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Original Article

Frameless Free-Hand Navigation-Guided Biopsy for Brain Tumors: A Simpler Method with an Endoscope Holder

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Abstract

Context/Aims: Given the limitations of current navigation-guided brain biopsy methods, we aimed to introduce a novel method and validate its safety and accuracy. **Setting and Design:** This was a retrospective study of twenty consecutive patients who underwent brain biopsy at Shimane University Hospital, Japan. **Subjects and Methods:** Clinical records of 13 and 7 patients who underwent brain biopsy with the novel frameless free-hand navigation-guided biopsy (FFNB) method or a framed computed tomography-guided stereotactic biopsy (CTGB) method, respectively, were retrospectively reviewed. We compared age, sex, tumor location, histological diagnosis, maximum size of the tumor (target), depth from target to cortical surface on the same slice of CT or magnetic resonance imaging, operative position, anesthesia method, setup time for biopsy, incision-to-closure time, trial times for puncture, success rate, and complications in the two groups. **Statistical Analysis:** Fisher's exact test and the Wilcoxon rank-sum test were performed. **Results:** Clinical characteristics and lesion size did not differ significantly between the FFNB and CTGB groups. The depth of the target lesion was significantly greater in the CTGB group ($P < 0.05$). All FFNB and CTGB procedures reached and obtained the target tissue. The number of punctures and the average incision-to-closure time did not differ between the FFNB and CTGB groups. However, the preoperative setup time was significantly shorter using FFNB ($P = 0.0003$). No complications were observed in either group. **Conclusions:** FFNB was comparable with CTGB in terms of safety, accuracy, and operative duration. The preoperative setup time was shorter using FFNB. Therefore, FFNB is a feasible method for brain tumor biopsy.

Keywords: *Biopsy, brain tumor, free hand, navigation*

Introduction

Multiple devices are now available for brain tumor biopsy, and the choice of device is made depending on patient factors, surgeon preference, or institutional factors, such as budgetary constraints. Frame-based stereotactic targeting devices, such as Komai's computed tomography (CT)-stereotactic apparatus®[1] (Mizuho Co., Ltd., Tokyo, Japan) or the Leksell Stereotactic System®[2] (Elekta, K. K., Stockholm, Sweden), are age-old reliable devices. However, they have some disadvantages for the patient and surgeon because of the need to move and retake CT or magnetic resonance imaging (MRI) with a rigid head frame before biopsy. Recently, the availability of image-guided navigation systems, such as the VarioGuide system®[3] (Brainlab AG, München, Germany) or Vertek Biopsy solution®[4] (Medtronic Inc., Minneapolis, MN, USA), has allowed surgeons to biopsy the tumor in the operating room without the need for stereotactic frames or transfer to CT or MRI. However, the setup for such systems remains slightly bothersome because of the need for extra steps in instrument setup. In addition, the implementation costs of these systems are usually expensive. On the other hand, a free hand is needed to perform safe brain puncture in certain situations, such as ventricular drainage for hydrocephalus[5] or a fence postprocedure for tumor resection.[6] In view of these facts, we devised a simpler method, the frameless free-hand navigation-guided biopsy (FFNB), for brain tumor biopsy by applying an endoscope holder. Herein, we report the technical features and the

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results of a retrospective evaluation to validate the utility of FFNB.

Subjects and Methods

A total of twenty consecutive patients with suspected brain tumors and biopsied lesions seen between April 2013 and April 2020 at our university hospital were enrolled. The clinical records for these twenty cases were retrospectively reviewed, and we identified 13 patients who underwent biopsy using FFNB and 7 patients who underwent biopsy using framed CT-guided stereotactic biopsy (CTGB) (Komai's CT-stereotactic apparatus®; Mizuho Co., Ltd.). The following characteristics of patients and procedures were assessed and compared in the two groups: age, sex, tumor location, histological diagnosis, maximum size of the tumor (target), depth from target to cortical surface on the same slice of CT or MRI, operative position, anesthesia method, setup time for biopsy, incision-to-closure time, trial times for puncture, success rate, and complications. Fisher's exact test and the Wilcoxon rank-sum test were performed for statistical analysis of each parameter and comparison between FFNB and CTGB groups. $P < 0.05$ was considered statistically significant. This study was conducted in accordance with the Institutional Ethics Committee of our university (approval: 20200401-2).

Technical methods and illustrative cases of frameless free-hand navigation-guided biopsy

Illustrative case of frameless free-hand navigation-guided biopsy with optical navigation system

An 81-year-old woman presented with a gait disturbance. Contrast-enhanced MRI revealed a lesion in the left cerebellum [Figure 1a]. Trajectory planning for needle biopsy was performed using the navigation software iPlan Cranial 3.0® (Brainlab AG). The patient's head was fixed with a Mayfield head holder under general anesthesia, and the navigation system was set up [Figure 1b]. The instrument adapter array was attached to the biopsy needle through contact with an adapter clamp, and this biopsy needle was registered as a navigation tool using an instrument calibration matrix [Figure 1c]. The endoscope instrument holding arm® (Karl Storz SE and Co., Tuttlingen, Germany) was connected to the operating table, and the registered biopsy needle was clamped to the holding arm through a piece of 14 Fr nelaton catheter as an intermediator to prevent slipping and wobbling [Figure 1d]. One burr hole in the skull and a small incision in the dura were made. The surgeon held the biopsy needle like a pistol with the dominant hand, leaving the other hand for stabilization [Figure 1e]. The brain was then punctured carefully with one eye on the navigation display [Figure 1f]. The assistant locked the holding arm when the tip of the needle reached its target [Figure 1g]. The tissue was aspirated and corrected. The diagnosis of malignant lymphoma was made by intraoperative rapid diagnosis.

Illustrative case of frameless free-hand navigation-guided biopsy with electromagnetic navigation system

A 51-year-old woman presented with a severe headache. Contrast-enhanced MRI revealed a lesion in the frontal lobe from one side to the other through the corpus callosum [Figure 2a]. Trajectory planning for needle biopsy was performed using the navigation software StealthStation S7® (Medtronic Inc.). The patient's head was fixed with a radiolucent (carbon) head holder under general anesthesia. The noninvasive patient tracker was positioned at the radiolucent head holder, and EM Emitter® (Medtronic Inc.) was placed in the appropriate position. The navigation system was then set up [Figure 2b]. The endoscope instrument holding arm® (Karl Storz SE and Co.) was connected to the operation table, and the biopsy needle was clamped to the holding arm through a piece of 14 Fr nelaton catheter as an intermediator to prevent slipping and wobbling [Figure 1d]. The EM flexible stylet® (Medtronic Inc.) was inserted into the inside of the inner lumen of the biopsy needle [Figure 2c], and one burr hole in the skull and a small incision in the dura were made. The surgeon held the biopsy needle like a pistol with the dominant hand and the other hand was used for stabilization. The brain was then punctured carefully with one eye on the navigation display [Figure 2d and e]. The assistant locked the holding arm when the tip of the needle reached its target. The tissue was aspirated and corrected. The diagnosis of malignant lymphoma was made by intraoperative rapid diagnosis.

Results

Patient demographics

The clinical characteristics of the patients are summarized in Table 1. The FFNB and CTGB groups did not differ significantly with respect to patient age, sex, proportion of the target lesions, proportion of the histopathology of biopsied lesions, operative position, or anesthesia method.

Target lesion parameters

The size of the target lesion for biopsy did not differ significantly between the FFNB and CTGB groups, but the depth of the target lesion in the CTGB group was significantly greater than that in the FFNB group ($P < 0.05$) [Table 1].

Operative parameters

The target tissue was reached and obtained in both FFNB and CTGB. The number of punctures did not differ between the FFNB and CTGB groups [Table 2]. The average incision-to-closure time between the FFNB and CTGB groups (FFNB: 85.92 min vs. CTGB: 79.1 min) did not differ. However, the average setup time before surgery was significantly shorter with FFNB (53.2 min) than with CTGB (120.9 min) [Table 2]. No complications were observed in either group [Table 2].

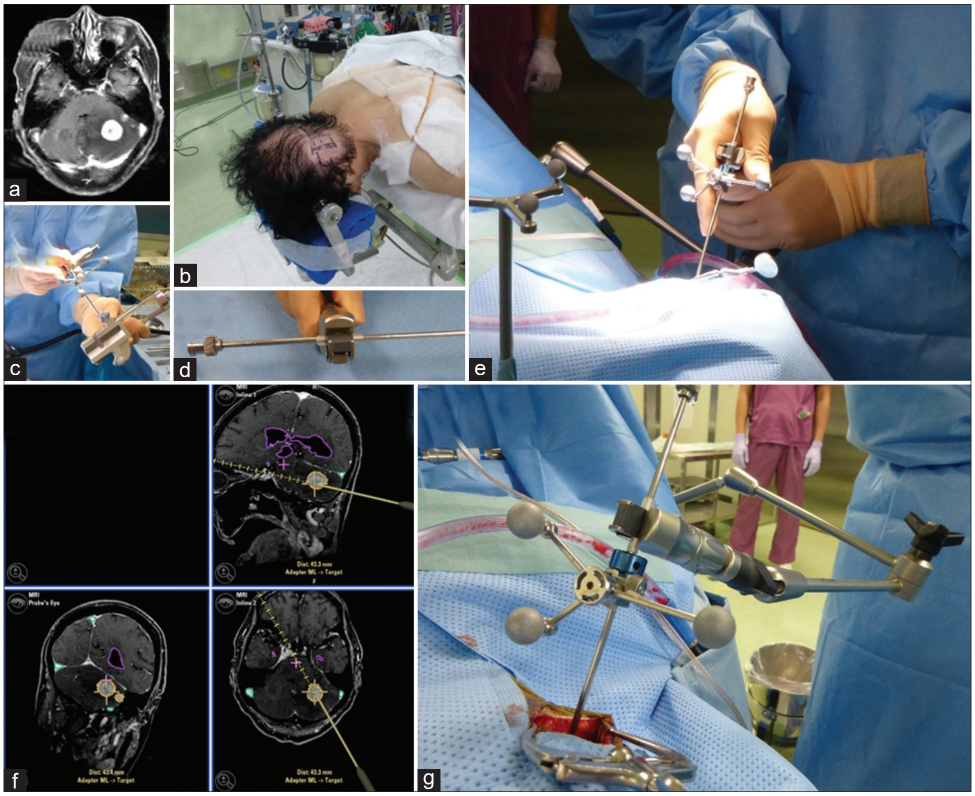

Figure 1: Illustrative case of frameless free-hand navigation-guided biopsy with optical navigation system. (a) The contrast-enhanced magnetic resonance imaging. (b) The patient's position. (c) Registration of the biopsy needle as a navigation tool by an instrument calibration matrix. (d) The registered biopsy needle is clamped to the endoscope arm through a piece of 14 Fr nelaton catheter. (e) The surgeon holds the biopsy needle like a pistol. (f) Navigation display during puncture. (g) The overview of frameless free-hand navigation-guided biopsy system

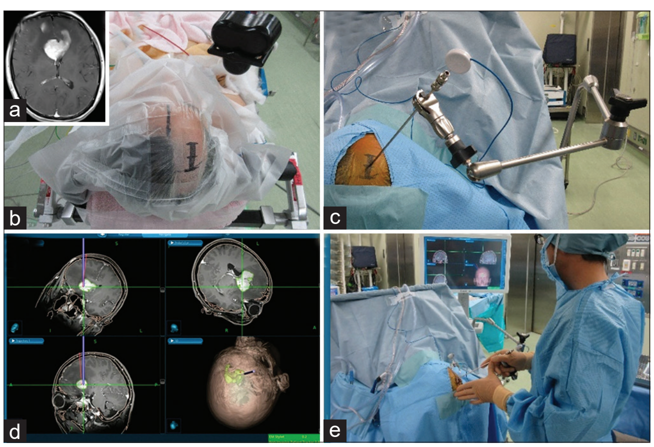

Figure 2: Illustrative case of frameless free-hand navigation-guided biopsy with electromagnetic navigation system. (a) The contrast-enhanced magnetic resonance imaging. (b) The setup scene for electromagnetic navigation system. (c) The endoscope arm is connected to the operation table and the biopsy needle is clamped to the holding arm through a piece of 14 Fr nelaton catheter. The electromagnetic flexible stylet is inserted into the inside of the inner lumen of the biopsy needle. (d) Navigation display during puncture. (e) The distant view of frameless free-hand navigation-guided biopsy during puncture

Discussion

The significant factors in brain tumor biopsy include planning for a safe puncture route, an accurate puncture based on the preoperative plan, and needle stability for handling associated with tissue aspiration. Currently, there are three major types of brain biopsy systems: frame-based stereotactic systems (Komai's CT-stereotactic apparatus®,[1] Leksell Stereotactic System®,[2] etc.) [Figure 3a], frameless arm-based stereotactic systems (VarioGuide®,[3] Vertek Biopsy solution®,[4] etc.) [Figure 3b], and frameless skull-mounted systems (Navigus®,[7] Nexframe®,[8] etc.) [Figure 3c]. All types of brain biopsy systems are compliant with all the abovementioned requirements, and most institutions choose one or two types of system.[9] In our institution, we used the frame-based stereotactic system before the introduction of the navigation system and the frameless arm-based stereotactic system after the introduction of the navigation system. However, both systems required a considerable amount of time and effort for the frame setting. Therefore, we devised a simpler method for tumor biopsy [Figure 3d].

Brain puncture for ventricular drainage used to be performed safely by free hand based on anatomical landmarks.[5] Needle puncture based on the free-hand echo guidance for brain abscesses or tumors has been previously reported.[10] Recently, a navigation-guided free-hand procedure for tumor resection, and for tumor biopsy using endoscopy,[11] the fence posttechnique[6] has been reported. Based on these established facts, we chose the

Table 1: Clinical characteristics of the patients

	Frameless free-hand navigation-guided biopsy	CT-guided biopsy	*P*
Number of cases	13	7	
Age (years)	65.3±18.9	70.1±10.1	0.9051
Sex			
Male	4 (30.8)	5 (71.4)	0.1597
Female	9 (69.2)	2 (28.6)	
Pathology			
Glioma	3 (23.1)	2 (28.6)	1.0000
Lymphoma	9 (69.2)	5 (71.4)	
Other	1 (7.7)	0	
Location			
Frontal lobe	5 (38.5)	2 (28.6)	0.7898
Temporal lobe	2 (15.4)	0	
Parietal lobe	0	1 (14.3)	
Occipital lobe	1 (7.7)	0	
Basal ganglia	2 (15.4)	2 (28.6)	
Corona radiata	2 (15.4)	1 (14.3)	
Cerebellum	1 (7.7)	1 (14.3)	
Target size on the slice, including maximum size of the tumor (cm^2)	4.9±4.2	5.9±4.2	0.3618
Distance from the brain surface to the target on the slice, including maximum size of the tumor (cm)	3.4±1.5	5.2±1.8	0.0432*
Operative position			
Supine	11 (84.6)	5 (71.4)	0.6901
Semi-prone	0	1 (14.3)	
Prone	2 (15.4)	1 (14.3)	
Anesthesia			
General	6 (46.2)	1 (14.3)	0.3285
Local	7 (53.8)	6 (85.7)	

*$P<0.05$, Data are presented as mean±SD or *n* (%). SD – Standard deviation; CT – Computed tomography

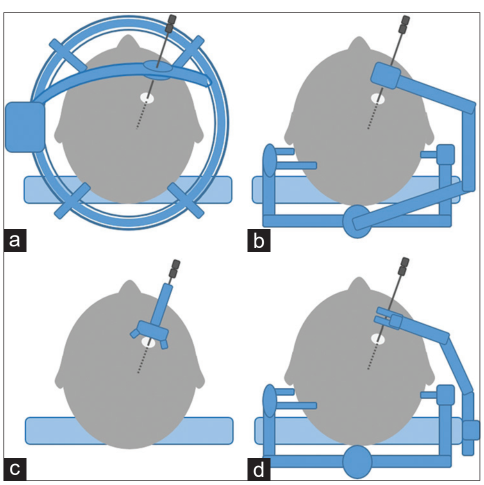

Figure 3: Schematic drawing of the different types of targeting devices for the brain tumor biopsy. (a) frame-based stereotactic targeting device, (b) frameless arm-based stereotactic targeting device, (c) frameless skull (or burr hole) mounted targeting devices, and (d) frameless free-handed navigation-guided targeting device (our method introduced in this study)

free-hand method for puncture under navigation guidance. With regard to the safety and accuracy of the puncture, our FFNB method achieved equivalent success to that of CTGB in this study.

Application of the Yasargil Leyla retractor arm® (Codman GmbH, Norderstedt, Germany) for fixation of the biopsy system has also been previously reported.[12] We adopted the endoscope instrument holding arm to ensure steady fixation. The stability was sufficient while the biopsy needle attached to the endoscope instrument holding arm® (Karl Storz SE and Co.) was manipulated during tumor aspiration, and this was the most important aspect of FFNB. We also confirmed its stability in laboratory simulations [Figure 4a]. Based on laboratory experiments, the tip of the biopsy needle was found to swing only 3 mm by almost 2 newtons of pressure at the end of the biopsy needle when the biopsy needle was grasped at the three-quarter point [Figure 4b]. Therefore, another instrument holding arm could be applied for FFNB if the holding arm exerts the same stability as shown in this experiment.

Limitation

In this study, FFNB was performed under general or local anesthesia in six and seven patients, respectively. However, we considered rigid head fixation as essential for avoiding the risk of discrepancy between the head and holding arm by patient motion during the operation, irrespective of the anesthesia method. In this respect, FFNB has one

Table 2: Comparison between frameless free-hand navigation-guided biopsy and computed tomography-guided biopsy

	Frameless free-hand navigation-guided biopsy	CT-guided biopsy	*P*
Setup time (min)	53.2±15.5	120.9±21.7	0.0003*
Incision-to-closure time (min)	85.9±31.5	79.1±9.2	0.3413
Trial times	1.2±0.4	1.0	0.2863
Successful cases	13 (100)	7 (100)	1.0000
Complicated cases	0	0	1.0000

*$P<0.05$, Data are presented as mean±SD or *n* (%). SD – Standard deviation; CT – Computed tomography

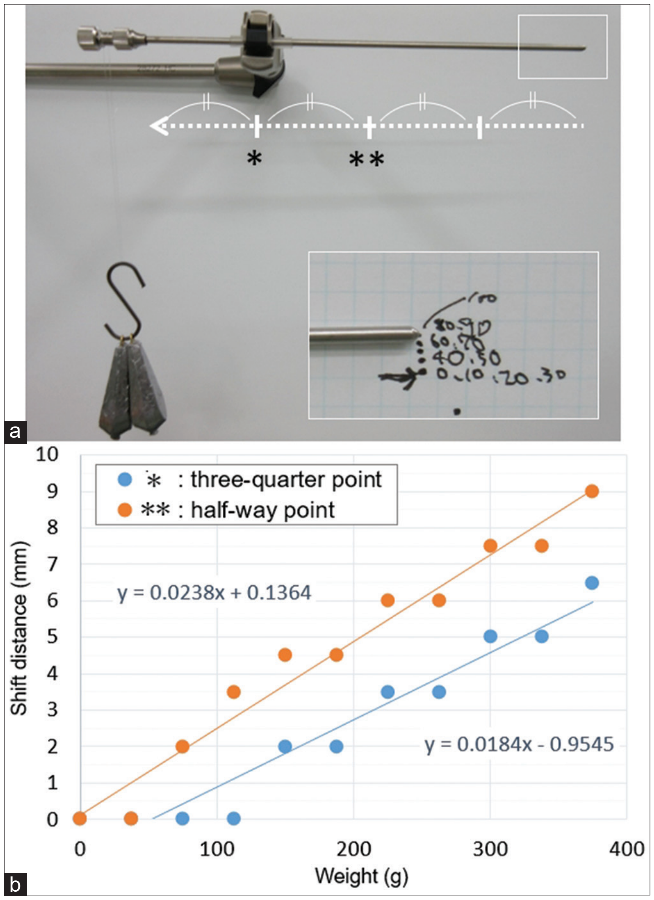

Figure 4: The fundamental experiment to confirm the stability of biopsy needle during frameless free-handed navigation-guided biopsy. (a) A layout photograph of the experimental system. The biopsy needle is horizontally clamped to the endoscope arm and the end of the needle is hung with the tested weights and the shift distance of the needle tip is dotted and measured on the backboard. (b) Approximate graphs showing correlation between load on the end of the needle and shift of the needle tip for the three-quarter point (single asterisk) and the half-way point (double asterisks)

disadvantage, although not to the extent of the frame-based stereotactic method. In addition, the depth of the target lesion for FFNB was significantly shallower than that for CTGB (3.4 ± 1.5 vs. 5.2 ± 1.8, $P < 0.05$). One of the likely possibilities is that the operator chose CTGB instinctively for a deeper target because of a sense of safety for a longer puncture route. Hence, the safety of FFNB for lesions deeper than 5 cm from the brain surface remains unclear. Further research on FFNB with a greater number of patients is required to prove its safety for deeper lesions.

Conclusions

In this retrospective study, FFNB was compared with classical CTGB in terms of safety and accuracy. FFNB was comparable to CTGB in terms of safety, accuracy, and operative duration. One benefit of FFNB is a shorter setup time compared to CTGB. In conclusion, FFNB is a quick, safe, and effective method for brain tumor biopsy.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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