Application of diffusion tensor tractography in the surgical treatment of brain tumors located in functional areas

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Abstract. The present study aimed to explore the application of diffusion tensor tractography (DTT) in the preoperative planning and prognostic evaluation of tumors located in the functional areas of the brain. A total of 42 patients diagnosed with intracranial tumors were randomly assigned to either the trial or the control group. DT imaging (DTI) was performed on the basis of preoperative conventional magnetic resonance imaging (MRI) and analyzed for patients in the trial group. Patients in the control group underwent only routine MRI scans. The effect of DTT on the prognosis of patients was evaluated by tumor resection rate and quality of life evaluation using Karnofsky performance score (KPS) comparison between the trial and control groups. There were no significant differences for total tumor removal rate in the trial group (85.71%) compared with that in the control group (71.43%) ($P>0.05$). The rate of postoperative symptom improvement in the trial group (85.71%) was significantly higher compared with that in the control group (47.62%) ($P<0.05$). The KPS value of the trial group was significantly higher postoperatively (78.57±17.40) compared with that preoperatively (66.67±16.23) ($P<0.05$). The KPS value of the control group postoperatively (72.38±19.21) was significantly higher compared with that preoperatively (66.67±16.00) ($P<0.05$). The postoperative KPS improvement rate [postoperative value-preoperative value)/preoperative value] of the trial group was significantly higher compared with that in the control group. In conclusion, the use of DTT is an effective supplement to traditional MRI, with particular relevance in preoperative planning, particularly for tumors in the functional area of the brain, and can significantly improve the prognostic function of patients.

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Introduction

The traditional magnetic resonance imaging (MRI) scan can reveal the intracranial structure, intracranial tumor size, location and surrounding edema; however, it cannot precisely reveal the shape of the intracranial nerve fibers. With the development of high-field MR and computer technology, diffusion tensor imaging (DTI) has enabled non-invasive studies of the white matter fiber fascicle (1). DT tractography (DTT), which is developed from DTI, can reflect the pathological state of the white matter fiber fascicle and the anatomical connection with adjacent lesions, and assist the surgeon to design a suitable surgical strategy prior to surgery (2).

DTI is a functional MRI technique that is commonly used to evaluate the integrity of the white matter by measuring the water diffusion (3). DTI has been extensively applied to evaluate the specific white matter bands by using fiber tracking and to examine the axonal impairment resulting from the different disorders, such as corticospinal tract stroke, impairment in chronic spinal cord injury and asymptomatic neurocognitive impairment (4). The corpus callosum, which is known to be involved in the process of dichotic listening (5) and auditory hallucinations (6), can be visualized using DTI. Traditional MRI is limited by a resolution that is 1to 2orders of magnitude greater compared with the dimensions of cells and individual axons, therefore, revealing the surrounding axonal structure is difficult (7). However, DTI could be used to characterize the white matter fiber structure, integrity within the brain and how the water within the brain is affected. Compared with the traditional MRI technique, DTI is susceptible to numerous detrimental artefacts that may impair the reliability and validity of the obtained data (8). Meanwhile, DTI is not typically applied to detect the changes in the auditory processing. According to a previous study, the acquisition of DTI usually requires a number of primary conditions (7), including i) behavior of all the particles to be identical; ii) distribution of the displacements to be a finite variance; and iii) the displacement of DTI in future should be free of any influence that derives from the past DTI application. If the aforementioned conditions are not met, this may lead to a mono-exponential decay of MR signal (7). The purpose of the surgical strategy is to guarantee the integrity of the functional nerves of patients during surgery and to improve the quality of life of patients following surgery. Therefore, DTT can be a reliable strategy for doctors to improve surgical results and reduce the risk of surgery (9,10).

In the present study, DTI scans were performed and the generalized q-sampling imaging (GQI) methods were used to track the function-related fiber fascicles (pyramidal fascicle, associated with limb activity, and arcuate fascicle, associated with language) on the basis of a conventional MRI scan, in the trial group. The best safe surgical approach between the location of the tumor and the fiber fascicle was subsequently designed, and the results were compared with that in the patients of the control group, who only underwent a preoperative conventional MRI scan. Tumor resection rate, quality of life using Karnofsky performance score (KPS) (10) and the differences in postoperative functional improvement were compared between the trial and control groups to explore the importance of DTI in the protection of neurological function and the improvement of prognosis in functional brain tumor surgery.

Materials and methods

Selection of subjects. A total of 42 patients, who were diagnosed with a tumor located in the functional areas of the brain at The Affiliated Hospital of Qingdao University (Qingdao, Shandong, China) between June 2014 and June 2016, were randomly assigned to either the trial group or the control group. A total of 21 patients were recruited to the trial group where they underwent conventional MRI and DTI scans (Fig. 1); this group included 13 males and 8 females, with a mean age of 53.29 years. The tumors were located in 4 areas of the brain, including 8 tumors in the frontal lobe, 2 in the temporal lobe, 8 in the precentral gyrus and 3 in the cerebral falx. The mean tumor volume was 38,038.86±3,578.47 mm^3. A total of 21 patients were recruited to the control group where they underwent conventional MRI scans; this group included 11 males and 10 females, with a mean age of 48.24 years. The tumors were located in 4 areas of the brain, including 6 tumors in the frontal lobe, 3 in the temporal lobe, 7 in the precentral gyrus and 5 in the cerebral falx. The mean tumor volume was 46,788.62±3,095.99 mm^3. The clinical symptoms of the patients included headaches, epilepsy and limb hemiplegia. In addition, all patients underwent a craniotomy. The KPS score was used to evaluate the quality of life and functional status of the patients prior to and following surgery, and the postoperative pathological examination findings were considered as the final diagnosis basis. Briefly, the brain tissue samples were fixed using 4% paraformaldehyde at room temperature for 10 min, dehydrated using graded ethanol (85, 95 and 100%) (3 min per grade) and subsequently paraffin-embedded. Subsequently, the paraffin blocks were sectioned (with thickness of 4 μm) and stained using hematoxylin (cat. no. C0107) for 10 min at room temperature and eosin (cat. no. C0109) for 5 min at room temperature, according to the manufacturers protocols (both regents were purchased from Beyotime Institute of Biotechnology). Finally, the sections were sealed using the neutral-resin (Beyotime Institute of Biotechnology) and observed using the light microscope (model, BX-51; Olympus Corporation) at magnification of x400.

The tumors were classified according to the 2007 the World Health Organization classification of tumors of central nervous system (11).

The present study was approved by the Ethics Committee of The Affiliated Hospital of Qingdao University and all patients provided written informed consent.

MRI. MRI scans were performed using a 3.0T GE MR machine (GE Medical Systems, Milwaukee, WI, USA). The images were constructed by using the image-processing Living Image v3.2 software (Caliper Life Sciences; PerkinElmer, Inc.). Conventional MRI scans included the T1-weighted imaging (WI) sequence, T2WI sequence and fluid-attenuated inversion recovery sequence. Gadopentetate dimeglumine was used as the enhanced contrast agent, scanning 24 layers with a layer thickness of 5.0 mm and a layer spacing of 1.5 mm. DTI scans were performed using a 32-channel head coil in which the patient's head was held in place securely to prevent movement during the scan. The scan sequence was a single shot spin-echo planar image, and the number of the diffusion-sensitive gradient direction was 30. The following parameters were used: b value, 1,000 sec/m^2; repetition time (TR), 7,700 msec; echo time (TE), 77 msec; vision fields of view (FOV), 230x230 mm^2; voxel size, 2x2x2 mm^3; layer thickness, 2.0 mm; the number of excitations, 1; and 40 layers were continuously scanned without interval. The scan time was 286 sec. To distinguish between the anatomical regions, 3-dimensional T1WI scans were used with the sequence of a double flash using the following parameters: TR, 1,900 msec; TE, 2.99 msec; reversal time, 900 msec; layer thickness, 0.9 mm; flip angle, 9˚; number of excitations, 1; vision FOV, 230x230 mm^2; and voxel size, 0.9x0.9x0.9 mm^3. The scan time was 344 sec.

Image processing and analysis. The diffusion data in the Digital Imaging and Communications in Medicine format generated by the scan were imported into the DSI studio (http://dsi-studio.labsolver.org/) and processed with the GQI data reconstruction method. The fibers were tracked using the Trackvis software v0.6.1 (http://trackvis.org/), in which the commissural tracts were depicted in red, the association fibers were presented in green and the super-to-inferior running projection fibers were depicted in blue. The quality assurance (QA) threshold was set to 0.03574, the maximum angle to 7˚, the step length to 0.469 and the total number of brain fibers to 20,000 in the DSI studio software to reconstruct the GQI. The region of interest (ROI) method was used to separate the pyramidal fascicle and arcuate fascicle. For the pyramidal fascicle, the ROI was placed in one-third of the bilateral internal capsule of the posterior limb and in the lateral three-fifths of the bottom of the brain using the 'AND' logic to track. For the arcuate fascicle, the seeding area was placed in the bilateral superior temporal gyrus, middle temporal gyrus and inferior temporal gyrus, and a mask area of interest was then placed on the coronal position in the central posterior position for fiber tracking. At the same time, the QA values of the functional fiber fascicle were measured prior to and following surgery, and the changes were observed.

Surgical management. All the patients underwent craniotomy of the brain resection, which was completed by the same neurosurgeon using a microscope. In the trial group, the design of the skin flap and the surgical approach, the shape of the functional fascicle around the tumor and the spatial association with the tumor according to the preoperative DTT results were taken into consideration to avoid damage to the functional conducting fascicle. In the control group, the location of the tumor prior to surgery, as provided by the MRI scan and the natural fissures, including the sulcus and lateral fissure (which were close to the tumor), was selected for entry into the brain to avoid damage to the important cortex, nerves and blood vessels.

Postoperative evaluation. The postoperative tumor resection rate, the postoperative functional changing status and the behavior status (KPS score) were compared between the trial and control groups to evaluate any differences. The fractional anisotrophy (FA) value is the most commonly used quantitative analysis parameter of DTI, which reflects the percentage of water molecule anisotropy to the whole dispersion movement. The FA value ranges from 0 to 1, where 0 represents the isotropic dispersion of the water molecule, which means that the probability and distance of dispersion in all directions are equal, and 1 represents a large degree of directional dependence of the dispersion motion of the water molecules.

Statistical analysis. SPSS (v17.0; SPSS, Inc., Chicago, IL, USA) was used for the statistical analysis. All of the data analyzed were obtained from 6 repeat experiments, and 2 experts evaluated or analyzed the imaging data. The χ^2 test was used for count data. Analysis of variance (ANOVA) was used to compare the differences among multiple groups followed by Tukey's post-hoc test. P<0.05 was considered to indicate a statistically significant difference.

Results

Comparison of the preoperative data between the trial and control groups. There were no significant differences with regard to gender (data not shown; χ^2=0.389; P=0.533) or the distribution of age (data not shown; χ^2=0.452; P=0.414) between the trial and control groups. There were also no significant differences with regard to the lesion sites (data not shown; χ^2=4.057; P=0.908) or the volume of the lesion (χ^2=2.272; P=0.140). There were no statistically significant differences with regard to lesion location (χ^2=2.682; P=0.139) and tumor volume (χ^2=2.469; P=0.158) between the trial and control groups. There was also no significant difference with regard to the preoperative muscle strength (χ^2=0.138; P=0.864) and aphasia symptoms (χ^2=0.125; P=0.989) between the 2 groups.

Representative case reports. A 61-year-old male patient was admitted to the Affiliated Hospital of Qingdao University (Shandong, China) with progressive speech loss as the main complaint and included in the present study. Conventional MRI revealed lesions in the left temporal lobe space and a tumor located in the left temporal linguistic function area. Preoperative DTI examination revealed the location of the tumor and the arcuate fascicle and was used to assist with the surgery. The DTI management (GA) graph (Fig. 1A and B) illustrates the DTI images. The different colors reveal the shape of the fiber fascicle. Red represents the horizontal direction, green represents the front and rear direction, and blue represents the vertical direction. The GA graph reveals the reconstructed arcuate fascicle (Fig. 1C). The tumor was in the ventral temporal section of the arcuate fascicle and the tail part of the arcuate fascicle was pushed back. The red arrow reveals the safe surgical approach to avoid the destruction of the arcuate fascicle. The pyramidal fascicle on the left and right side is shown in Fig. 1D. Due to the large tumor and peritumoral edema, the pyramidal fascicle should be protected during the removal process. The vector phase reveals the shape of the arcuate fascicle and the locational association between the cortical end point and the tumor (Fig. 1E and F). The postoperative GA graph, the postoperative GA color graph, complete tumor resection are shown in Fig. 1G, H and I, respectively. The shape of the arcuate fascicle following the removal of the tumor in the axial and sagittal positions is shown in Fig. 1J-L. These images reveal that the temporal segment of the arcuate fascicle was integrate, and the fiber fascicle was thicker, indicating that there was a possibility to restore the function of the fiber fascicle following the removal of the tumor and the edema compression. The status prior to the opening of the dura mater (Fig. 1M) was evaluated and the appropriate tumor-removal angle was designed according to the preoperative DTI. The dark blue, straight line represents the lateral cut. The opening of the dura mater and the exposure of the tumor (Fig. 1N) were also observed. The careful removal of the tumor is shown in Fig. 1O; the black arrow reveals that the resection boundary of the tumor was deep into the middle cranial fossa, and the yellow arrows reveals the posterior temporal cut to the edema. In Fig. 1P, the completed tumor resection is shown and the green arc reveals the normal brain tissue boundary. The patient improved with regard to sensory aphasia following surgery. Postoperative pathological analysis revealed that the tumor was an astrocytoma (using World Health Organisation grade II) (12).

A 44-year-old female suffering from headaches and clumsiness in the right limb was admitted to the Affiliated Hospital of Qingdao University (Shandong, China) and recruited to the present study. MRI revealed lesions occupying the left temporal pelvic area and edema. Due to the limitation of limb activity, DTI examination was performed prior to surgery. The preoperative video material was collected (Fig. 2A-D) and the tumor was shown to compress the pyramidal fascicle from the posterior internal side. The pyramidal fascicle from the coronal display of the tumor side is significantly squeezed to the vicinity of the center line compared with the pyramidal fascicle of the uninjured side. The postoperative DTI review data were also collected (Fig. 2E-H). Following the complete resection of the tumor from axial and coronal phase, the pyramidal fascicle of the injured side was reset, and the postoperative limb activity of the patient was improved. Postoperative pathological analysis revealed that the tumor was a glioblastoma (World Health Organization grade IV) (12).

A third patient, a 51-year-old female suffering from a laborious right foot raise was also admitted to the Affiliated Hospital of Qingdao University (Shandong, China) and subsequently recruited in to the present study. The MRI revealed lesions on the left side of the brain (Fig. 3). Diffusion tensor tractography was performed to reconstruct the peritumoral fiber and indicated that the clear midline 13˚ angle was the safe surgical approach, with no damage to the peritumoral fiber.

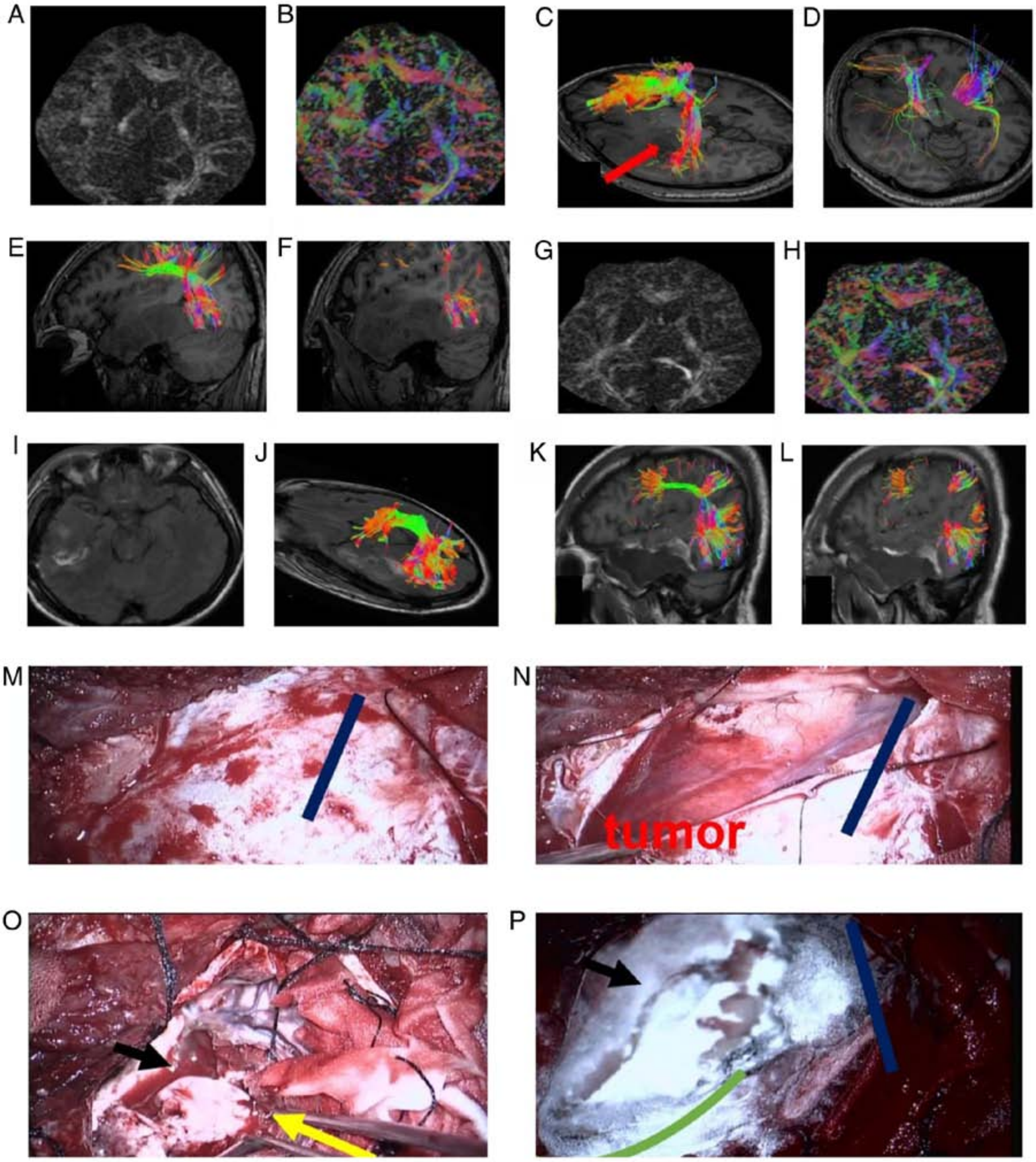

Figure 1. A 61-year-old male patient was admitted to the Affiliated Hospital of Qingdao University with progressive speech loss as the main complaint. (A-F) Preoperative DTI data: (A) The GA graph of DTI and (B) the GA color graph. (C) The GA graph reveals the reconstructed arcuate fascicle. (D) The pyramidal fascicle on the left and right side is revealed. (E and F) The vector phase reveals the shape of the arcuate fascicle and the locational association between the cortical end point and the tumor. (G-L) The postoperative review of DTI: (G) The postoperative GA graph. (H) The postoperative GA color graph. 9I) Complete tumor resection. (J-L) The shape of the arcuate fascicle following the removal of the tumor in the axial and sagittal positions. (M-P) The intraoperative situation: (M) The status prior to the opening of the dura mater. (N) The opening of the dura mater and the exposure of the tumor. (O) The careful removal of the tumor; the black arrow reveals that the resection boundary of the tumor was deep into the middle cranial fossa, and the yellow arrows reveals the posterior temporal cut to the edema. (P) The completed tumor resection and the green arc reveals the normal brain tissue boundary. DTI, diffusion tensor tractography; GA, DTI management.

Following surgery, the muscle strength of the patient improved with no secondary neurological dysfunction. Postoperative pathological analysis revealed that the tumor was a central neurocytoma (using World Health Organization grade II) (12).

Postoperative pathological types and number of cases. To compare the clinical outcomes effectively, the postoperative pathological types were determined. There were no significant differences with regard to the postoperative histopathological types (including meningioma, oligodendroglioma, astrocytoma, glioblastoma, metastatic carcinoma, cavernous hemangioma and central neurocytoma) and the number of cases between the trial and control groups (χ^2=2.500; P=0.927; Table I).

Resection numbers do not significantly differ. In the trial group, 18 patients underwent total resection, while 3 patients underwent subtotal resection; the total resection rate was 85.71%. In the control group, 15 patients underwent total resection, while

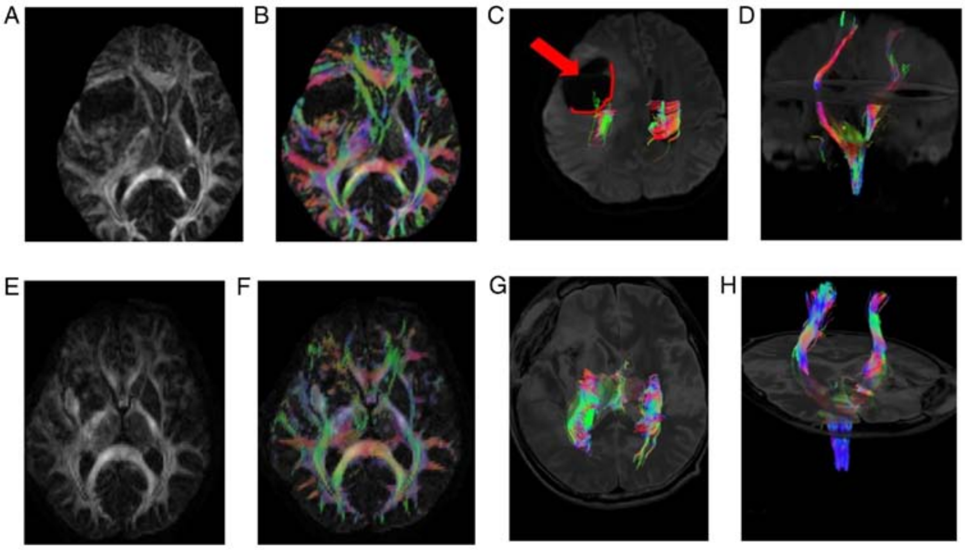

Figure 2. A 44-year-old female suffering from headaches and clumsiness in the right limb was admitted to Affiliated Hospital of Qingdao University. (A-D) The preoperative DTI video material. (A) The GA graph. (B) The colored GA graph. (C) The tumor compressing the pyramidal fascicle from the posterior internal side; the red arrow reveals the appropriate surgical approach, while the red arc indicates the safe removal range. (D) The pyramidal fascicle from the coronal display of the tumor side is significantly squeezed to the vicinity of the center line compared with the pyramidal fascicle of the uninjured side. (E-H) The postoperative DTI review data: (E) The GA graph. (F) The colored GA graph. Tumor from the (G) axial and (H) coronal phase. DTI, diffusion tensor tractography; GA, DTI management.

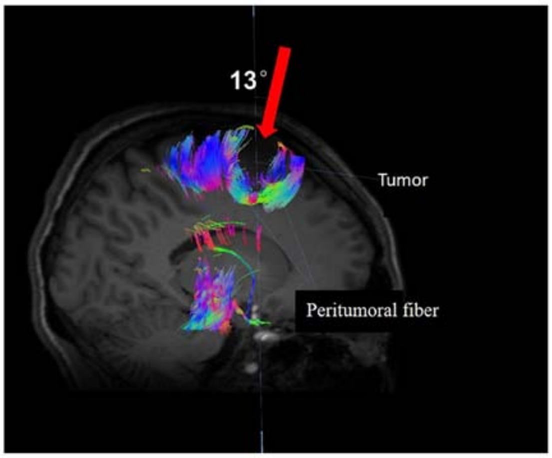

Figure 3. A 51-year-old female suffering from a laborious right foot raise was admitted to the Affiliated Hospital of Qingdoa University. The magnetic resonance imaging revealed lesions on the left side of the brain. Diffusion tensor tractography was performed to reconstruct the peritumoral fiber and indicated that the clear midline 13˚ angle was the safe surgical approach, with no damage to the peritumoral fiber. Following surgery, the muscle strength of the patient improved with no secondary neurological dysfunction. The red arrow indicates the tumor region.

6 patients underwent subtotal resection; the total resection rate was 71.43%. The χ^2 test revealed no significant differences between the trial and control groups for the total number of resections (χ^2=1.273; P=0.259; Table II).

Symptom improvement rate is significantly higher in the trial group. The changes in the postoperative symptoms were classified into 3 types (worse, no change or better) in terms of functional impairment (hemiplegia or aphasia) compared with that in the preoperative condition. The symptom improvement rate was 85.71% in the trial group and 47.62% in the control group. The χ^2 test revealed that the symptom improvement rate was significantly higher in the trial group compared with that in the control group (χ^2=6.952; P=0.031; Table III).

KPS value of the patients is significantly increased in the trial group. The KPS value of the patients in the trial group was 68.59±6.73 preoperatively and 79.06±7.40 postoperatively. ANOVA revealed that the KPS value postoperatively was significantly higher compared with the value preoperatively (P<0.001; Table IV). The KPS value of the patients in the control group was 65.84±9.05 preoperatively and 73.45±6.18 postoperatively. ANOVA revealed that the KPS value was significantly higher postoperatively compared with the value preoperatively (P<0.001; Table IV). ANOVA also revealed that the KPS value of the trial group was significantly higher compared with that in the control group (P=0.039; Table IV).

Discussion

DTI is a novel technique of signal acquisition and image contrast based on traditional MRI (12,13). The technique utilizes the difference in the diffusion of water molecules in the brain for imaging (14). Clinically, DTT can be a reliable strategy for doctors to improve surgical results and reduce the risk of surgery (15,16).

Numerous reports exist in the literature on the application of DTI and its guidance for craniotomy with functional MRI and intraoperative navigation. Previous studies reported that the preoperative DTI can affect the choice of surgical strategy, and with a combination of intra-operative DTI and navigation, surgeon scan better resect tumors and protect neurological function (17,18). Kuhnt *et al* (19) performed preoperative and intraoperative MRI scanning and reconstruction of language-related fibers for 32 patients diagnosed with glioma in the linguistic area, and suggested that the application

Table I. Postoperative tumor pathological types and the number of cases.

Pathological types	Trial group, n	Control group, n	χ^2	P-value
Meningioma	5	6	2.5	0.927
Oligodendroglioma	6	5		
Astrocytoma	4	5		
Glioblastoma	3	2		
Metastatic carcinoma	1	1		
Cavernous hemangioma	1	2		
Central neurocytoma	1	0		

Table II. Comparison of the resection rates between the trial and control groups.

Group name	Number of cases	Subtotal resection, n	Total resection, n	χ^2	P-value
Trial group	21	3	18	1.273	0.259
Control group	21	6	15		

Table III. Changes in the postoperative functional impairment symptoms compared with the preoperative symptoms.

		Functional impairment, n/total n				
Group name	Number of cases	Worse	No change	Better	χ^2	P-value
Trial group	21	1/21	2/21	18/21	6.952	0.031
Control group	21	5/21	6/21	10/21		

Table IV. Changes in the KPS values prior to and following surgery between the trial and control groups.

KPS value	Prior to surgery	Following surgery
Trial group	68.59±6.73	79.06±7.40^{a,b}
Control group	65.84±9.05	73.45±6.18^{c}

Data is presented as mean ± standard deviation. ^{a}P<0.001 vs. prior to surgery in the trial group; ^{b}P=0.039 vs. following surgery in the control group; ^{c}P<0.001 vs. prior to surgery in the control group. KPS, Karnofsky performance score.

of intra-operative MRI is essential for tumor resection and functional protection. D'Andrea *et al* (20) used preoperative DTI for patients with glioma near the right lateral temporal lobe to illustrate the tumor and the optic fascicle spatial shape. The through-temporal safety surgery approach was designed to avoid the destruction of the optic fascicle and included preoperative DTI and reconstruction of the optic fascicle to reduce the impact of cerebrospinal fluid caused by the release of brain drift. Thus, the complete removal of the tumor and the integrity of the optic fascicle was confirmed (20,21). Hayashi *et al* (22) performed preoperative and postoperative DTI for patients with brain tumors and found that in 5/7 patients, the arcuate fascicles following surgery were more clearly visible compared with those prior to surgery. In addition, in 6 patients, the language function score increased compared with that prior to surgery, and the difference was statistically significant (P=0.004). This study not only validates the important role of the arcuate fascicle in language function, but also reveals the positive effect of preoperative DTI-guided surgery on functional protection (22).

In the present study, the arcuate fascicle and the pyramidal fascicle, which are the 2 fiber fascicles associated with language and limb movements, respectively, were selected as the fiber-tracking objects, and conventional MRI and DTI scans were performed for the 21 patients in the trial group. According to DTI tracking of the fiber fascicles, the designated surgical strategy was chosen. The control group, with 21 patients, underwent a conventional MRI scan only, and the surgeon chose the surgical approach nearest to the cortex and away from the functional area. In the trial group, 18 patients underwent total tumor resection and 3 patients underwent subtotal resection (85.71% total resection rate). In the control group, 15 patients underwent total resection and 6 patients underwent subtotal resection (71.43% total resection rate). There were no statistically significant differences in the total resection rate between the trial group and the control group. Although preoperative DTI can indicate the positional association between the functional fiber and the tumor, and guide the design of the surgical approach, the tumor resection rate was not significantly improved, as without intra-operative navigation and intra-operative MRI, the tumor resection rate and resection scope are mainly associated with the experience of the surgeon. Following surgery, the symptom improvement rate was compared between the trial and control groups. The trial group had an improvement rate of 85.71%, while the control group had an improvement rate of 47.62%. The symptom improvement rates were statistically significant when comparing between the trial and control groups. The KPS improvement values between the trial and control groups were compared prior to and following surgery, and it was revealed that the postoperative KPS values for the trial and control groups were increased compared with the preoperative KPS values; the KPS improvement rate for the trial group was higher compared with that of the control group. This suggests that preoperative DTI can guide a safer surgical approach to improve the symptoms of the patients and to avoid the occurrence of iatrogenic dysfunction with a surgeon's limited operation experience. In summary, the present study revealed that for patients with tumors in the functional areas of the brain, preoperative DTI can 3-dimensionally reveal the tumor and its location with regard to the peripheral nerve, and this can guide the surgical approach and removal of the scope of assessment. However, the use of preoperative DTI cannot significantly improve the rate of total resection of the tumor. Meanwhile, only 3 glioblastoma cases were discovered in the trial group and 2 in the control group, therefore, it is difficult to improve the prognosis among these patients, which is important to avoid neurological function of iatrogenic injury. The effects of preoperative DTI on the improvement of the prognosis of patients would require evaluation in future investigations. Moreover, the present study was not restricted to primary brain tumors, such as metastatic carcinoma and meningioma, which would also require specific investigation in further studies.

In conclusion, the use of DTT is an effective supplement to traditional MRI; it has particular relevance in preoperative planning, particularly in functional areas of brain tumors, and can significantly improve the prognostic function of patients.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Authors' contributions

HZ and HJ designed the study. HZ, YF, LC and JL performed the imaging analysis and associated tests or experiments. HL reviewed the literature. JL and HL conducted the statistical analysis. HZ wrote the manuscript. HJ critical corrected and final reviewed the manuscript for publication. All authors read and approved the final manuscript.

Ethics approval and consent to participate

The present study was approved by the Ethics Committee of The Affiliated Hospital of Qingdao University (Qingdao, China) and the patients provided written informed consent.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

References

1. Tian W, Zhang J, Tian F, Shen J, Niu T, He G and Yu H: Correlation of diffusion tensor imaging parameters and Gleason scores of prostate cancer. Exp Ther Med 15: 351-356, 2018.
2. Castellano A, Bello L, Michelozzi C, Gallucci M, Fava E, Iadanza A, Riva M, Casaceli G and Falini A: Role of diffusion tensor magnetic resonance tractography in predicting the extent of resection in glioma surgery. Neuro Oncol 14: 192-202, 2012.
3. Stadlbauer A, Nimsky C, Buslei R, Salomonowitz E, Hammen T, Buchfelder M, Moser E, Ernst-Stecken A and Ganslandt O: Diffusion tensor imaging and optimized fiber tracking in glioma patients: Histopathologic evaluation of tumor-invaded white matter structures. Neuroimage 34: 949-956, 2007.
4. Lee JS, Han MK, Kim SH, Kwon OK and Kim JH: Fiber tracking by diffusion tensor imaging in corticospinal tract stroke: Topographical correlation with clinical symptoms. Neuroimage 26: 771-776, 2005.
5. Musiek FE and Weihing J: Perspectives on dichotic listening and the corpus callosum. Brain Cogn 76: 225-232, 2011.
6. Seok JH, Park HJ, Chun JW, Lee SK, Cho HS, Kwon JS and Kim JJ: White matter abnormalities associated with auditory hallucinations in schizophrenia: A combined study of voxel-based analyses of diffusion tensor imaging and structural magnetic resonance imaging. Psychiatry Res 156: 93-104, 2007.
7. Ye AQ, Hubbard Cristinacce PL, Zhou FL, Yin Z, Parker GJ and Magin RL: Diffusion tensor MRI phantom exhibits anomalous diffusion. Conf Proc IEEE Eng Med Biol Soc 2014: 746-749, 2014.
8. Liu B, Zhu T and Zhong J: Comparison of quality control software tools for diffusion tensor imaging. Magn Reson Imaging 33: 276-285, 2015.
9. Savardekar AR, Patra DP, Thakur JD, Narayan V, Mohammed N, Bollam P and Nanda A: Preoperative diffusion tensor imaging-fiber tracking for facial nerve identification in vestibular schwannoma: A systematic review on its evolution and current status with a pooled data analysis of surgical concordance rates. Neurosurg Focus 44: E5, 2018.
10. Rades D, Bolm L, Kaesmann L and Bartscht T: Karnofsky performance score is predictive of survival after palliative irradiation of metastatic bile duct cancer. Anticancer Res 37: 949-951, 2017.
11. Louis DN, Ohgaki H, Wiestler OD, Cavenee WK, Burger PC, Jouvet A, Scheithauer BW and Kleihues P: The 2007 WHO classification of tumours of the central nervous system. Acta Neuropathol 114: 97-109, 2007.
12. Hattori N, Hirose Y, Sasaki H, Nakae S, Hayashi S, Ohba S, Adachi K, Hayashi T, Nishiyama Y, Hasegawa M and Abe M: World Health Organization grade II-III astrocytomas consist of genetically distinct tumor lineages. Cancer Sci 107: 1159-1164, 2016.
13. Ouyang A, Jeon T, Sunkin SM, Pletikos M, Sedmak G, Sestan N, Lein ES and Huang H: Spatial mapping of structural and connectional imaging data for the developing human brain with diffusion tensor imaging. Methods 73: 27-37, 2015.

14. Jang SH and Shin SM: The usefulness of diffusion tensor tractography for estimating the state of corticobulbar tract in stroke patients. Clin Neurophysiol 127: 2708-2709, 2016.
15. Landi A, Innocenzi G, Grasso G, Meschini A, Fabbiano F, Castri P and Delfini R: Diagnostic potential of the diffusion tensor tractography with fractional anisotropy in the diagnosis and treatment of cervical spondylotic and posttraumatic myelopathy. Surg Neurol Int 7 (Suppl 25): S705-S707, 2016.
16. Singh S, Trivedi R, Singh K, Kumar P, Shankar LR and Khushu S: Diffusion tensor tractography in hypothyroidism and its correlation with memory function. J Neuroendocrinol 26: 825-833, 2014.
17. Sun GC, Chen XL, Zhao Y, Wang F, Hou BK, Wang YB, Song ZJ, Wang D and Xu BN: Intraoperative high-field magnetic resonance imaging combined with fiber tract neuronavigation-guided resection of cerebral lesions involving optic radiation. Neurosurgery 69: 1070-1084, 2011.
18. Muthusami P, James J, Thomas B, Kapilamoorthy TR and Kesavadas C: Diffusion tensor imaging and tractography of the human language pathways: Moving into the clinical realm. J Magn Reson Imaging 40: 1041-1053, 2014.
19. Kuhnt D, Bauer MH and Nimsky C: Brain shift compensation and neurosurgical image fusion using intraoperative MRI: Current status and future challenges. Crit Rev Biomed Eng 40: 175-185, 2012.
20. D'Andrea G, Familiari P, Di Lauro A, Angelini A and Sessa G: Safe resection of gliomas of the dominant angular gyrus availing of preoperative FMRI and intraoperative DTI: Preliminary series and surgical technique. World Neurosurg 87: 627-639, 2016.
21. Kis D, Mate A, Kincses ZT, Voros E and Barzo P: The role of probabilistic tractography in the surgical treatment of thalamic gliomas. Neurosurgery 10 (Suppl 2): S262-S272, 2014.
22. Hayashi Y, Kinoshita M, Nakada M and Hamada J: Correlation between language function and the left arcuate fasciculus detected by diffusion tensor imaging tractography after brain tumor surgery. J Neurosurg 117: 839-843, 2012.