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Neuroanatomical Study

The usefulness of arcuate fasciculus tractography integrated navigation for glioma surgery near the language area; Clinical Investigation

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ABSTRACT

Background: The utility of corticospinal tract (CST)-tractography-integrated navigation was reported for brain tumors near pyramidal tracts. However, the efficacy of arcuate fasciculus (AF)-tractography-integrated navigation is unclear. Awake craniotomy is recommended to preserve language function for glioma located near the language area, although the patients' condition can limit its application. In such cases, AF-tractography-integrated navigation may help protect neurological function.
Methods: We performed a retrospective analysis of AF-tractography-integrated navigation. We evaluated 11 patients who underwent glioma surgery near the language area using AF-tractography-integrated navigation. Six patients received intraoperative awake language functional mapping, whereas five did not due to adverse preoperative or intraoperative conditions. Language function was evaluated using the Western Aphasia Battery or Standard Language Test of Aphasia both preoperatively and postoperatively (2–4 weeks and 2–3 months after surgery).
Results: Extent of resection (EOR) ranged from 59.5% to 100% (mean 82.1%). Language function at 2–3 months after surgery was improved in one patient, intact in nine, and moderately disturbed in one compared with preoperative function. Among the non-awake craniotomy group, EOR ranged from 78.7% to 100% (mean 89.82%). Language function at 2–3 months after surgery was improved in one patient, intact in three, and moderately disturbed in one, in whom tumor removal very close to the AF tract was performed following preoperative patient's intent.
Conclusions: AF-tractography-integrated navigation is useful for glioma surgery near the language area, especially for patients with unsuitable conditions for awake craniotomy.

1. Introduction

In glioma surgery, the maximum extent of resection (EOR) is critical for the survival of patients [1]. Nevertheless, minimizing tissue removal for preservation of brain function is also important for their quality of life. To remove a glioma near the language area, we generally perform language mapping and monitoring under awake craniotomy to protect language function [2]. However, the patient's condition can limit the application of this technique; for example, if the patient has insufficient language potential remaining for intraoperative language evaluation, or the patient's intraoperative condition is unsuitable for intraoperative language evaluation.

Abbreviations: 3D, three-dimensional; AF, arcuate fasciculus; AQ, aphasia quotient; CCEP, Cortico-cortical evoked potential; CST, corticospinal tract; DTI, diffusion tensor imaging; EOR, extent of resection; FLAIR, fluid attenuated inversion recovery; FOV, field of view; GdT1WI, gadolinium-enhanced T1 weighted imaging; MEP, motor evoked potential; PDD, photo dynamic diagnosis; SLTA, Standard Language Test of Aphasia; TE, echo time; TI, inversion time; TR, repetition time; VOI, volume of interest; WAB, Western Aphasia Battery.

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Recently, tractography, a neural fiber bundle imaging technique derived from diffusion tensor MRI using fiber tracking technology, has been widely used to evaluate white matter connectivity. The arcuate fasciculus (AF) is considered a key associative pathway controlling verbal language function [3,4]. Several studies have reported that corticospinal tract (CST) tractography can be applied to navigation systems for operating on tumors near the motor area to protect the patient's motor functions [5–7]. As for the CST, visualization of the AF and its application to surgical navigation may be useful to protect language function during neurosurgery. However, application of AF tractography for intraoperative navigation has not been fully elucidated. Since 2012, we have used preoperative AF-tractography-integrated navigation for patients undergoing glioma surgery near the language area. In the present study, we performed a retrospective analysis of the utility of preoperative AF-tractography-integrated navigation for tumor removal.

2. Patients and methods

2.1. Patient background

Between January 2012 and June 2014, we performed surgical resection for 62 patients with gliomas (WHO grade II–IV). Among those cases, 11 patients who underwent radical glioma surgery near the language area were provided precise preoperative analysis with diffusion tensor imaging (DTI). Consequently, AF tractography was integrated into the navigation system for all patients to prevent further neurological deterioration. We obtained informed consent from each patient or next of kin in the use of AF-tractography-integrated navigation for tumor removal.

2.2. Clinical evaluation

All patients were clinically assessed by neurosurgeons and rehabilitation therapists before and after surgery. The evaluation of language function was performed using the Western Aphasia Battery (WAB) or Standard Language Test of Aphasia (SLTA), a commonly used test battery to evaluate Japanese patients with aphasia [8]. Postoperative evaluation of language was also performed at 2–4 weeks and 2–3 months after the operation.

Postoperative language function was compared with preoperative function, and was ranked as improved (improvement of aphasia quotient (AQ) in WAB, or increase in average percentage of correct answers in SLTA, by more than 3% than preoperative evaluation), intact (between 3% decline and 3% gain compared with preoperative evaluation), slightly disturbed (decline between 3% and 10% compared with preoperative evaluation), moderately disturbed (decline between 10% and 50% compared with preoperative evaluation), or severely disturbed (decline by more than 50% compared with preoperative evaluation).

2.3. Radiological data acquisition

Preoperative three-dimensional (3D) fluid attenuated inversion recovery (FLAIR), 3D gadolinium-enhanced T1 weighted imaging (GdT1WI), DTI using a 3.0 T MRI (Philips Achieva 3.0, Philips Medical Systems, Eindhoven, the Netherlands), TI parameter for GdT1WI, and scan technique for DTI were performed for tumor characterization. The acquisition methods were as follows: FLAIR: scan technique = 3D fast spin-echo sequence, repetition time (TR) = 6000 ms, echo time (TE) = 270 ms, inversion time (TI) = 2200 ms, slice thickness = 1.3 mm, field of view (FOV) = 240 mm; GdT1WI: scan technique = 3D gradient-echo sequence, TR = 8.2 ms, TE = 3.8 ms, flip angle = 8°, slice thickness = 1.0 mm, FOV = 240 mm; DTI: TR = 7700 ms, TE = 90 ms, slice thickness = 2 mm, FOV = 230 mm, b value = 800 s/mm^2, motion probing gradient directions = 15. Patients also received postoperative FLAIR and GdT1 MRI as described above. Preoperative and postoperative tumor size measurement was performed by 3D volumetry. The tumor was defined as inside the GdT1WI-enhanced areas for glioblastoma, and FLAIR hyperintensity lesion for other tumors.

2.4. DTI analysis and application for the navigation system

Analysis of DTI for visualization of AF was performed using the Medtronic Stealth S7 planning station (Medtronic, Inc., Minneapolis, MN, USA). The DTI dataset and the GdT1WI or FLAIR dataset were merged automatically on the planning station. A fractional anisotropy (FA) color map was then calculated from the DTI datasets. Fiber tracking was performed as previously reported [9,10], although we modified the volume of interest (VOI) to be set on three regions, the inferior frontal gyrus (pars opercularis), the dorsolateral parietal white matter, and the superior temporal gyrus, using GdT1WI or FLAIR anatomical feature points, and the fibers crossing all of these VOI were visualized. The FA cutoff value used for AF fiber tracking was set between 0.15 and 0.2, and the maximum directional change was set between 60° and 150°. The obtained 3D AF tractography data were then superimposed onto the GdT1WI or FLAIR datasets in three planes. In some patients, tractography was also performed on the CST or optic tract (OT). Tractography superimposed images were then sent to the navigation system (Medtronic Stealth Treon; Medtronic, Inc.). Marker registration was performed and intraoperative navigation was performed.

2.5. Intraoperative use of DTI-integrated navigation system

For the awake craniotomy patients, we used the AF-tractography-integrated navigation system mainly to identify the site of direct electrical stimulation at the border of the tumor. When electrical stimulation caused any speech disturbance at the site, further tumor resection was aborted. When the electrical stimulation did not cause any speech disturbance, careful resection was continued with a continuous speech task until any sign of the speech disturbance was detected.

For the non-awake craniotomy patients, AF tractography played more important role in deciding the border of resection compared with the awake craniotomy patients. When the navigation presented AF tractography very close to the tumor removal sight, the 5-ALA system and intraoperative ultrasonography was used to detect the residual tumor. We confirmed each patient's intent before surgery to decide whether we should stop or continue removal of the tumor when residual tumor seemed very closely located to the AF tractography.

2.6. Intraoperative evaluation of language function during awake craniotomy

We performed language monitoring for awake craniotomy patients. After the patient achieved awake state, a speech therapist gave the patient language task, such as counting, reading characters, calling the things in the card, repeating small sentences, mental arithmetic, and so on during tumor resection. Surgeons sometimes gave electrical stimulation (2–10 mA, 60 Hz) to identify the language area and language pathway with 1-mm bipolar electrode separated by 5 mm. When speech arrest, anomia, alexia, or paraphasia occurred, the stimulated area was identified as a language related lesion.

3. Results

There were six males and five females, ranging from 33 to 72 years of age (mean age, 47 years). There were four grade II glioma patients, three grade III glioma patients, and four grade IV glioma patients. Tumor location was parietal (around the angular gyrus) in four patients, frontal in three patients, temporal in two patients, and insular in two patients. Two patients had anomia, one patient had fluent aphasia, one patient had alexia with agraphia, and the remaining seven patients had normal language function preoperatively (Table 1). Six patients received