Video Article

DTI of the Visual Pathway - White Matter Tracts and Cerebral Lesions

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Abstract

DTI is a technique that identifies white matter tracts (WMT) non-invasively in healthy and non-healthy patients using diffusion measurements. Similar to visual pathways (VP), WMT are not visible with classical MRI or intra-operatively with microscope. DTI will help neurosurgeons to prevent destruction of the VP while removing lesions adjacent to this WMT. We have performed DTI on fifty patients before and after surgery between March 2012 to January 2014. To navigate we used a 3DT1-weighted sequence. Additionally, we performed a T2-weighted and DTI-sequences. The parameters used were, FOV: 200 x 200 mm, slice thickness: 2 mm, and acquisition matrix: 96 x 96 yielding nearly isotropic voxels of 2 x 2 x 2 mm. Axial MRI was carried out using a 32 gradient direction and one b0-image. We used Echo-Planar-Imaging (EPI) and ASSET parallel imaging with an acceleration factor of 2 and b-value of 800 s/mm². The scanning time was less than 9 min.

The DTI-data obtained were processed using a FDA approved surgical navigation system program which uses a straightforward fiber-tracking approach known as fiber assignment by continuous tracking (FACT). This is based on the propagation of lines between regions of interest (ROI) which is defined by a physician. A maximum angle of 50, FA start value of 0.10 and ADC stop value of 0.20 mm²/s were the parameters used for tractography.

There are some limitations to this technique. The limited acquisition time frame enforces trade-offs in the image quality. Another important point not to be neglected is the brain shift during surgery. As for the latter intra-operative MRI might be helpful. Furthermore the risk of false positive or false negative tracts needs to be taken into account which might compromise the final results.

Video Link

The video component of this article can be found at http://www.jove.com/video/51946/

Introduction

Diffusion tensor imaging (DTI) is used to portray WMT non-invasively in the human brain[1]. It has been used in the past decade to reduce the risk of harming eloquent areas of the brain during surgery[1].

DTI was performed in fifty patients between March 2012 and January 2014 to portray the visual pathway. DTI might improve preservation of eloquent areas of the brain during surgery by providing important information about the anatomical location of white matter tracts. It has been incorporated into strategic planning for resection of complex brain lesions[1]. However, the portrayal of the visual pathway remains a challenge because there is no standard for the parameters of DTI, the placement of the seed volumes and interpretation of results[12].

Different algorithms have been implemented so far [19-21]. Some approaches concentrated on deterministic methods [19, 22-25]. Others were using probabilistic methods[,26,27,29]. More recently, techniques using Q-ball tensor fields, diffusion spectral imaging and High Angular Resolution Diffusion Imaging (HARDI) are being used to depict white matter tracts among others the visual pathway [1,13-15,18] . Nevertheless, the necessary time for HARDI is significantly longer with 45 min, the software is not commercially available and emphasizes scientific applications[18]. The teaching period for HARDI seems to be longer than for DTI[18].

The presented protocol is easy feasible and can be used for everyday routine in neurosurgical operations in order to avoid morbidity and improve the postoperative outcome. The additional time for this protocol is less than 9 min which is significantly faster than other protocols[1,9,12,16]. Acknowledging the fact that many sophisticated algorithms have been developed recently the paper restricts itself to the use of a commercially available and FDA approved software. However it is mandatory to take into account the limitations of this technique which are mentioned above.

Protocol

NOTE: This protocol follows the guidelines of the Centre Hospitalier de Luxembourg in Luxembourg.

1. Preparation of Diffusion Tensor Imaging for the Visual Pathway for Neurosurgery and Follow Up

1. Perform an MRI-scan at least one day before surgery strictly axial using 32 gradient directions and one b0-image. Keep in close touch with the neuroradiology unit at any moment.
   NOTE: Make clear to the neuroradiologist that the images after surgery are the same as those before the operation.
2. Using a 3-Tesla MRI, perform a 3DT1-weighted and DTI-sequence scans. Perform a 3DT1-weighted sequence after surgery as well.

2. Using the Planning Station

1. Transfer the T2-weighted, 3DT1-weighted and DTI-sequence scan data to digital imaging and communications in medicine (DICOM). This procedure takes up to 7 min.
   NOTE: Don`t stop the procedure before having transferred all the sequences. It is possible to stop and continue later depending on the date of surgery.
2. Open the surgical navigation system program. Click on File and then on Import DICOM. Repeat this procedure three times for all the sequences mentioned above.
   1. Click Add to view. Add every sequence separately. Don`t try to proceed with View.
3. Click on Tools. Open DTI Tensor preparation. Observe a new window in the middle of the screen.
4. Complete the following four steps.
   1. Perform Gradient Assignment as the first step.
      1. Change the b-value from 1,000 to 800 s/mm² on the bottom right of the window.
      2. Adjust the Threshold on the top right of the window. Do it manually by simply writing a number or moving a cursor. 20 might be an acceptable value. It is a personal experience and it is not mandatory.
   2. Perform Gradient Registration as the second step.
      1. Click the button All Auto. This procedure takes up to 5 min.
      2. Click Verify All Registrations. Without verifying the registrations it is not possible to continue.
   3. Perform Coregistration as the third step.
      1. Coregister MR1 and b0 MR2 images manually. In the end Verify All Registrations.
         NOTE: It is possible to perform this step automatically. However, the results may not be always satisfactory in the end.
   4. Perform Tensor computation as the fourth and last step,
      1. Make sure FA / DEC / ADC are on. If not click ON.
      2. Click on Compute. This procedure will take only some seconds.
5. Save all the data and continue with fibertracking. Do not stop without saving everything.

3. Fibertracking

NOTE: Anatomic knowledge of the visual pathway is very important for the successful result.

1. Prepare to find the three important points where the fibers have to go through.
2. Determine the optic chiasm using anatomical knowledge.
   1. Use a ROI as a starting point and let the fibers go through. ROIs are defined by the physician.
   2. Alternatively, segment the suspected region. Click Segmentation on the bottom left and another window will appear. Segmented areas are anatomically defined areas.
      1. Paint the region manually. Scroll up and down to include the whole optic chiasm. Save the procedure and go back.
   3. Track the fibers either from the region of interest or from the segmented area or both.
   4. The fibers reach the left geniculate nucleus (LGN), which is the second important point of the visual pathway. The maximum angle was 50. The risk of false tracts will rise with if the angle is too high.
      1. There is a possibility to segment the LGN as shown with the optic chiasm and then track the fibers. After having segmented the optic chiasm, track fibers which run from the LGN and finish in the optic chiasm or vice versa.
   5. Segment the visual cortex. Proceed like in the case of the optic chiasm. This might take some time as 3DT1-weighted image contains 160 slices.
   6. Track the fibers from the visual cortex to the LGN. It is possible to track them from the LGN to the visual cortex as well.
   7. If the visual cortex is invaded by a tumor or edema then use a region of interest in place of a segmented area and then let the fibers run in direction of the LGN.

NOTE: If the edema is segmented it sometimes might invade the visual cortex then then the visual cortex might not be able to segmented entirely because the computer can`t distinguish between them. That`s why it is necessary to put a ROI.

8. Repeat everything for the other hemisphere.
9. Start with the healthy hemisphere first.
   NOTE: It is possible to start with the other one too but it might be easier to track the fibers of the healthy hemisphere first to become a first idea about the situation. It is not mandatory, it is only an advice.

3. Segment the cerebral lesion and the edema. Proceed as mentioned above in 3.2.2.
   1. Assign a color for every segmented area or lesion in order to distinguish better.

4. Save the procedure after each step in case of unforeseen events or in case of an emergency.
5. Export the entire data locally. It is possible to export it to the operating room directly but it isn`t recommended.
   1. Press File and then Export 3D-Objects. Make sure to export only the Navigation Exam.
   2. Don`t export the Hybrid Exam.

6. Enter Cranial. Choose the right patient then press Stealthmerge. Choose 3DT1-weighted images as reference exam.
7. Create a 3D-model and insert everything.
8. Import the data in the operation room.

Representative Results

This protocol enables the physician to portray adequately the major parts of the VP. It can be used with a little amount of time in order to prevent damages in patients with cerebral lesions next to eloquent areas. Postoperative controls show also good results. VP is portrayed in **Figure 7** after the patient was operated from a glioblastoma. **Figure 2** shows the VP after recurrence of a glioblastoma. The authors recognize the fact of the difficulties presented by this protocol to depict the Meyer loop which remains a major challenge.

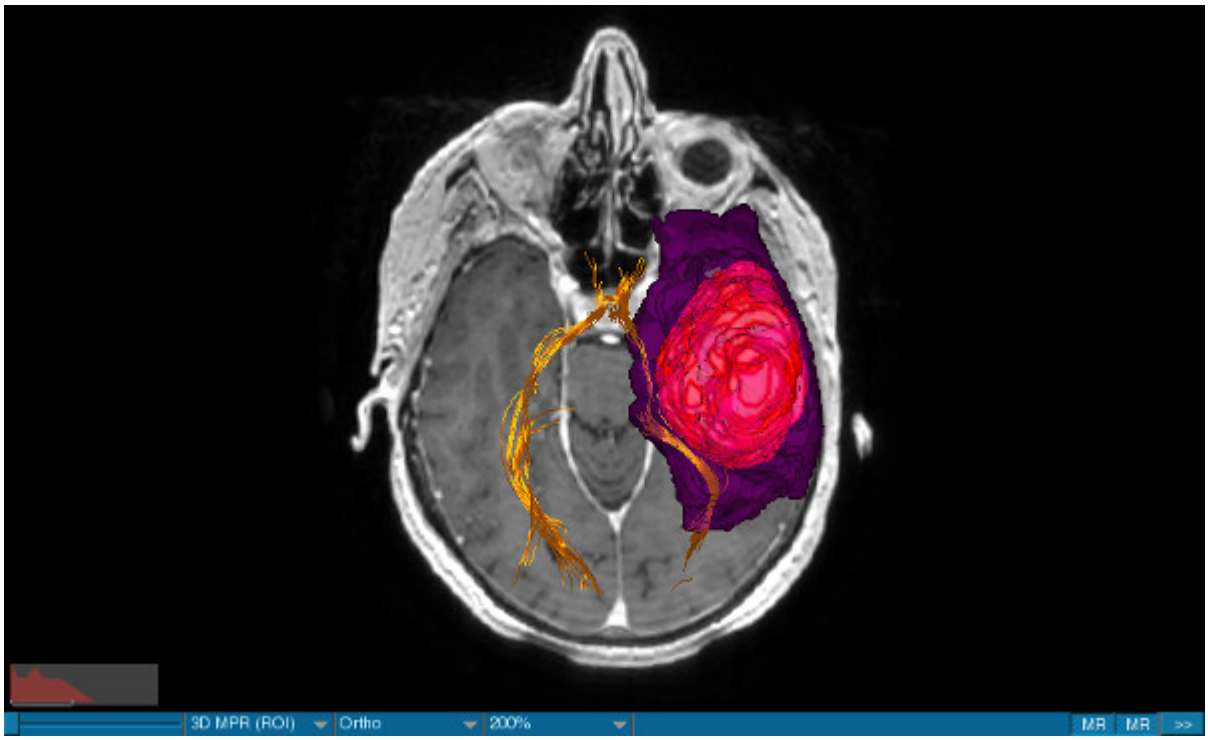

Figure 1. VP 1: Glioblastoma before surgery. The tumor is red. Edema is shown in purple and gold represents the VP. Displacement of the VP on the other side is shown. Please click here to view a larger version of this figure.

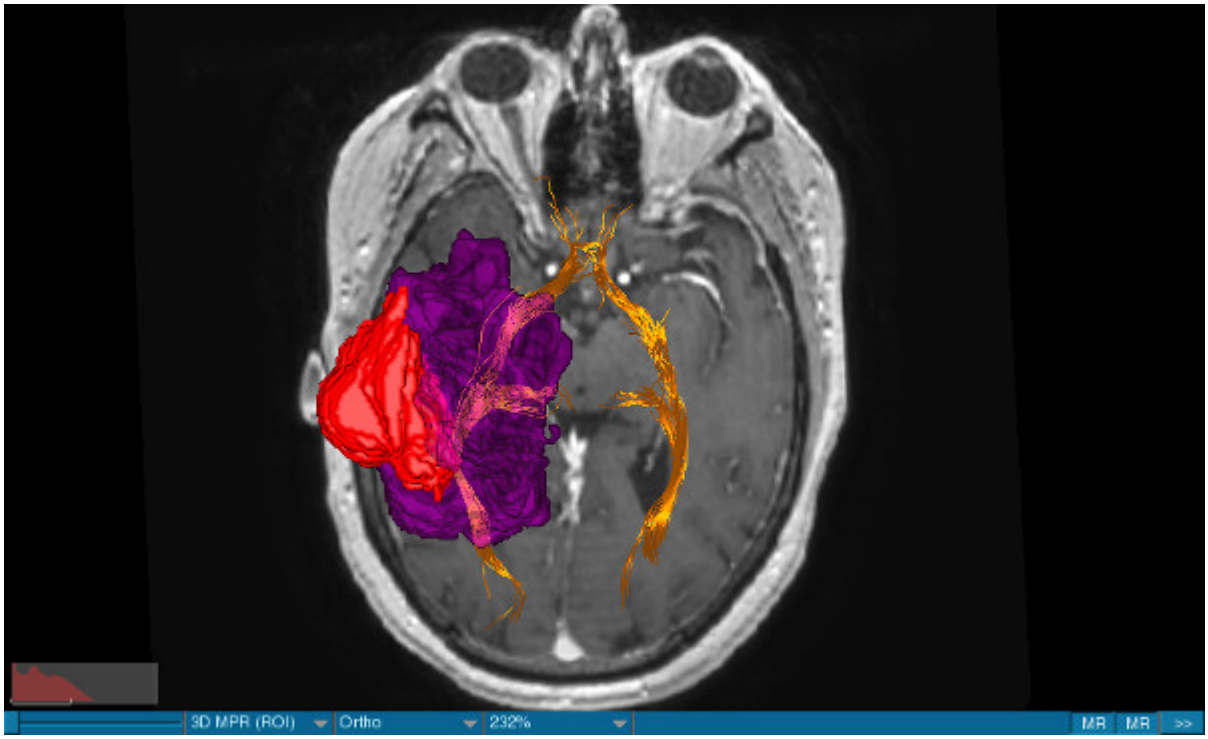

Figure 2. VP 2: Glioblastoma recurrence. The tumor is red. The edema (purple) surrounds the VP (gold). Please click here to view a larger version of this figure.

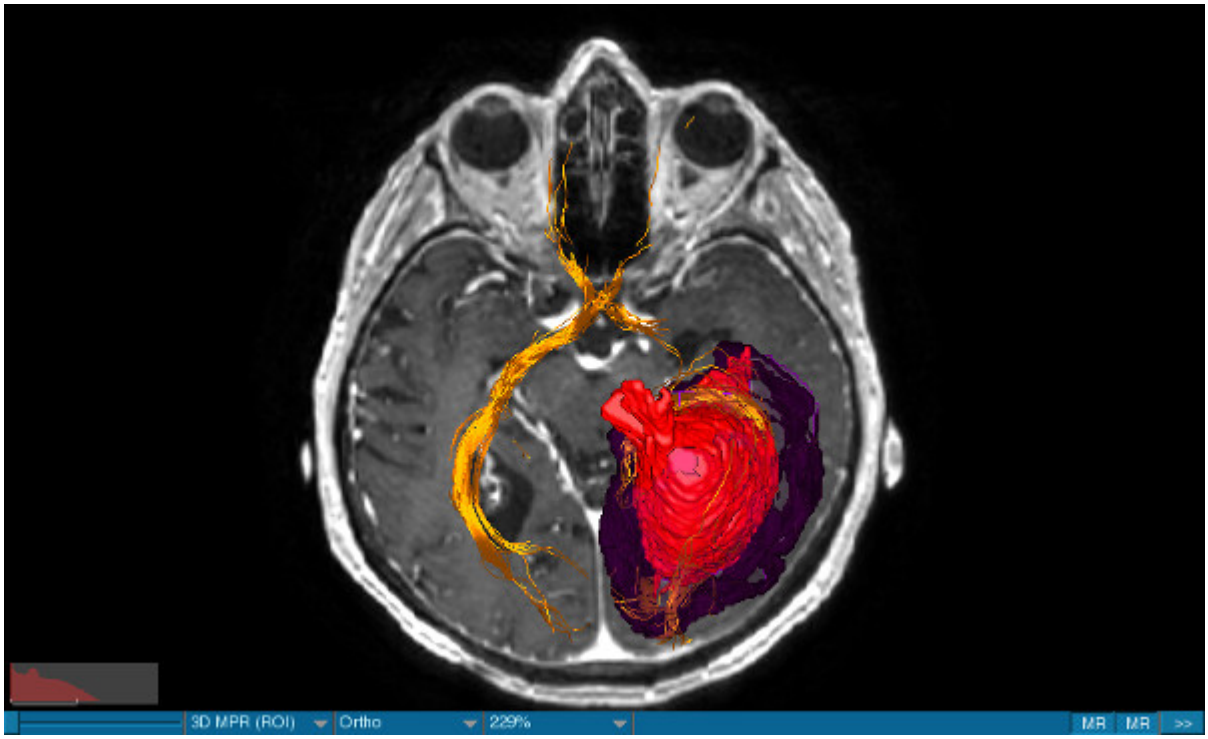

Figure 3. VP 3: Glioblastoma occipital. The tumor is red. Disruption of the VP (gold) anteriorly by tumor and edema (purple). Please click here to view a larger version of this figure.

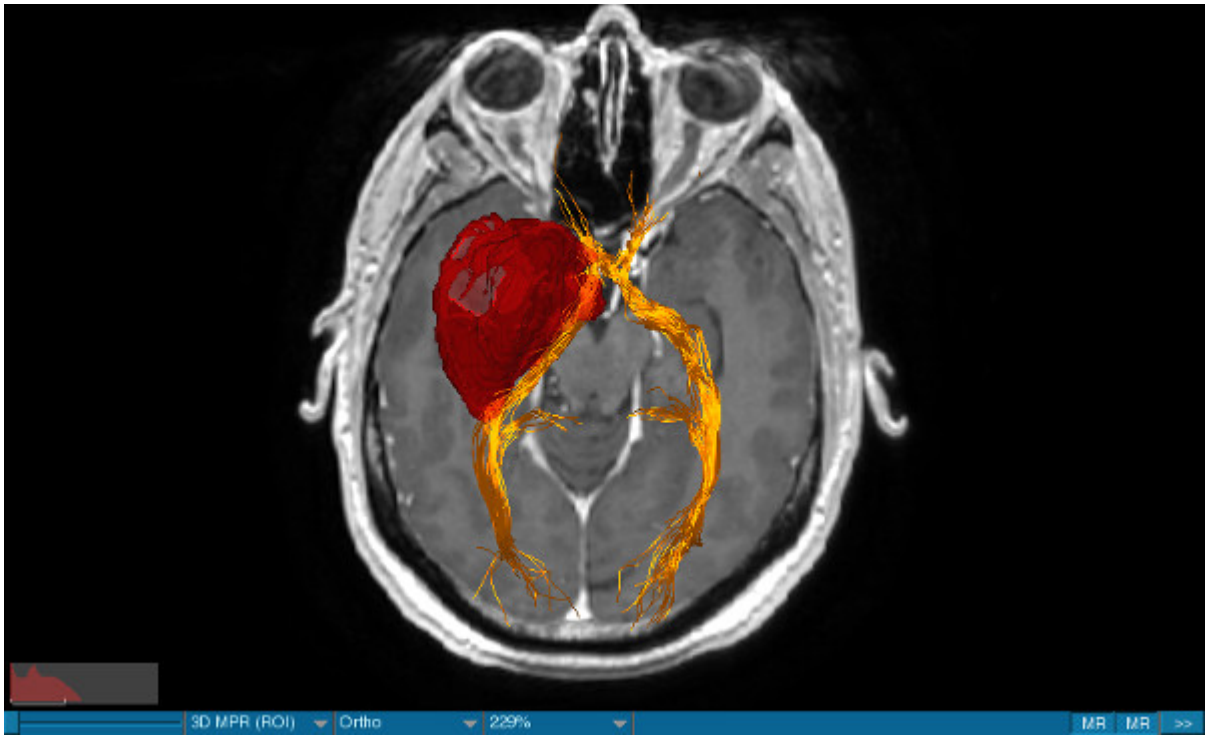

Figure 4. VP 4: Temporal glioblastoma. The tumor (red) touches the VP (gold) anteriorly. Please click here to view a larger version of this figure.

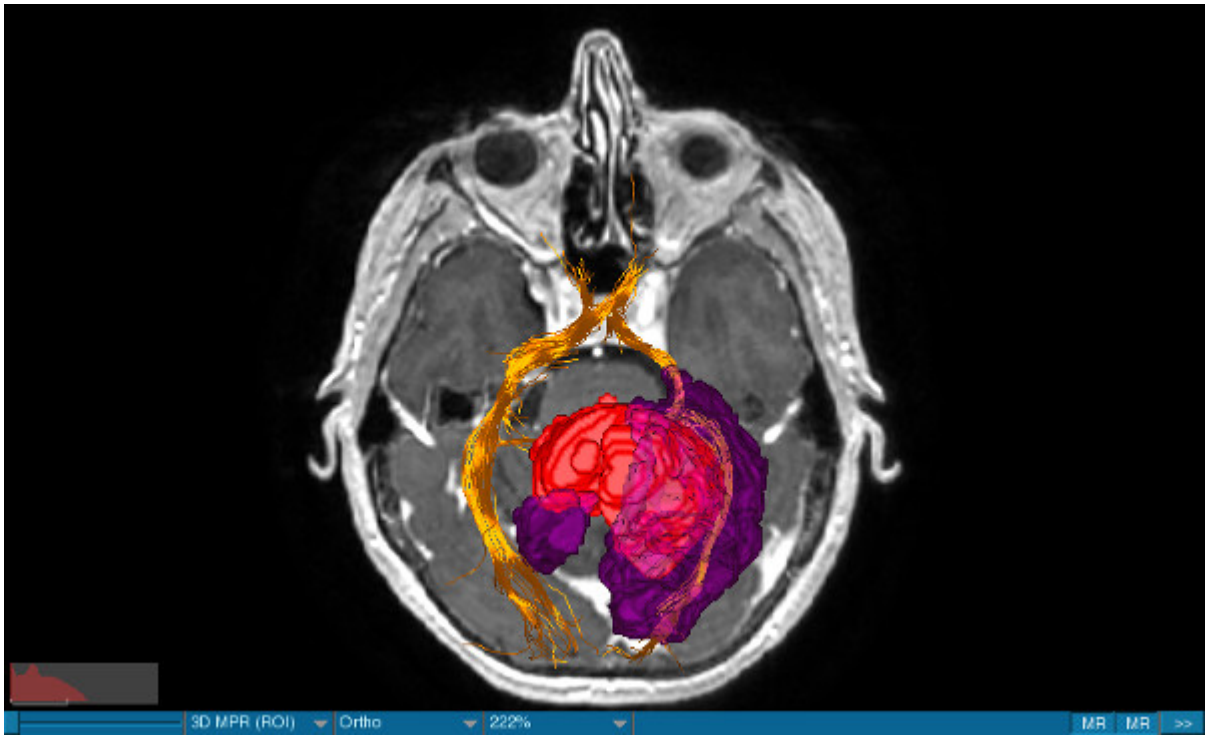

Figure 5. VP 5: Glioblastoma of the corpus callosum. The tumor (red) with edema (purple) surround the VP (gold). Please click here to view a larger version of this figure.

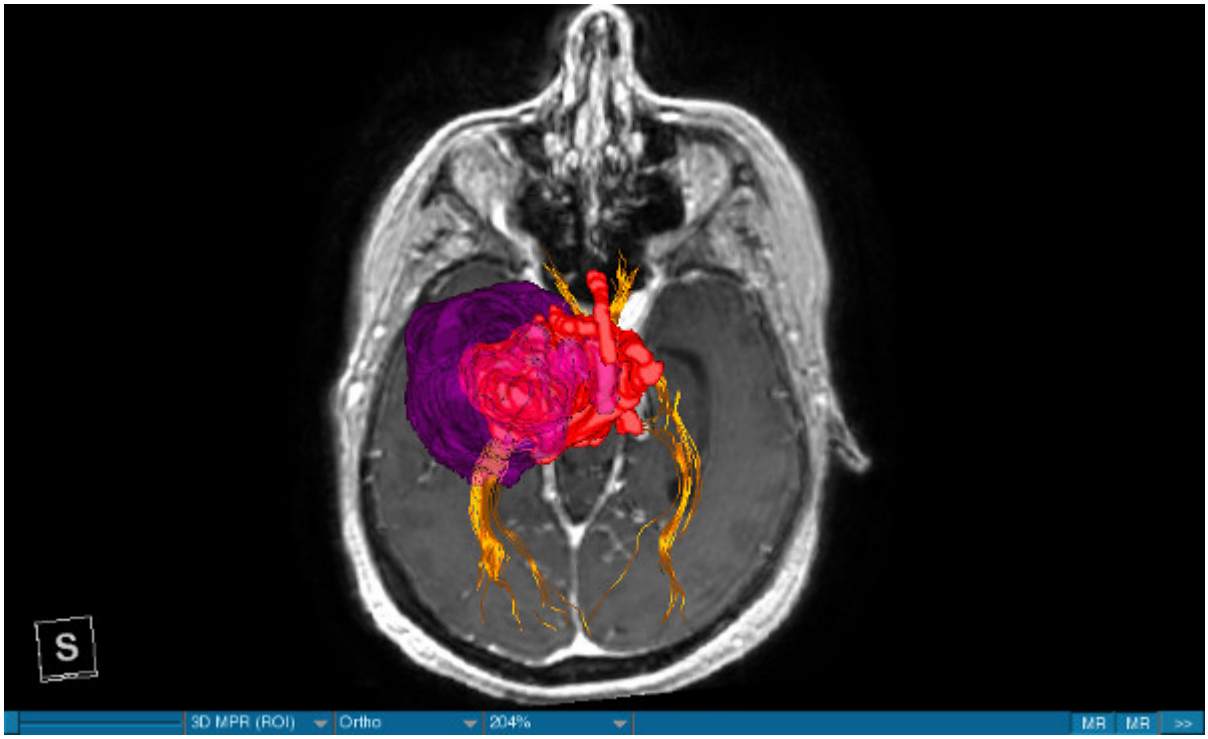

Figure 6. VP 6: Glioblastoma anterior. The tumor (red) and the edema (purple) surround the VP (gold). Please click here to view a larger version of this figure.

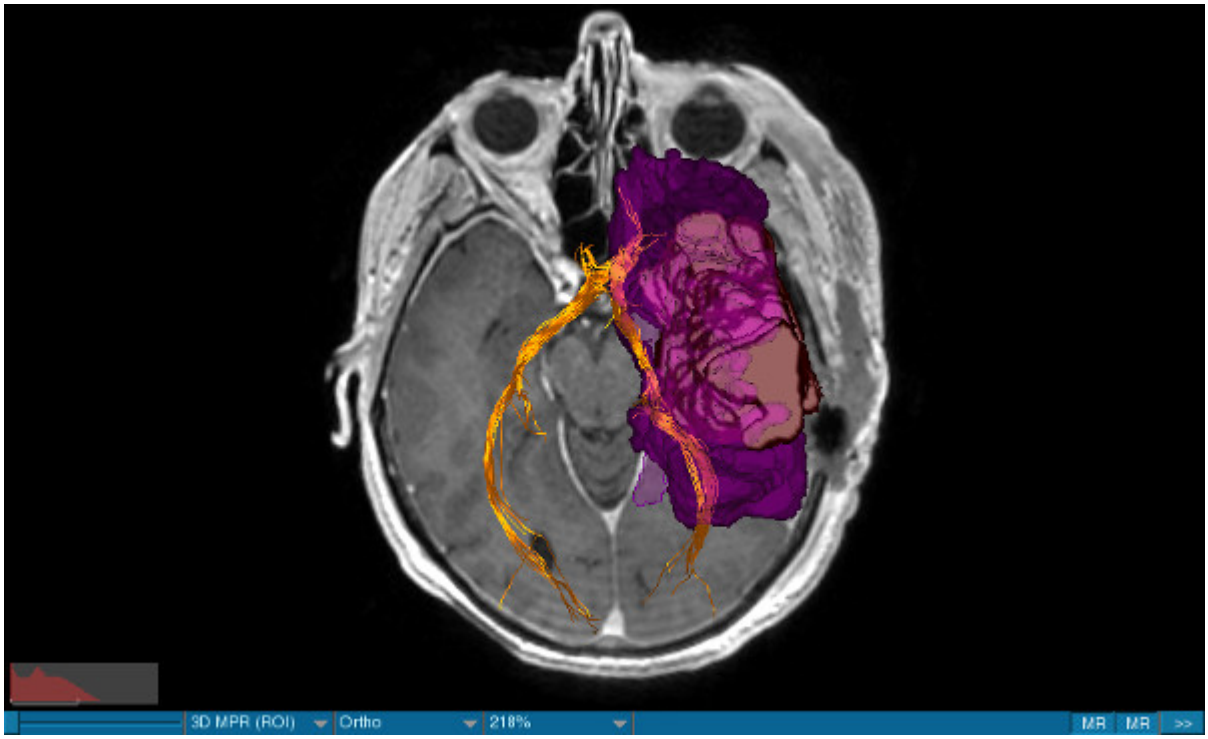

Figure 7. VP 7: VP after glioblastoma surgery. Black represents the cavity of the tumor. Edema (purple) is adjacent to the VP (gold). Please click here to view a larger version of this figure.

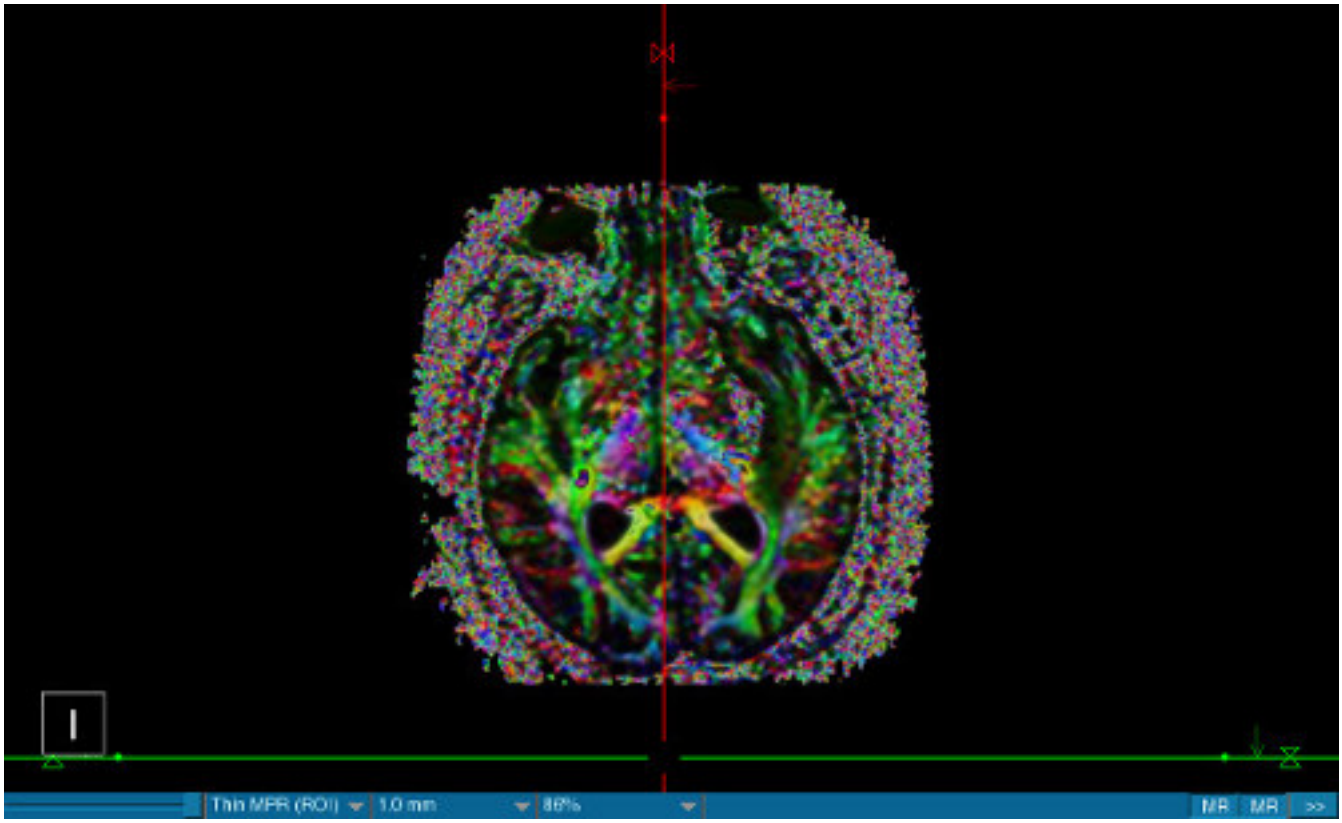

Figure 8. Preparation for fibertracking. Please click here to view a larger version of this figure.

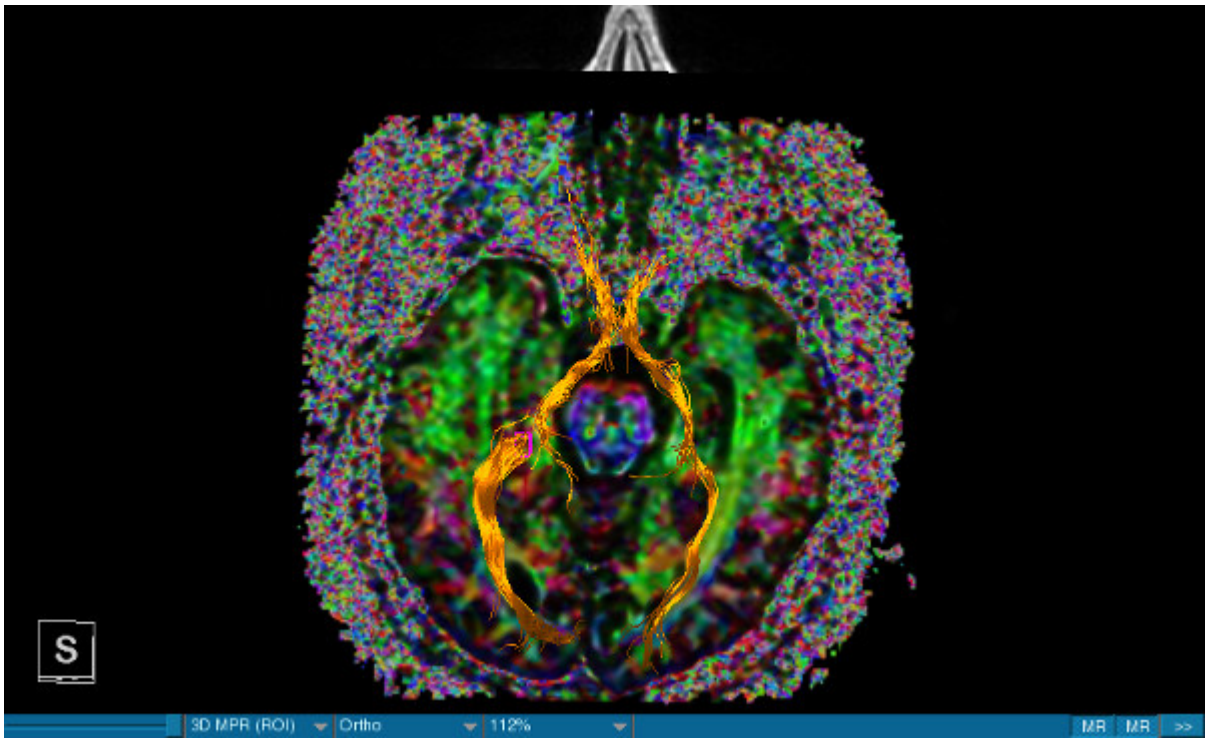

Figure 9. Preparation for fibertracking / VP. Please click here to view a larger version of this figure.

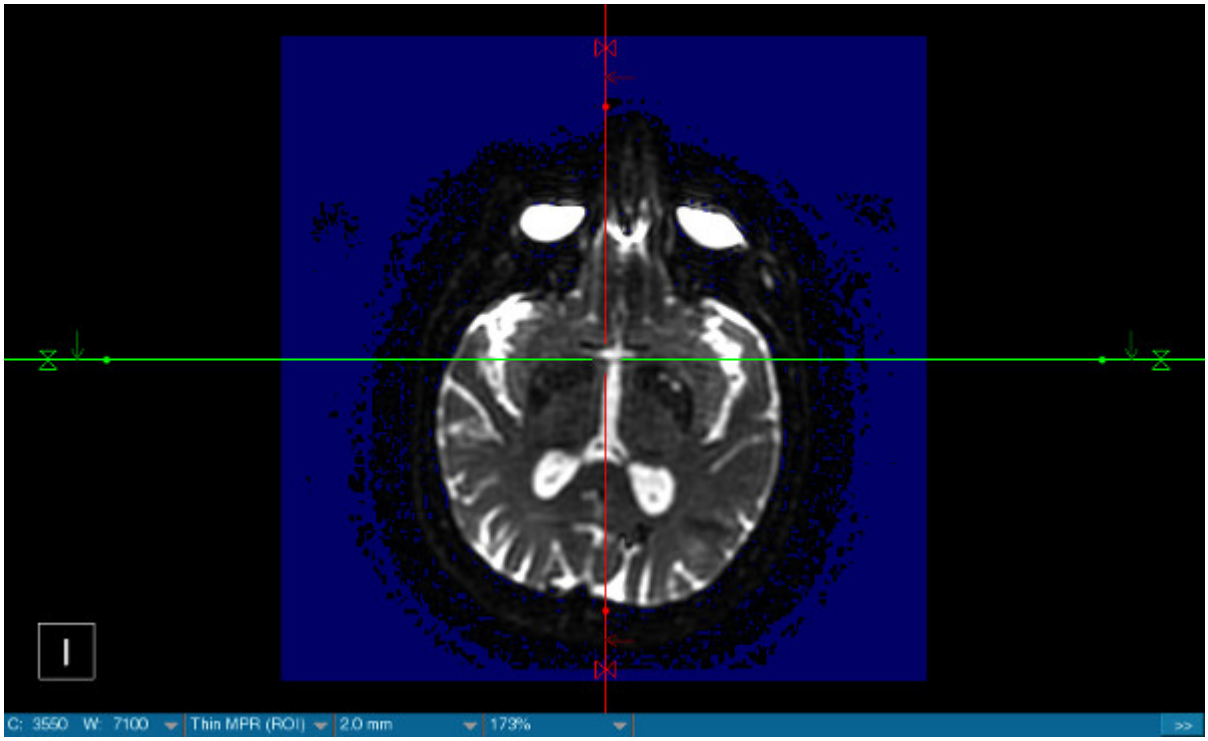

Figure 10. Preparation for fibertracking 3. Please click here to view a larger version of this figure.

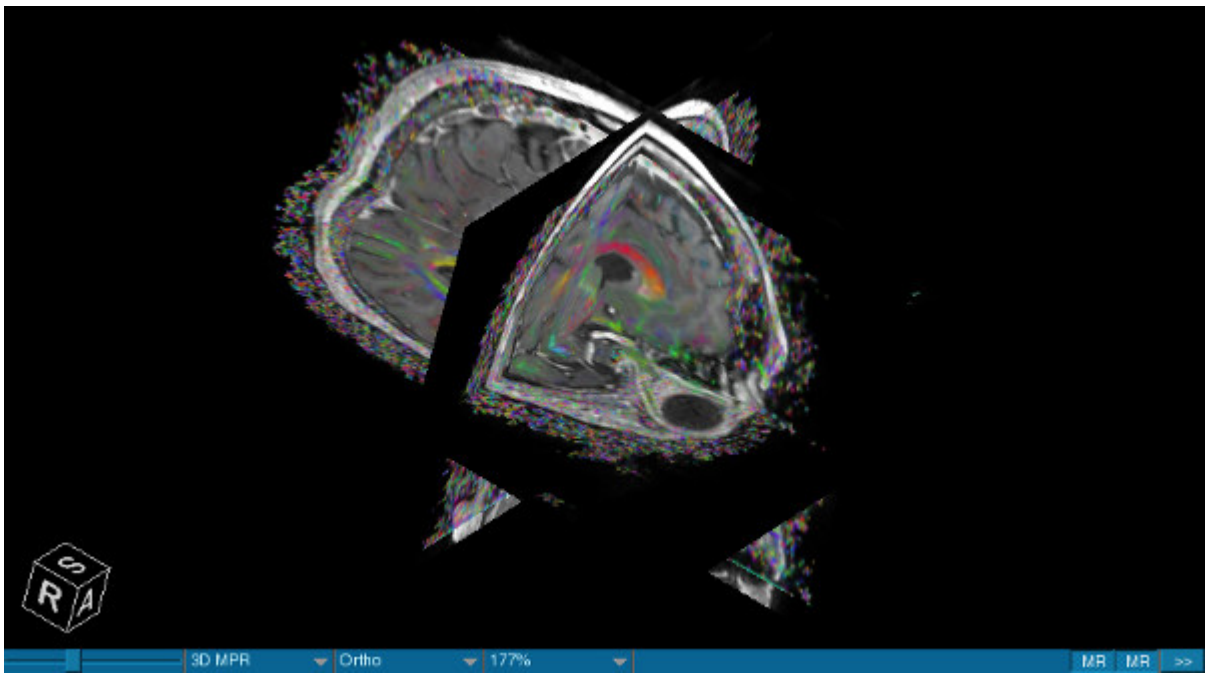

Figure 11. Preparation for fibertracking 4. Please click here to view a larger version of this figure.

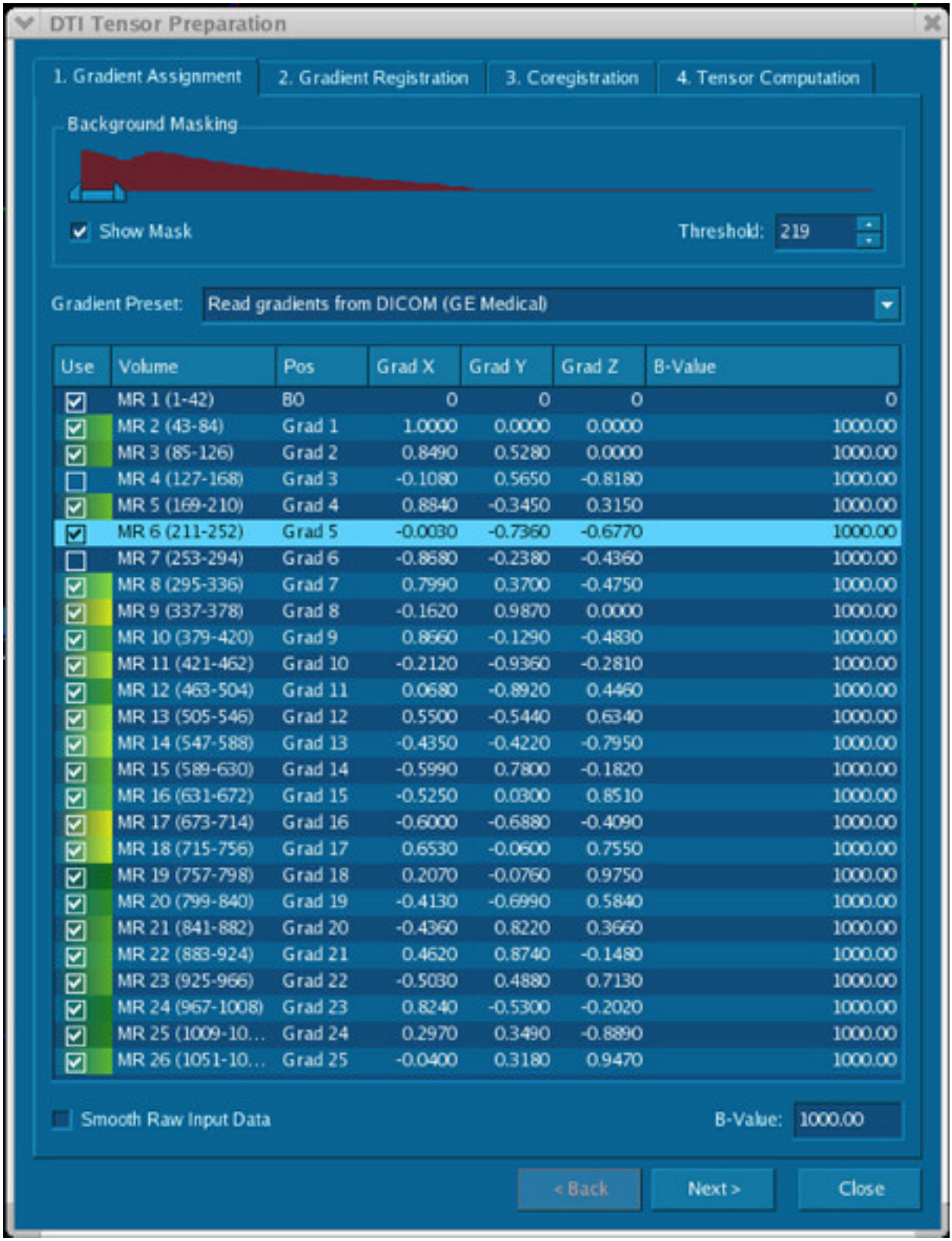

Figure 12. Preparation for fibertracking 5.

Discussion

DTI is a technique enabling the neurosurgeon to visualize white matter tracts *in vivo*[8]. The visual pathway is one of these tracts. Although this method provides physicians with new possibilities regarding the treatment of patients with lesions concerning eloquent regions of the brain we have to say that some limitations of this technique do still exist. The first and most obvious challenge is brain shift, which remains an issue under

investigation[4]. After opening the dura mater and after manipulation in the brain by removing the tumor or the cerebrospinal fluid loss we don`t have the same conditions as before surgery. Furthermore DTI is unable to solve the crossing or kissing of fibers and to determine with accuracy the origin and destination of fibers, producing multiple artifacts and false tracts[1-3]. Another problem is the resolution of fibers in areas of disturbed diffusion, for example due to tumor or peritumoral edema[22]. Small tracts with different directions within a voxel will not be imaged due secondary to partial volume artefacts[28]. The possibility of false positive and false negative tracts should always be taken into account. The results might be compromised. Other algorithms have shown the VP in a more complete way, however an international standardized procedure to depict the VP doesn`t exist up to date which might be confusing additionally. The portrayal of the Meyer loop remains a challenge for this protocol. Another limitation might consist in the depiction of the Baum loop. However we couldn`t find any note of the depiction of this loop elsewhere.

As mentioned before this protocol is easily feasible for the everyday routine. However a good preparation is required for a satisfactory outcome. It is necessary to take care that the images are performed strictly axial. It might compromise the quality of the images afterwards if this is not taken into account. A 3DT1-weighted image is always needed for the navigation. The slices should be thin enough in order to have good results. For this protocol we use 2 mm slices with no gaps in between. Respecting the protocol will lead to a good portrayal of the major parts of the VP. The VP was portrayed using multiple ROIs . The VC was always segmented additionally. Others have also used a multiple ROI approach[16,17]. DTI-angulation has also been tried out. It might have good results for anteroposterior fiberbundles but other fibers might come in an unfortunate position[12]. Further methods include seeding the fiber tracking from multiple fiducials placed on the optic tract near the LGN[11].

Future applications include the use of DTI in brain ischemia, multiple sclerosis, Alzheimer`s disease, portrayal of cranial nerves, gamma knife surgery and others [7, 13,28]. They are being used already in some institutions but this is not a routine everywhere. Intrasurgical mapping of optic radiation using subcortical electrical stimulation is a reliable method to identify and preserve this tract during glioma surgery[6]. Another possibility to monitor the functional integrity of the visual pathway is the intraoperative use of cortically recorded VEPs[5,10]. Intraoperative use of MRI might be a possibility to reduce the problem which arises with the brain shift alternatively the application of a 3D ultrasound might present an alternative[18]. Other diffusion imaging and reconstruction schemes have become increasingly relevant to portray the visual pathway. The visual pathway has more fibers and the Meyer loop is more reliably displayed[18].

Disclosures

The authors declare that they have no competing financial interests.

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