Available online at http://www.journalcra.com

International Journal of Current Research
Vol. 15, Issue, 01, pp.23226-23231, January, 2023
DOI: https://doi.org/10.24941/ijcr.44593.01.2023

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

ISSN: 0975-833X

RESEARCH ARTICLE

TRACTOGRAPHY IN NEUROSURGERY A REVIEW ARTICLE

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ARTICLE INFO

Article History:
Received 16th October, 2022
Received in revised form
19th November, 2022
Accepted 15th December, 2022
Published online 20th January, 2023

Key words:

Tractography,
dMRI, Neurosurgery,
DTI, DWI, Neuronavigation.

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ABSTRACT

Background: To create a 3D representation of the white matter bundles in the brain, dMRI uses the diffusion of water molecules along axons. This function is very helpful for planning a surgical approach and seeing how a tumor affects the surrounding white matter. ***Objective:*** This article examines the various applications of dMRI in improving brain surgery, as well as its advantages and drawbacks. We discuss surgical methods that can be used in conjunction with dMRI to enhance the impact of the procedure on the patient's recovery, such as loading 3D tractography into the neuronavigation system and using direct electrical stimulation to confirm the location of the targeted white matter bundles. ***Methods:*** We looked at research that support dMRI results with other anatomical study methods, like postmortem dissections, manganese-enhanced MRI, electrical stimulations, and phantom experiments with established ground truth, in recent meta-analysis, research articles. We will talk about the parts of the brain where dMRI works well and where the obstacles lie in the future. ***Results:*** Tractography has lots of potential. Preoperative Tractography can assess the neural pathways and assist surgeons for optimal surgical approach. The technology is still in development. ***Conclusion:*** The review will be concluded with recommendations and key takeaways for neurosurgeons, on how to advance the discipline and reap the rewards of using tractography in clinical practice.

Citation: ***Rakesh Ashok Kadam, Hussam Aldeen Ahmed, Melita Rodrigues and AreebaTajammul.*** **2023.** "Tractography in neurosurgery a review article". *International Journal of Current Research*, 15, (01), 23226-23231.

INTRODUCTION

In order to minimize functional loss and maintain quality of life, one of the key challenges in brain tumor surgery is to adhere to the maxim of safe resection, which is to remove as much of the tumor as is safe while preserving the healthy surrounding tissue. This is particularly difficult with infiltrative or diffuse tumors like glioma's which don't have distinct boundaries between the tumor and healthy brain tissue. It is crucial to maintain the integrity of the working peritumoral white matter bundles in order to accomplish this goal. White matter diffusion MRI (dMRI) tractography, or the three-dimensional representation of white matter bundles in the brain, is one technology that has demonstrated promising potential for this purpose. Applying tracking algorithms to diffusion-weighted MRI images allows for its acquisition (DWI). We are aware that DTI is a methodology for gathering diffusion data rather than a specific tracking method, and that a variety of algorithms, including deterministic, probabilistic, path-finding, and tensor deflection methods, can be used on the DTI data. The ideal number of gradient directions in the context of neurosurgical planning is still up for debate and would require thorough consideration in a systematic investigation modelled after a clinical trial. A typical recommendation from current research calls for an isotropic 2 mm voxel size, b = 1000 s/mm2, and roughly 60 gradient directions, which on current systems would take roughly 6 minutes to complete. When using a "DTI"-like scan with 30 or more directions, it is occasionally advised to utilise a HARDI local reconstruction, such as fODF from constrained spherical deconvolution (CSD), which provides greater local crossing information than typical DTI. Due to the nature of malignant tumors, a significant portion of them must be removed without damaging the brain's functions. The balance between EOR and neurocognitive outcome can now be improved with the help of new tools. One such tool is dMRI tractography, which helps surgeons see the white matter tracks surrounding the tumor so they can perform surgery without damaging them. Some publications claim that dMRI can increase the safety of tumor removal by enabling the surgeon to see how the tumor interacts with the surrounding white matter. The gyral and sulcal patterns of the brain, the claustrum's shape, the fiber crossings of the centrum semiovale, the superior cerebral peduncle decussation, the terminal arborization of the arcuate fasciculus, thalamic radiations, and connections between the red and dentate nuclei were all precisely replicated using advanced tractographictechniques (Yeh, 2021)

History and physics of Diffusion: Diffusion Magnetic resonance Imaging (dMRI) is an exclusive method that is vastly being employed in imaging and understanding the structural connectivity pathways in the brain, especially revolutionizing the study of stroke and white matter disorders. It measures the water molecule movement at a micrometer level which makes it sensitive to microstructural changes in nervous tissue which increases especially in white matter fibers.

Brownian motion – Robert Brown: The diffusion MRI method wraps around the idea of Brownian motion, which was presented by Botanist Robert Brown in 1827, in which he explained that the Random transitional motion of the water molecule in a liquid state is constant due to their thermal energy and the molecules change the direction of motion due to collisions between the water molecules. Unfortunately, he was unable to determine the mechanism that caused this motion.

Brownian motion – Albert Einstein: Papers Published by German physicist Albert Einstein in 1905 gave mankind an unexpected gift of a powerful method of cerebral exploration. In those papers, he illustrated Brownian motion mathematically giving rise to new theories regarding the idea of random walk and self-diffusion co-efficient D. it is impossible to predict the distance in which a molecule will diffuse in each time interval however we can obtain a statistical value on how a group of molecules will diffuse. While illustrating statistical mechanics to produce his quantitative theory of Brownian motion Albert showed it is possible to commute the probability (P) of moving particle in one dimensional space (x), in any given direction, in each time interval (t) in a medium whose coefficient value is mass diffusivity (D).

$$P = \frac{e^{-x^2/4Dt}}{2\sqrt{\pi Dt}}\ .$$

This value is the mean square displacement which is similar to the mean of gaussians distribution of displacements of water molecules in a given period of time. Hence Einstein's equation stated that (r^2) increases with diffusion time (t) with diffusion coefficient D being the proportionality constant (Claudia da costa leite, 2016)

$$(r^2) = 2Dt$$

Nuclear Magnetic Resonance – Spin Echo: Later in 1950, Erwin Hahn became the first American physicist to introduce the effect of molecular diffusion on Nuclear Magnetic Resonance (NMR) signal, discovering the spin echo or Hahn echo that refocuses the spin magnetization by a pulse of resonant electromagnetic radiation. Spin echo was later employed by Carr and Purcell in presence of static magnetic resonance. It ended up with remarkable results with high accuracy. In 1965 Stejskal and tanner presented the hypothesis of measuring the diffusion coefficient of the liquids by NMR using pulsed gradients before and after the application of a 180-degree pulse in the spin echo. The way spin echo works are that the first 90- degree pulsed gradient is given to the molecules causes a fast and controlled phase shift of spins, then a 180-degree pulse is given, which invents all spins causing them to rephase for the formation of echo later. However, for the complete rephrasing of spins, the same pulse field gradient should be given. In case there is no change in position relative to the pulse field gradient applied during the given time interval (between the two pulsed field gradients) all spins will be correctly rephrased and will contribute to the echo signal.

By quantifying the signal intensity of the spin echo with (S) and without with (S0), the diffusion coefficient (D) can be calculated from the following Stejskal and Tanner equation:

$$\frac{S}{S_0} = e^{xp-}$$

Measuring of dMRI: While measuring diffusion using MRI, magnetic field gradients are used to produce an image sensitized to diffusion in a one-dimensional direction. Extra gradient pulses are introduced to cancel out stationary water molecules ending in a phase shift for molecules that diffuse. This process is then repeated multiple times in different directions to create a three-dimensional diffusion model of our brain.

b - Value: The b value is the b factor of the diffusion acquisition and depends on the DWI sequence parameters:

$$b = \gamma^2 \cdot G^2 \cdot \delta^2 \left(\Delta - \frac{\delta}{3}\right)$$

The more sensitive the DWI sequence is to molecular motion; the higher will be the b-value. (6)b = 0 is applied the result is a T2-weighted image (higher signal intensity for liquid) b = 1000 s/mm^2 when applied the result is a DWI

Diffusion-weighted imaging (DWI) and Diffusion-tensor imaging (DTI): In the brain, the diffusion of water molecules in white matter is highly restricted and, therefore, presents a diffusion anisotropy, i.e. the motion of water molecules is eased in the direction parallel to the long axis of nerve axons and myelinated fibres, but restricted perpendicular to them (Koh, 2007). The concept of using magnetic resonance imaging techniques to determine and measure the water diffusion coefficient was first introduced by Drs. Stejskal and Tanner in 1965 (Hagmann, 2006; Huisman, 2010). However, it was between the mid-1980s to early- to mid-1990s, diffusion MRIs (dMRIs) were made possible by pairing the principle of nuclear magnetic resonance imaging with the concept of the anisotropic, Brownian motion of water molecules within brain tissue (Soares, 2013; Charles-Edwards, 2006). dMRI is sensitive to changes in the microstructure of the soft brain tissue, enabling it to detect early and slight changes in the white matter architecture of the brain, and thus, making it particularly powerful as a neurodiagnostic tool for evaluation of various diseases such as Alzheimer's, epilepsy, multiple sclerosis, schizophrenia, dyslexia and more (Tournier, 2011; Jones, 2010). Diffusion-weighted imaging (DWI) is a non-invasive method that produces tissue contrast imaging on the basis of the differences in the degree of Brownian motion of water molecules in the brain. The most common technique used to obtain the image is a single-shot echo-planar imaging (ssEPI), owing to its high acquisition speed (11). The signal for the MRI is made by the addition of a pair of large magnetic gradient pulses to the standard pulse sequence. The first gradient pulse dephases the magnetization applied across the subject. The second gradient pulse has an effect that is equal and opposite of the first gradient pulse, and rephases the magnetization across the subject. The drawback of this type of DWI is that it is, in itself, a low-resolution technique that is further affected by its sensitivity to physiologic motion apart from diffusion and any inhomogeneity in the applied magnetic field, which leads to the production of artifacts. The presence of eddy currents due to the quick switching between the large gradient pulses also warps the image acquired (Gumeler, Ekim, 2021).

Diffusion-tensor imaging uses DW datasets to analyses the 3-D shape of diffusion. It uses 3x3 symmetric matrix called a tensor, which can be sampled by repeating a DW sequence. With three degrees of freedom, the tensor uses a measure of six independent elements (Dxx, Dyy, Dzz, Dxy = Dyx, Dxz = Dzx, and Dyz = Dzy) and a low b value (which represents the degree of applied diffusion weighting) to generate seven images. This is the minimum number of images required to generate a map of the ROI that is being analysed. Using DTI, it is now possible to quantify properties such as mean diffusivity (MD), also known as apparent diffusion coefficient (ADC), and fractional anisotropy (FA). As mentioned above, DWI and DTI is used in clinical applications for the early diagnosis of cerebral ischemia, infarction, stroke, edemas and lesions. It also finds use in detecting and tracking physiological and pathological changes to gray and white matter, in both pediatric and adult patients and plays an important role in tract reconstruction in neurosurgical applications.

Current limitations in Neurosurgery

Current limitations in Epilepsy surgery: Epilepsy surgery is the procedure of removing part of the brain known as the ''seizure focus'', the place where the seizure arises from, without causing irreversible neurologic deficit. Epilepsy surgery can face lots of challenges and limitations, and one of the main challenges when trying to outline and obstruct the network of the seizures is the rearrangement that occurs over time. The network characteristics of epilepsy varies depending on the type of epilepsy. When the brain starts to develop the epileptogenic zones shrinks or even diminish, but in some cases, it could develop by time. For instance, in Benign rolandic epilepsy - a syndrome that starts causing seizures in children between ages 6 and 8- in most cases children that reaches 12-14 years old will recover from seizure disregarding their treatment plan. On the other hand, in case of Rasmussen encephalitis, patients usually have a very fast development of the seizure network, thus causes epilepsy development and neurologic fall of. Due to the restrictions in outlining and obstructing the electric connectivity, the most efficient approach rotates on global network disruption. Noninvasive approaches are also available to outline the epilepsy network and one example is surface (scalp) electrodes, small device that is attached to the skin to measure or cause electrical activity in the tissue under it that is more illustrative for the symptomatogenic zone than the seizure-onset zone. EEG can ideally portray temporal localization, but mediating tissues can interrupt EEG from spotting the irregular activity from deeper foci. Due to the space between the leads and the altering of signals that occurs, spatial localization is very restricted. Another example could be MRI, which is a structural imaging that is useful in detecting scars on the brain caused by epilepsy. MRI also faces challenges and restrictions when it comes to detecting alterations in myelination sequence, and diseases that causes alterations in the connectivity and appearance of the lesions. MEG is another diagnostic tool used to sense the areas of activity in the brain and help doctors to pinpoint areas of epileptic zone. And studies have shown that it's more efficient than EEG, especially when it comes to image quality. On the other hand, due to its inability to sense radial dipoles; thus, it's unable to define deeper foci or show the middle phase of epilepsy. There's argument on whether to rely on MEG independently or use it as a supplement with other tools like EEG and semiology. Cognitivityevalution is considered an applicable method for secure noninvasive interventions. This method is often used before surgery in order to assess patient cognitivity and help in surgical planning; if patient was evaluated with poor congitivity associated with lesions, patient will mostly have cognitive side effects after undergoing surgery. Poor cognitive results of an epilepsy patient could be due to various reasons; for instance, it can be due to numerous psychological disorders or the side effects of AEDs and can also be due to seizure. Along with age, brain development and the starting time of seizure plays important roles in the outcomes of patient's cognitive evaluation. After undergoing cognitiveevaluation, physical exams should be done in order to have good and safe surgical plan (Kuzan-Fischer, 2020).

Current Limitations of minimally invasive spinal surgery in adult deformity: Minimally invasive surgery method was created as an alternative of the conventional open spine surgery. After showing efficacy in treating degenerative spinal diseases, it then showed the efficacy of MIS lumbar underbody fusion (LIF) in treating indirect foramina and central decompression and fusions. Although this method is showing great efficacy in treating several types of spine deformities, the major limitation lies in its impotence in enhancing sagittal balance to the same extent as the open spine surgery. Thus, it's believed that MIS only show efficacy in correcting mild sagittal imbalance or coronal deformity. Another challenge a surgeon can face is the right selection of the patient. Stand-alone lateral constructs, is an effective surgical approach for specific spinal pathologies, its advantage lies in avoiding morbidity and complications associated with anterior lumbar interbody fusion like plate fixation. This technique is only used for selected patients like those having comorbidities or degenerative scoliosis. Thus, its usage is restricted in patients having any degree of either spinal instability, coronal and sagittal deformities or patients having osteoporosis or osteopenia. These kinds of patients should seek any alternative of surgery or undergo limited decompressed surgery. Hence, MIS shows more efficacy compared to open surgery, along with advantage of causing less blood loss, on the other hand MIS have showed impotence in decreasing the rates of proximal junctional kyphosis (PJK) and proximal junctional failure (PJF). MIS, have so many complications that should be understood. Rhabdomyolysis, although it's infrequent but its occurrence can lead to acute renal failure. Especially associated with obese patients or surgeries that needs a long time. Another type of complications are hernias that mainly occur at lateral incisions. In MIS, surgeons create a small incision; which makes it difficult later to close it layer by layer especially in obese patients where vision is challenging. Most these complications arise from having insufficient planning before surgery. Detailed analysis of patient and evalution of the neurovascular structures should be done carefully before surgery, to avoid any mistake during surgery (Januszewski, 2018; Yoo, 2017).

Role of DTI Tractography in Neurosurgery: Any surgical injuries to the white mater can lead to permanent neurological damage which include loss of vision, Hearing, mobility, memory, and balance along with which the patient can be at greater risk to develop cardiovascular diseases making the exactitude of tractography paramount. The major use of DTI in neurosurgery is in Preoperative and Intraoperative image guidance as it assists in providing the knowledge of precise location of white mater tracts which can be advantageous in guiding the surgical resection minimizing injury to surrounding tissues in surgery and optimize the post-surgical outcome.

Preoperative Applications of DTI: Brain-mapping preoperative diagnosis in this era is a crucial investigative strategy to predict the extent of intracranial tumor resection as it can be notoriously difficult especially in case of primary brain tumors. Magnetic resonance imaging (MRI) has some ability to classify the pathology of intracranial tumors with rate of 81% of accurate diagnostic results (Villanueva-Meyer, 2017) yet it doesn't provide the accuracy required for clinical decision making as it is just the measurement of signal differences and highlights them in colored Area. However, DTI is a unique technique in which the diffusion of water molecules in the neural tissue is recorded. In gray matter and CSF, the diffusion of water is same in all directions making it isotropic part of DTI but in white matter diffusion is parallel to the axonal tracts but not in perpendicular direction forming the anisotropic component of DTI (Horská, 2010). This technique helps in distinguishing gliomas and other clinical pathologies such as metastases and lymphomas, they display analogous signal intensities and contrast enhancement patterns, with an extremely low error rate and specificities of about 90% (18).

Intraoperative Application of DTI: DTI imaging prior to neurosurgery is constructive for surgeons as it guides them through the pathways and tracts of white matter as described earlier. It also helps in specifying the region of interest and invasiveness of disease to the surrounding tissue consequential in protection of the functional tissues and contributes to good progress in post operational outcome. Brain shift is a phenomenon that is known to affect the reliability of preoperative tractography (DDT). In this phenomenon the brain deforms itself during surgery due to several explanations that include gravitational changes, head position, fluid drainage, use of hyperosmotic drugs, any changes in intracranial pressure and swelling of brain tissue. However, this barrier can be minimized by revising intraoperative DTI or tractography. This process will include image re-processing and fiber tract reconstruction according to patient's current position. This can be completed under 20 minutes which benefits as its less time consuming and can be done in surgical setting especially in asleep surgeries. This can be advantageous and ease resection of tumors in speech and language areas. The data received is then integrated into navigational datasets. This can be done much faster and improved by integrating models compensating for intraoperative brain shift that can predict physiological brain shift depending completely on typical deformation inducing events mentioned above. This would give promising results up to 95% aiding in the neuro-navigation and tumor resection during brain surgery.

Neuronavigational Application of DTI: DTI also helps in visualizing the white matter tracts for instance the corticospinal tracts which is important for their preoperative involvement leading to prediction of postoperative motor defects, optic radiations which is useful in tracking the fibres in Meyer's loop helping in concordance with anatomical dissections, and language pathways. Method of tracking is an important decision to make. Currently there are two approaches to method of tracking which is deterministic or probabilistic approach. Deterministic approach assumes that the orientation of the fibres can be described by a single orientation whereas probabilistic approach is a way of reconstructing the white matter tracts using diffusion MRI data. Probabilistic approach is used less frequently such as in cases of Optic tract more specifically Meyer's loop, it creates a three-dimensional map of all the possible connectivity of white matter tracts, but deterministic approach is preferred due to it being less time consuming (Zolal, 2017).

Limitations of DTI tractography: DTI tractography is an old radiological intervention, that's been used for years. The latest development of visualisation of neural tracts and the recurrent use of tractography brings on advances of reconstruction methods, which is reflected on the treatment being efficient and accurate. Nevertheless, tractography on the other hand has many limitations, variability of obtained data and lack of standardisation of image acquisition parameters which doesn't make it the first choice. Also, while dealing with cases like brain edema or malignant tumors, tractography does not have the ability to identify the neural pathways accurately. Moreover, DTI can be functionally limited due to the risk of motion artifacts in case of sizable cerebrospinal fluid flow (Kieronska, 2019). Tractography can also be limited in many cases of spinal cord trauma especially in cord edema and hemorrhage, it could be able to show fibers that are flowing through the area of incomplete transection, and most importantly tractography will be limited due to artifacts which can damage the data of the DTI. In the case of corddisplacement, we will notice unexpected angles and noticeable decline in FA values, reflecting inaccurately tract disruption. Although DTI tractography can precisely portray patterns of axonal disruption in many cases of spinal cord injuries, it also can be limited in cases where there's partial or complete transection leading to prolonged recovery (Rutman, 2018).

The main important limitations from the author's strict perspective is the computational estimation, fiber direction and noise. Even though each of them can be solved individually by certain methods in order to lessen the tracking errors, it's challenging to treat the combined influence independently (Azad, 2020). By applying different tractography approaches, eight teams from international institutions were able to enhance the corticospinal tract near the motor cortex in glioma cases. After reviewing the results, neurosurgeons and DTI experts have came to a conclusion that there is inter-algorithm variability in the hemisphere affected with glioma as well as the other hemisphere. They noticed weak effect in outlining the lateral projections compared to the medial projection (Ranzenberger, 2022). (SNR) or signal to noise ratio is the ratio between the desired information and the undesired signal or the power of the background noise. In this case a DTI limitation is because it has low SNR which can increase the scanning time. Hence, affects the image quality causing it to be below standard. Nonetheless, this may simply be evident and what really exists in the specific voxel is different anisotropic designs orientated in various headings bringing about isotropy. Eventually, this means that the non identical molecular water displacement can only be seen through DTI when all the structures passes through the voxel are adjusted on either tiny structure like myelin sheath and protein filaments or through a macroscopic scale like axons and dendrites. When these macroscopic structures get messed up or unorganized, FA on the cortex becomes low. Higher patterns of anisotropy will mostly be manifested by the cortex when improving the image resolution (Zhang, 2022). By DTI expects that the strands seen in each voxel are very much depicted by a solitary direction gauge; in this way, the method performs inadequately in locales where there are more than one group of strands or where filaments cross, "kiss", combine, or veer. Patients with Alzheimer's disease-associated dementia, won't benefit from DTI tractography due to its symptoms like atrophy which makes it difficult for tractography to access affected areas, this lessens the probability of tracking down huge contrasts between the patients and controls (false negatives) However, the atrophic changes found in the white matter and the cortex of patients with dementia can cause incomplete volume impacts and subsequently increment the likelihood of false positives. Same thing happens in some patients with Parkinson disorder (Thomas, 2014).

Challenges and Future of Tractography in Neurosurgery: This section aims to highlight several important challenges that arise in the current state of tractography in neurosurgical practice as the future of tractography-based imaging in neurosurgery.

Challenges:

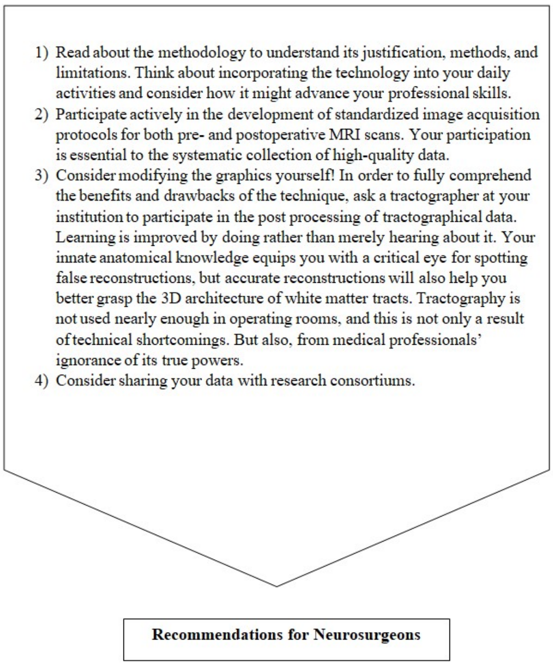
Lack of recognition of tract orientation: Although reconstruction of nerve tracts that are correct spatially and orientation-wise is an established application of tractography, this use is limited. The nature of the human brain is complex and it is relatively rare for the myelinated fibres to run a parallel course. This leads to one of the most important complications of diffusion-tensor imaging: difficulty in recognizing the crossing of nerve fiber bundles. Typically, at these nerve crossings, the tensor algorithms map out a mathematical average of the course which does not give a true reading of either of the crossing tracts. Other complications include a low valid to invalid/undetermined connection creation ratio and difficulty in delineating regions of splitting, branching and curving of nerve fiber bundles (Poulin *et al.*2019; Schilling, 2019). Qualitatively, tract grams produced by most methods are limited to only recognizing the pyramidal tracts arising from the medial region of the motor cortex and display complications in recognizing the lateral projections of the corticospinal tract of the motor cortex associated with movements of the face, tongue and hands (Rheault, 2019; Nimsky, 2016).

Creation of false-negatives and false-positives: Another challenge associated with the difficulty in recognizing tracts is the creation of false-negative and false-positive results. A false-negative result is created when the analysis of nerve fiber microarchitecture results in the sudden termination of the tractogram's algorithm due to the former's complexity. A false-positive, on the other hand, is when an (incorrect) image of potential tract pathway is created where it, in reality, doesn't exist. This is caused due to the intersection or close association of two fiber tracts (Pujol, 2015). Apart from the complication in recognizing the lateral projections of the pyramidal tracts in the motor cortex, another example of false-negative results are the ones that are typically found in edematous areas in the brain. Challenges caused due to false-positives are observed in the tractograms of the corticobulbar tract that involve intersecting fibres at the level of the corona radiata. Other false-positive results are also seen in regions of interest (ROIs) in the corona radiata, like the frontal and parieto-occipital zones.

Lack of standardization among the different methods of tractography: The heterogeneity of DTI evaluations and its complications in creating a reproducible image pose a key challenge to the clinical applications of DTI tractography. While DTI tractography is a useful tool that is used in pre- and post-operative care and management, the inconstancy of results across the algorithms of different tractography methods results in a lack of standardization. According to the findings of a study conducted by Pujol *et al.* (2015), a common, anatomically well-known pyramidal tract was chosen for the purpose of reconstruction using DTI tractography, however, there was a marked variability in outcomes among the different methods. This lack of standardization could, therefore, cause an invalidation of tractography algorithms in neurosurgical planning. These non-standard results could occur due to a difference in the approach strategies proposed by the different DTI methods, or due to the application -or lack thereof- of preprocessing to correct for variables (Maier-Hein, 2017).

Future: Considering that dMRI is a technique that has only developed recently within the last 20 years, it has not yet reached its full potential. The future of diffusion tractography is bright and constantly evolving. Mathematical modelling is improving every year to increase accuracy and resolution while eliminating imaging artifacts, and there are remarkable changes in the quality of imaging and post-processing techniques. Lesser well-defined tracts, including the Meyer loop, are increasingly visualized by newer tractography studies. Highly advanced dMRI techniques are now being used in the neurosurgical procedures of many benign lesions and elective surgeries. There are certain demands, however, that need to be addressed in order to advance the efficacy of DTI tractography in clinical practice. As mentioned above, there is a need for the standardization and reproducibility of DTI results which could drastically improve is application in pre- and post-operative planning.

Table: Recommendations for Neurosurgeons



1) Read about the methodology to understand its justification, methods, and limitations. Think about incorporating the technology into your daily activities and consider how it might advance your professional skills.
2) Participate actively in the development of standardized image acquisition protocols for both pre- and postoperative MRI scans. Your participation is essential to the systematic collection of high-quality data.
3) Consider modifying the graphics yourself! In order to fully comprehend the benefits and drawbacks of the technique, ask a tractographer at your institution to participate in the post processing of tractographical data. Learning is improved by doing rather than merely hearing about it. Your innate anatomical knowledge equips you with a critical eye for spotting false reconstructions, but accurate reconstructions will also help you better grasp the 3D architecture of white matter tracts. Tractography is not used nearly enough in operating rooms, and this is not only a result of technical shortcomings. But also, from medical professionals' ignorance of its true powers.
4) Consider sharing your data with research consortiums.

Recommendations for Neurosurgeons

There are several advanced MR techniques that have been developed that are not applicable in an acute neurosurgical setting as the image processing speed are too long and are not compliant with the requirements of an urgent surgical procedure. An improvement in the imaging resolution and a deeper visualization of the microstructures in the brain can also lead to less false-negative or false-positive results. That being said, diffusion MRI is a wonderful tool that can be used in the coming future to help widen our knowledge of the brain and its related pathological processes by providing a means of mapping out the white matter tracts.

DISCUSSION

Diffusion examines the displacement of water molecules in the size order of cell structures and is an effective diagnostic technique (a few micrometers). As a result, it is capable of detecting microstructural changes in brain tissue before other forms of magnetic resonance imaging can (MRI). Depending on the characteristics of the diffusion pulse sequence, one can see more or less of this restriction since water diffusion in the brain is relatively constrained. The apparent diffusion coefficient (ADC) is utilized since the observed water diffusion coefficient depends on the (b values). Anisotropic water diffusion means that it is restricted perpendicular to myelin fibers and axons and facilitated parallel to them in the brain. This diffusion anisotropy is described using the tensor model, which also makes it possible to measure anisotropy parameters (associated to white matter integrity) and reconstruct the path of white matter fibers (diffusion tractography) (Yang *et al*., 2021). White matter pathways in the brain can be found using a technique called tractography. Based on the knowledge of each voxel, various algorithms can be used to reconstruct these fiber pathways in three dimensions. The algorithm that will be used will differ fundamentally depending on whether it is based on probabilistic or deterministic tractography. The streamline principle underlies the deterministic tractography, which is most frequently used in clinical applications. Starting from a specified region of interest (seed location), adjacent voxels will be integrated to the same streamline as long as their primary eigenvectors are parallel to one another or at the very least do not deviate significantly from the specified direction. (Chakravarthi, 2021) The curvature threshold (often 30–60 degrees) sets the upper limit for this deviation, thus if the following voxel has an angle greater than this threshold, it won't be included in the streamline and the tract will end there. Because determining the eigenvector is associated with significant mistakes in voxels with low fractional anisotropy (FA), this streamline's growth is also constrained by the value of FA in the voxel. The tract will end if the following voxel falls below a predetermined FA threshold (often 0.2-0.3). Deterministic tractography is frequently combined with some prior anatomical knowledge, allowing the user to choose multiple regions of interest that a white matter tract should pass through. Streamlines that do not pass through these chosen regions of interests will be excluded from the graphical representation of the white matter tracts. Tractography has a significant drawback in that its resolution (2mm) is insufficient to determine the orientation of individual white matter fibers, which have a diameter of about 1 m. Even though the fiber bundles containing hundreds of thousands of axons that make up these white matter tracts are largely coherently structured, many of the DTI voxels will have fiber bundles that cross, divide, or merge. These "crossing fibers" have the result that the resultant 1 will not accurately represent the voxel's fiber orientation because it contains multiple fiber orientations. When multiple fiber orientations coexist, the voxel's FA falls below the set threshold for streamlining tractography, interrupting the fiber tracking (Toescu, 2021).

CONCLUSION

A technology that is still in development, diffusion tractography has a lot of potential. Benefits include a higher rate of safe resection and reduced functional decline. Preoperative tractography can be performed to assess how glial tumors affect the white matter pathways nearby and assist surgeons in determining the optimum surgical approach and plane of resection. The neuronavigation system can be loaded with 3D reconstructions of white matter bundles and coordinated with structural MRI data. When used in conjunction with DES, tractography enables the surgeon to discover eloquent fibers faster and with fewer electrical stimulations. The 3D architecture of the human brain can be seen by surgeons with the use of 3D models. Postmortem dissection, manganese-enhanced MRI, phantom investigations, and surgical electrical stimulation have all confirmed the accuracy of the tractographic results. Both intrinsic and extrinsic restrictions affect diffusion tractography. Peritumoral edema and brain displacement are examples of extrinsic restrictions. To compensate for brain shift, intraoperative ultrasound neuronavigation and intraoperative diffusion MRI tractography can be employed. Fiber crossings, inaccurate registration, false positives and false negatives, and imperfect repeatability are intrinsic limitations. Although more work still has to be done to overcome these restrictions, progress is being made continually. Despite these drawbacks, the future is promising as the methods advance as vendors, tractographers, and neurosurgeons work more closely together. While waiting for neurosurgeons to factor into his practice, dMRI tractography offers a special power and never-before-seen images.

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