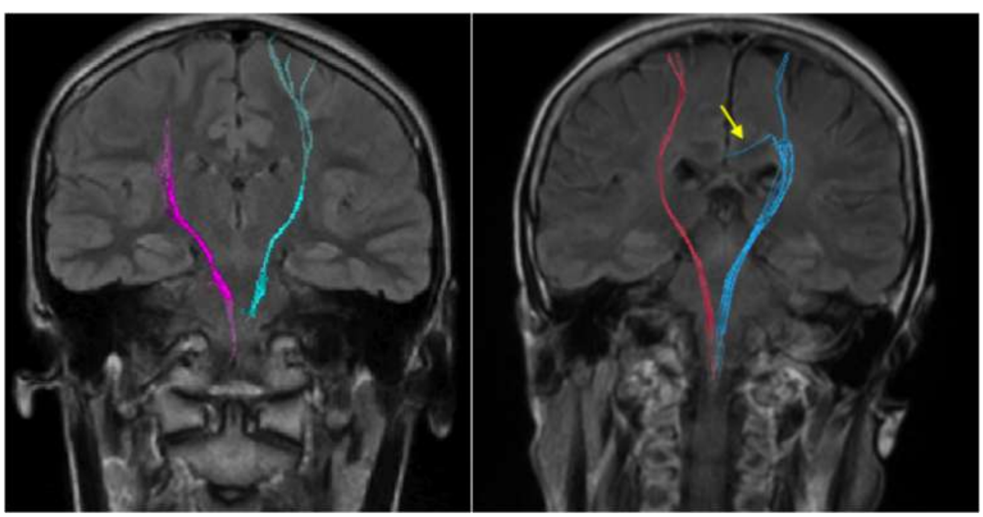


Fig. 2 Tractographic images of the patients included in the study, showing the PyT of both hemispheres. In the last patient we can see how part of the corticospinal tract is deviated to the right, over the lateral ventricles, towards the corpus callosum (yellow arrow)

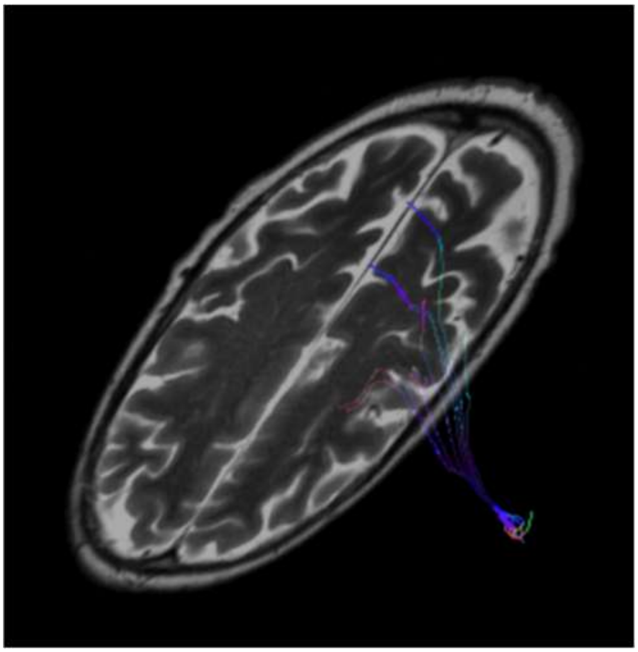


Fig. 3 Prolongation of PyT bundles towards the precentral gyrus of the frontal lobe

(Digital Imaging and Communication in Medicine) to an application for image post-processing located in the hospital. The software program was AW Server 3.2 ext. 2.0, installed on a Microsoft computer with Windows OS.

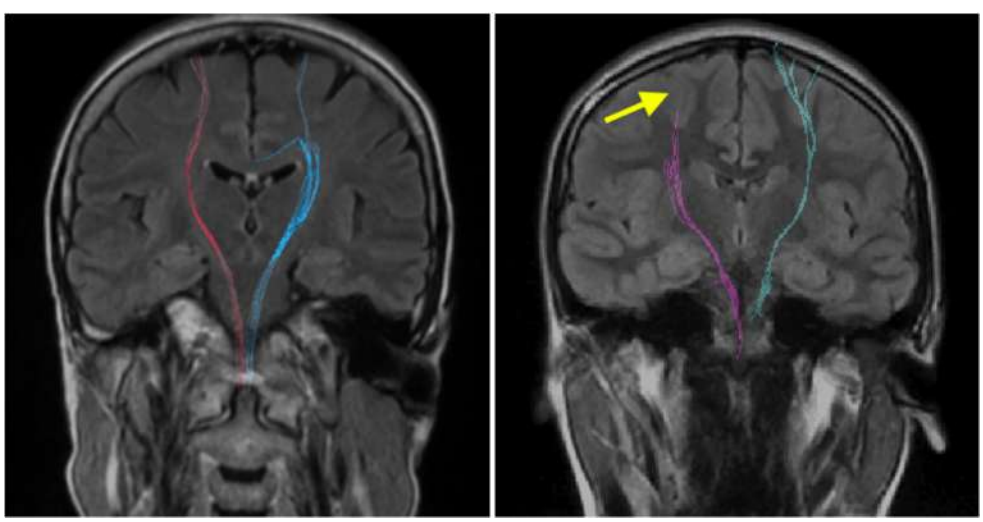
Results and discussion

Initially, the DTI sequence was assessed by carrying out a qualitative analysis of the fractional anisotropy image shown by the software, which is two dimensional and grayscale. In these images we have assessed an adequate representation of the white matter in white color which matches the area with the highest anisotropy due to the presence of the nerve tracts, including the PyT. In all the patients, areas of white matter have been found with a loss of white color, particularly those located adjacent to the frontal horns of the lateral ventricles. These are areas in which the nerve tracts cross, leading to low fractional anisotropy (Fig. 1).

Afterwards, with the fiber tract program, the same 2.9-mm^2 ROI has been used, and two ROIs were placed on the basilar portion of the pons, on both hemispheres, in the area theoretically crossed by the best-defined PyT. After the automatic tracing carried out by the program, we obtain the 3D tractographic image of the bilateral PyT. In all patients, the PyT shows an adequate route through the brain tissue. However, we can observe that sometimes the PyT is joined by other tracts that do not follow the known route of the PyT towards the brain cortex, even after repeated tracing. These tracts generally join the PyT when the fibers cross the semioval center towards the corpus callosum (Fig. 2). We may assume that they are association fibers or commissural fibers, and that the area with the lowest anisotropy is the point in which many bundles intersect. In addition, we observe some variability with regard to the length of the bundles, because some of them do not reach the precentral gyrus of the frontal lobe (Figs. 3 and 4). There is high interpersonal variability at this level; the PyT fibers separate and follow irregular routes, and they do not always seem to run through the frontal lobe. Instead, sometimes the fibers seem to move towards the parietal lobe.

On the other hand, we can observe a good correlation between the different patients in the part of the PyT that goes toward the spinal cord, more specifically in the posterior limb of the internal capsule, the mesencephalon and the medulla oblongata (Fig. 5). There was no significant variability regarding the age of the patients, but we do not have enough patients to prove a significant difference between them.

Fig. 4 Variability with regard to the length of the bundles. The second one do not reach the cortex (yellow arrow)



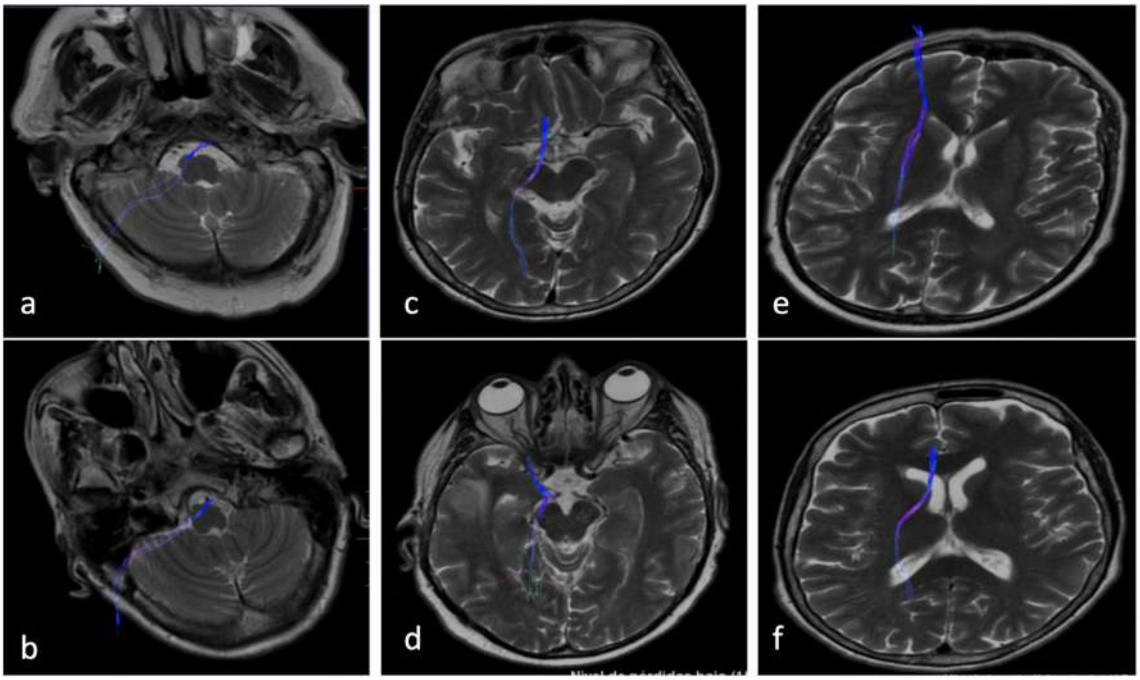


Fig. 5 orrelation between patients in the part of the PyT that goes toward the spinal cord, in the medulla oblongata (**a**, **b**), the mesencephalon (**c**,**d**) and the internal capsule (**e**,**f**)

Conclusions

In this article we have shown that there is variabilty between patients and even within the same patient, focusing only on the PyT. Our study, together with recent articles [11] has shown that there are inherent limitations in spite of an optimization of image acquisition in MR and an improvement of postprocessing software. The areas in which the PyT crosses the commissural fibers of the corpus callosum are particularly problematic, since they are also the sections with less fractional anisotropy. However, our qualitative analysis showed that the image was mostly concurrent with the path of the PyT on the brain stem and the basal ganglia, which means that it could be useful in the anatomic analysis from an educational perspective. In later studies it would be convenient to include a larger number of patients in order to assess the correlation between age and the tractographic image. We will also implement the improvements that have been recommended in recent articles to assess the tractographic image of the PyT, also from a qualitative perspective.

Compliance with ethical standards

Conflict of interest Katrin Muradas Mujika declares that she has no conflict of interest. Juan Antonio Juanes Méndez declares that he has no conflict of interest. Andrés Framiñán de Miguel declares that he has no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

References

1. Johansen-Berg, H., and Behrens, T. E., Just pretty pictures? What diffusion tractography can add in clinical neuroscience. *Curr Opin Neurol* 19(4):379–385, 2006.
2. Lazar, M., Mapping brain anatomical connectivity using white matter tractography. *NMR Biomed* 23(7):821–835, 2010. https://doi.org/10.1002/nbm.1579.
3. Dauguet, J., Peled, S., Berezovskii, V., Delzescaux, T., Warfield, S. K., Born, R., and Westin, C. F., Comparison of fiber tracts derived from in-vivo DTI tractography with 3D histological neural tract tracer reconstruction on a macaque brain. *Neuroimage* 37(2):530–538, 2007 Epub 2007 May 24.
4. Mukherjee, P., and McKinstry, R. C., Diffusion tensor imaging and tractography of human brain development. *Neuroimaging Clin N Am.* 16(1):19–43, 2006 vii.
5. Goh, S. Y., Irimia, A., Torgerson, C. M., Tubi, M. A., Real, C. R., Hanley, D. F., Martin, N. A., Vespa, P. M., and Van Horn, J. D., Longitudinal quantification and visualization of intracerebral hemorrhage using multimodal magnetic resonance and diffusion tensor imaging. *Brain Inj.* 29(4):438–445, 2015. https://doi.org/10.3109/02699052.2014.989907.
6. Golby, A. J., Kindlmann, G., Norton, I., Yarmarkovich, A., Pieper, S., and Kikinis, R., Interactive diffusion tensor Tractography

visualization for neurosurgical planning. *Neurosurgery* 68(2):496–505, 2011. https://doi.org/10.1227/NEU.0b013e3182061ebb.
7. Jellison, B. J., Field, A. F., Medow, J., Lazar, M., Salamat, M. S., and Alexander, A. L., Diffusion tensor imaging of cerebral white matter: A pictorial review of Phisics, Fiber tract anatomy, and tumor imaging patterns. *AJNR Am J Neuroradiol* 25:356–369, 2004.
8. Essayed, W. I., Zhang, F., Unadkat, P., Cosgrove, G. R., Golby, A. J., and O'Donnell, L. J., White matter tractography for neurosurgical planning: A topography-based review of the current state of the art. *Neuroimage Clin.* 15:659–672, 2017. https://doi.org/10.1016/j.nicl.2017.06.011.
9. Feigl, G. C., Hiergeist, W., Fellner, C., Schebesch, K. M., Doenitz, C., Finkenzeller, T., Brawanski, A., and Schlaier, J., Magnetic resonance imaging diffusion tensor Tractography: Evaluation of anatomic accuracy of different Fiber tracking software packages. *World Neurosurg.* 81(1):144–150, 2014. https://doi.org/10.1016/j.wneu.2013.01.004. Epub 2013 Jan 4.
10. Schilling, K. G., Daducci, A., Maier-Hein, K., Poupon, C., Houde, J. C., Nath, V., Anderson, A. W., Landman, B. A., and Descoteaux, M., Challenges in diffusion MRI tractography – Lessons learned from international benchmark competitions. *Magn Reson Imaging* S0730-725X(18)30516-2, 2019. https://doi.org/10.1016/j.mri.2018.11.014.
11. Schilling, K. G., Nath, V., Hansen, C., Parvathaneni, P., Blaber, J., Gao, Y., Neher, P., Aydogan, D. B., Shi, Y., Ocampo-Pineda, M., Schiavi, S., Daducci, A., Girard, G., Barakovic, M., Rafael-Patino, J., Romascano, D., Rensonnet, G., Pizzolato, M., Bates, A., Fischi, E., Thiran, J. P., Canales-Rodríguez, E. J., Huang, C., Zhu, H., Zhong, L., Cabeen, R., Toga, A. W., Rheault, F., Theaud, G., Houde, J. C., Sidhu, J., Chamberland, M., Westin, C. F., Dyrby, T. B., Verma, R., Rathi, Y., Irfanoglu, M. O., Thomas, C., Pierpaoli, C., Descoteaux, M., Anderson, A. W., and Landman, B. A., Limits to anatomical accuracy of diffusion tractography using modern approaches. *Neuroimage* 185:1–11, 2018. https://doi.org/10.1016/j.neuroimage.2018.10.029.
12. Jbabdi S, Johansen-Berg H (2011) Tractography: Where Do We Go from Here?. *Brain Connect*. Volume 1, Number 3, Mary Ann Liebert, Inc. DOI:https://doi.org/10.1089/brain.2011.0033.
13. Min, Z. G., Rana, N., Niu, C., Ji, H. M., and Zhang, M., Does diffusion tensor tractography of the corticospinal tract correctly reflect motor function? *Med Princ Pract.* 23(2):174–176, 2014. https://doi.org/10.1159/000353463. Epub 2014 Aug 13.
14. Mandelli, M. L., Berger, M. S., Bucci, M., Berman, J. I., Amirbekian, B., and Henry, R. G., Quantifying accuracy and precision of diffusion MR tractography of the corticospinal tract in brain tumors. *J Neurosurg.* 121(2):349–358, 2014. https://doi.org/10.3171/2014.4.JNS131160. Epub 2014 Jun 6.