Endoscopic Trans-Mini-Cylinder Biopsy for Intraparenchymal Brain Lesions

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Abstract

**Purpose:** Recently, the importance of molecular diagnosis has increased, along with the volume of specimens required for diagnosis. Biopsy procedures must simultaneously reduce invasiveness and ensure the collection of adequate tissue volume. We examined the efficacy and safety of endoscopic biopsy using a minimal diameter cylinder.

**Methods:** Patients who underwent endoscopic biopsy surgery with a 6-mm diameter cylinder for intraparenchymal lesions were included. Postoperative hematoma formation and the extent of trajectory scanning were assessed. Molecular genetic analysis was performed for cases of diffuse infiltrated glioma.

**Results:** Fifty-two procedures performed on 51 patients were analyzed in this study. Postoperative neurological deterioration was not observed in any case. A pathological diagnosis was made for all patients. Postoperative CT revealed no hematoma after 49 procedures and a small hematoma after 3 procedures, and no patients required additional treatment. A postoperative trajectory scar less than 5 mm in size was observed after 30 procedures, a scar of 5-10 mm was observed after 19 procedures, and a scar larger than 10 mm was observed after 3 procedures at 1 week after surgery, and 40, 6 and 0 scars were observed at 3 months after surgery. Molecular genetic analysis was performed in 17 cases, resulting in a change to a higher grade in the integrated diagnosis of 3 cases.

**Conclusions:** Endoscopic biopsy using a small-diameter cylinder is a possible alternative biopsy technique for intraparenchymal lesions. This surgical technique is useful especially in cases where hemorrhagic complications are expected.

**Trial registration**

Registry name and number: Efficacy and safety of the neuro-endoscopic treatment for brain tumors. (2019-0254)

Introduction

Histological diagnostics is essential to determine the treatment strategy for brain tumors [1, 2]. Biopsy is the treatment of choice for cases that are unrespectable or when it is difficult to determine a treatment strategy. The stereotaxic needle biopsy technique has been widely used, especially for deep seated lesions that cannot be treated with the usual open craniotomy approach [3, 4]. Although the stereotaxic needle biopsy technique is thought to be less invasive, intraoperative identification of hemorrhage and hemostatic manipulation is not possible because the sampling site is invisible [5, 6]. In addition, only small specimens can be obtained [1]. In the recent neurosurgical era, in addition to histological diagnosis, molecular diagnosis has become important for subsequent treatment and predicting patient prognosis, and the number of specimens required has increased accordingly [2].

According to recent advances in endoscopes, endoscopic use is spreading to the neurosurgical field. The image quality of endoscopes has improved over the years, making it easier to distinguish tumor tissue from the normal brain [7, 8]. Recent studies have shown various advantages of surgeries with cylindrical-shaped tubular retractors [1, 9–12]. The primary benefit of surgery using cylinders is the reduced size of the surgical corridor and distribution of the retraction pressure equally to the surrounding brain parenchyma, thereby reducing the occurrence of retraction injury [4, 13]. In biopsy surgery, it is necessary to secure an appropriate amount of specimen while ensuring the lowest level of invasiveness and safety. Since endoscopes provide a sufficient field of view in the deep surgical field and the technique required for biopsy surgery is simple enough to be performed in a narrow corridor, they can be useful in realizing the ideal biopsy procedure described above [10, 14]. Here, we report on our endoscopic biopsy technique using a small-diameter cylinder and its results.

Methods

Between January 2015 and March 2021, 51 consecutive patients underwent endoscopic trans-mini-cylinder biopsy at Nagoya University Hospital and satellite hospitals. We retrospectively reviewed the medical records, including surgical records, pre- and postoperative neurological symptoms, images, and pathological data. This study was approved by the Institutional Review Board at Nagoya University (2019 - 0254).

Preoperative settings

Magnetic resonance imaging (MRI) with and without contrast medium was performed preoperatively in all patients. MRI-diffusion tensor images were also taken to identify deep cortical fibers, especially in patients with lesions involving deep white matter. If the patients had multiple lesions, the lesions located in the noneloquent area or the largest lesion or highest uptake area in the methionine and FDG PET image were considered to be the target lesion. The surgical plan was planned based on these data using iPlan® (Brainlab, Munchen, Germany).

Surgical procedure (Video 1)

A navigation system (Curve®, Brainlab, Munchen, Germany) was used in all cases. Motor evoked potentials (MEPs) and somatosensory evoked potentials (SEPs) were elicited if the tumor was located near the motor cortex and fibers. Each patient's head was fixed with a sugita head clamp. A 1.5-cm burr hole was made at a location where there were no cortical vessels immediately below. A 2.7-mm endoscope (Endoarm®, Olympus, Tokyo, Japan) was used for visualization during this surgery. An instrument adapter array was attached to the endoscope, and the endoscope tip was calibrated by the navigation system (Fig. 1a). A transparent test tap needle with a 3-mm inner lumen and a 5-mm outer diameter was used during the insertion of the cylinder (Fig. 1b and c). A 2.7-mm endoscope could be inserted into this test tap needle so that the tip of the needle could be visualized directly during needle insertion (Fig. 1d). After reaching the lesion, a 6-mm diameter sheath (Neuroport Mini®, Olympus, Tokyo, Japan) was inserted into the same tract. Tumor biopsy was performed with thin pituitary forceps under a 2.7-mm endoscopic view (Fig. 1e). At this moment, we could detect the small vessels on and inside the lesion, which made it easy to avoid injury to these vessels. The amount of tissue sampling could be modified according to the lesion during the procedure. Most of the minor bleeding could be stopped by rinsing with artificial cerebrospinal fluid (aCSF) (Artcereb®, Otsuka, Osaka, Japan). Arterial bleeding was stopped using a thin
bipolar coagulator designed for this procedure (Fujita Medical Instruments, Tokyo, Japan) (Fig. 1f). At the end of the biopsy procedure, the surgical field was filled with aCSF, and the extraction cavity was spontaneously expanded by natural water pressure. Under this condition, the entire extraction cavity was visualized without any additional retraction, and sufficient hemostasis was confirmed (Fig. 1g).

Histopathological and molecular diagnoses

All patients underwent intraoperative frozen section diagnosis to confirm the presence or absence of the pathological lesion. In cases where no lesion was collected, the cylinder was reoriented by slightly tilting the cylinder without changing the surgical tract, and further lesion sampling was performed. Permanent histological diagnosis was performed using lesion specimens. Molecular genetic analysis was performed for cases classified as “diffuse astrocytic and oligodendrogial tumors” by permanent histological diagnosis.

DNA extraction from patient tumor specimens

Tumor samples were obtained intraoperatively. DNA was extracted from tumor samples using the QIAamp DNA Mini Kit following the manufacturer's instructions. The amount of obtained DNA was quantified using the Qubit dsDNA HS Assay Kit (Invitrogen, Paisley, Scotland, UK). We performed Sanger sequencing and MLPA analysis with DNA obtained from fresh frozen tissue samples.

Sanger sequencing

We performed Sanger sequencing to detect genetic mutations in the \( IDH1, IDH2, BRAF, H3F3A \) and \( TERT \) promoters in the DNA extracted from the tumor samples. We applied conventional PCR as follows: 35 cycles with denaturation at 98°C for 10 s, annealing at 62°C for 30 s, and extension at 68°C for 30 s for amplification of the \( IDH1, IDH2, BRAF \) and \( H3F3A \) genes or 35 cycles with denaturation at 98°C for 10 s, annealing at 65°C for 30 s, and extension at 68°C for 60 s for amplification of the \( TERT \) promoter, with a final extension step at 68°C for 5 min. The primer sequences of these analyses are described in the supplementary table 1. Sequence analysis was performed by ApE v2.0.55.

Multiplex ligation-dependent probe amplification

Multiplex ligation-dependent probe amplification (MLPA) was used to determine allelic losses and gains in the tumor samples. The analysis was performed using SALSA MLPA KIT P088-B1 and P105-C1 in accordance with the manufacturer's protocol (MRC Holland, Amsterdam, Netherland) [15]. Information regarding the probe sequences and ligation sites can be found at www.mlpa.com.

Postoperative evaluation

CT images were obtained from all patients to assess postoperative hemorrhages within 24 hours after the operation. Postoperative hematoma formation was assessed using this CT image. The postoperative trajectory injury was assessed based on the FLAIR image and/or T2 weighted image of MRIs taken at 1 week and 2–3 months postoperatively. Trajectory injury was assessed by measuring the maximum diameter of brain edema around the scar due to cylinder insertion and classified into three groups: Grade 1 (less than 5 mm) (Fig. 2a), Grade 2 (5 mm < 10 mm) (Fig. 2b) and Grade 3 (larger than 10 mm) (Fig. 2c).

Results

One patient underwent two biopsies for different lesions; therefore, 52 surgical procedures were enrolled in this study. A total of 39.2% were women, with a mean age at biopsy of 55.0 years (range 1–82 years). Electrocauterization of the bleeding vessels was performed in 23 procedures (44.2%), and small amounts of bleeding, such as oozing, could be stopped with continuous irrigation of aCSF. Complete hemostasis could be confirmed under direct endoscopic view at the end of the procedure in all cases. Postoperative CT and MRI revealed that the preoperatively planned site was sampled in all cases. Histopathological diagnoses were obtained in all cases, but in one procedure, inflammation was present, and another new lesion appeared in a different location, which was biopsied and diagnosed as lymphoma. Therefore, overall, the diagnostic yield was 98.1%. The histopathological diagnosis for all procedures is shown in Table 1.
Table 1
Histopathological diagnosis

<table>
<thead>
<tr>
<th>Histogical Diagnosis</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diffuse astrocytic and oligodendrogial tumors</td>
<td>25</td>
</tr>
<tr>
<td>Grade 2</td>
<td>7</td>
</tr>
<tr>
<td>Grade 3</td>
<td>5</td>
</tr>
<tr>
<td>Grade 4</td>
<td>13</td>
</tr>
<tr>
<td>Other Astrocytic tumors</td>
<td>2</td>
</tr>
<tr>
<td>Neuronal and mixed neuronal-glial tumors</td>
<td>2</td>
</tr>
<tr>
<td>Embryonal tumors</td>
<td>1</td>
</tr>
<tr>
<td>Meningiomas</td>
<td>1</td>
</tr>
<tr>
<td>Lymphomas</td>
<td>16</td>
</tr>
<tr>
<td>Metastatic Tumors</td>
<td>1</td>
</tr>
<tr>
<td>Inflammation/Demyelinating</td>
<td>4</td>
</tr>
</tbody>
</table>

In 17 of 25 patients with a histopathological diagnosis of diffuse astrocytic and oligodendrogial tumors based on the World Health Organization (WHO) classification system, genetic analysis was additionally performed. Sufficient specimen volume was collected in all cases for subsequent molecular analysis. These data are shown in Table 2.

Table 2
Molecular analysis data from 17 cases.

<table>
<thead>
<tr>
<th>Case</th>
<th>Age/sex</th>
<th>Histological diagnosis</th>
<th>IDH1</th>
<th>IDH2</th>
<th>H3F3A</th>
<th>BRAF</th>
<th>HIST1H3B</th>
<th>TERTp</th>
<th>1p19q</th>
<th>PDGFRA</th>
<th>CDKN2A/B</th>
<th>EGFR</th>
<th>PTEN</th>
<th>7 ga</th>
<th>10 los</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>44/M</td>
<td>DA</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>2</td>
<td>65/M</td>
<td>DA</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>C250T</td>
<td>-</td>
<td>-</td>
<td>homozygous deletion</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>61/F</td>
<td>DA</td>
<td>R132H</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>C228T</td>
<td>-</td>
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</tr>
<tr>
<td>4</td>
<td>33/F</td>
<td>DA</td>
<td>R132H</td>
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<tr>
<td>5</td>
<td>59/M</td>
<td>DA</td>
<td>-</td>
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<td>-</td>
<td>C228T</td>
<td>-</td>
<td>amp</td>
<td>-</td>
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</tr>
<tr>
<td>6</td>
<td>60/M</td>
<td>AA</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>C228T</td>
<td>homozygous deletion</td>
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</tr>
<tr>
<td>7</td>
<td>35/F</td>
<td>AA</td>
<td>R132H</td>
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<tr>
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<td>69/F</td>
<td>AA</td>
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<tr>
<td>9</td>
<td>31/M</td>
<td>AA</td>
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<tr>
<td>10</td>
<td>26/M</td>
<td>AA</td>
<td>-</td>
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<td>-</td>
<td>G34R</td>
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<tr>
<td>11</td>
<td>80/F</td>
<td>GBM</td>
<td>-</td>
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<tr>
<td>12</td>
<td>74/M</td>
<td>GBM</td>
<td>-</td>
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<tr>
<td>13</td>
<td>9/F</td>
<td>GBM</td>
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<td>-</td>
<td>K27 M</td>
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<tr>
<td>14</td>
<td>18/F</td>
<td>GBM</td>
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<tr>
<td>15</td>
<td>40/M</td>
<td>GBM</td>
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<td>-</td>
<td>C228T</td>
<td>-</td>
<td>homozygous deletion</td>
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<td></td>
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<tr>
<td>16</td>
<td>32/M</td>
<td>GBM</td>
<td>-</td>
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<td>-</td>
<td>-</td>
<td>amp</td>
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<tr>
<td>17</td>
<td>44/F</td>
<td>GBM</td>
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<td>-</td>
<td>amp</td>
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</tbody>
</table>

DA: diffuse astrocytoma, AA: anaplastic astrocytoma, GBM: glioblastoma, amp: amplification

According to the above genetic analysis, two patients with a histopathological diagnosis of grade II diffuse astrocytoma and one patient with grade III anaplastic astrocytoma had TERT promoter mutation without an accompanying IDH mutation and were molecularly diagnosed with “diffuse astrocytic glioma, IDH wildtype, with molecular features of glioblastoma (WHO grade IV)” [16–18].
No significant intraoperative complications were experienced by any patient. Postoperative neurological deterioration was not observed. Postoperative CT showed slight hematoma formation localized in the extraction cavity during 3 procedures (Fig. 2d), but no hematoma formation was observed in the other 49 procedures (Fig. 2e and Table 3). There were no symptomatic hematoma cases, and no additional treatment was required. All patients underwent MRI one week after surgery, and grade 1, 2, and 3 trajectory scars were evaluated in 30 (57.7%), 19 (36.5%), and 3 (5.8%) patients, respectively. Follow-up MRI at 3 months after surgery was performed in 46 of 52 patients, with 40 (87%), 6 (13%) and 0 patients having grades 1, 2 and 3 scars, respectively.

Table 3
Postoperative hematoma formation and trajectory scar analysis

<table>
<thead>
<tr>
<th>Hematoma formation</th>
<th>Number of procedures</th>
<th>Postoperative MRI</th>
<th>Follow-up MRI at 3 mo</th>
</tr>
</thead>
<tbody>
<tr>
<td>No hematoma</td>
<td>49 (94.2%)</td>
<td>30 (57.7%)</td>
<td>19 (36.5%)</td>
</tr>
<tr>
<td>Asymptomatic hematoma</td>
<td>3 (5.8%)</td>
<td>6 (13%)</td>
<td>0 (0%)</td>
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<tr>
<td>Trajectory scar</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Postoperative MRI</td>
<td>52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Follow-up MRI at 3 mo</td>
<td>46</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade 1</td>
<td>19 (36.5%)</td>
<td>30 (57.7%)</td>
<td>46 (87%)</td>
</tr>
<tr>
<td>Grade 2</td>
<td>19 (36.5%)</td>
<td>19 (36.5%)</td>
<td>6 (13%)</td>
</tr>
<tr>
<td>Grade 3</td>
<td>3 (5.8%)</td>
<td>3 (5.8%)</td>
<td>0 (0%)</td>
</tr>
</tbody>
</table>

Discussion

Histopathological and molecular diagnoses

The rate of positive pathological diagnosis is one of the most important factors in evaluating the effectiveness of biopsy techniques [1]. In our biopsy technique, a 2.7-mm endoscope that is recognized with a navigation system is inserted inside the test tap needle, and the needle is advanced in a straight line along the preoperatively planned route. The endoscope makes it possible to detect the difference in coloration between the normal brain and the lesion throughout the biopsy procedure, including during the insertion of the test tap needle, and this information can be used to adjust the biopsy site intraoperatively. As a result, the preoperatively planned site was sampled in all cases. Endoscopic biopsy with the transparent test tap needle under navigation guidance allows for accurate sampling of the target lesion.

In the present study, one case (1.9%) required rebiopsy. In this case, a color difference between the lesion and the normal brain was observed with the endoscope during the initial biopsy procedure. Postoperative MRI confirmed that the planned area had been sampled, and a pathological diagnosis of inflammation was made. In the subsequent follow-up, the lesion at the initial biopsy site disappeared, and a new lesion at a different site appeared. We performed re-biopsy of the new lesion, which led to a diagnosis of lymphoma. This suggests that there may have been a problem in setting the target site for the initial biopsy. Even if an endoscope is used, it is only possible to harvest the specimen around the set target site. Therefore, even if the biopsy method is improved, further improvement in the diagnosis rate may not be possible.

In recent years, the importance of molecular diagnosis has increased, especially for the diagnosis of diffuse infiltrative gliomas. With the discovery of molecular biomarkers such as TERT promoter mutations, appropriate prognostic prediction has become possible. In this study, two of the patients with histopathologically diagnosed grade II diffuse astrocytoma and one of the patients with grade III anaplastic astrocytoma were diagnosed with highly malignant tumors by molecular diagnosis and were able to receive aggressive chemotherapy at an early stage.

One of the problems related to needle biopsy is the small specimen volume compared with other biopsy techniques [1]. It has been reported that a larger amount of specimen can be harvested using the endoscopic method compared to needle biopsy [1]. In endoscopic biopsy surgery, the necessary amount of specimen can be adjusted on a case-by-case basis without changing the corridor, which may lead to sufficient diagnosis without additional injury to the brain tissue [19, 20]. In recent years, advances in molecular biology have led to more reliable diagnoses, but the amount of specimen required has increased because molecular genetic analysis is generally performed in addition to conventional histopathological diagnosis [2, 21]. Endoscopic cylinder biopsy is an effective biopsy method that is compatible with performing both molecular and histopathological diagnoses and may at least contribute to improving the positive diagnosis rate of lesions identified during preoperative planning.

Trajectory injury and maneuvering the mini-cylinder

The most important concern with endoscopic biopsy is the larger surgical corridor compared with needle biopsy, which has the possibility of brain tissue injury. To address this problem, we used a smaller diameter cylinder and a transparent test tap needle for puncture. The transparent test tap needle used in our technique has a tapered shape, which allows us to approach the lesion by dilation of the brain parenchyma during insertion of the sheath. Since a 2.7-mm endoscope can be inserted inside the test tap needle, the surgical site can be continuously visualized. If a vessel is encountered by the test tap needle during insertion, the vessel could be saved by slightly changing the direction of the needle. The test tap needle is then advanced, and the vessel naturally escapes to the outside of the needle without damage. Additionally, if the surface of the tumor is very hard, the puncture needle may slip, but our technique can detect this slippage at an early stage because of the continuous visualization of the needle tip with endoscopy. This early detection of the slip phenomenon and linear insertion of the sheath can minimize trajectory injury. Since the endoscope in the needle is registered in the navigation system, it is possible to continuously...
monitor the position of the endoscope tip during puncture. This allows the needle to be inserted in a minimally injurious path along the preoperatively planned tract.

In this study, we evaluated the surgical trajectory scar with postoperative MRI and found that approximately 60% of the cases had scars less than 5 mm in diameter, which was smaller than the inserted cylinder diameter. Follow-up MRI taken at 3 months after surgery showed a trajectory scar of less than 5 mm in 87% of the cases, and no case had a scar of more than 10 mm. Our technique has the potential to reduce brain injury surrounding the tract and is thought to be sufficiently less invasive. Although the 6-mm cylinder provides only a very limited surgical space, the surgical maneuvers required for the biopsy procedure are relatively simple. Therefore, by using a 2.7-mm endoscope and fine-diameter pituitary forceps, the biopsy procedure could be easily performed. Our trans-mini-cylinder biopsy method is capable of safely collecting sufficient tissue samples with minimal invasiveness.

**Postoperative hematoma formation**

Postoperative hematoma formation is one of the most worrisome complications of biopsy procedures. It has been reported that the rate of symptomatic hematoma formation after needle biopsy is approximately 5% [5, 15, 22, 23]. Asymptomatic hematoma formation is frequently observed after needle biopsy, with an incidence of up to 56% according to Kulkami et al. [22] In a review of 14760 cases, Riche et al. reported an average symptomatic bleeding rate of 3.5% and an overall bleeding rate of 21.3% [5]. In our study, a CT scan taken on postoperative day 1 revealed that the hematoma was completely undetectable in 94.2% of cases, while there was slight hematoma formation in 5.8% of cases and no cases of symptomatic hematoma.

One of the advantages of endoscopic biopsy is that all surgical procedures can be performed under endoscopic direct visualization. Endoscopy can make it possible to visualize the vessels on and inside the lesions during the biopsy procedure, minimizing the risk of injury to these vessels and subsequent intra- and postoperative hematoma formation. After the biopsy procedure, the extraction cavity was filled with aCSF, and the water pressure expanded the cavity by natural water pressure [14, 24]. Thus, we could observe the entire extraction cavity without any additional retraction and confirm complete hemostasis. If slight bleeding was found, spontaneous hemostasis was promoted by continuing irrigation with aCSF and applying water pressure [25, 26]. In the case of arterial bleeding, it was possible to achieve hemostasis by using the thin bipolar coagulator that we developed for this surgical technique.

The endoscopic biopsy technique allows for adequate intraoperative confirmation of hemostasis and may be effective in preventing postoperative hematoma formation.

**Limitations**

There are some limitations to this study. First, postoperative trajectory injury was assessed using postoperative MRI T2-weighted images and FLAIR images in this study, which may not be sufficient to assess subcortical fiber damage. Prospective studies including fiber injury evaluation using MRI-diffusion tensor imaging should be conducted. Second, brainstem lesions were not included in this study. Although this procedure may be effective for deep-seated tumors, whether it can be safely performed in brainstem regions, which have dense and eloquent structures, requires further investigation. Third, precision medicine based on molecular diagnosis has not been sufficiently established at present. Endoscopic biopsy has made it possible to secure the necessary specimen volume for molecular genetic analysis and thus enables better prognosis prediction. However, its role in precision medicine is currently limited. Its importance is expected to increase with the further development of molecular therapy in the future.

**Conclusions**

The proposed biopsy technique using a small-diameter cylinder allows sufficient specimen sampling for pathological and molecular diagnosis and minimizes tract damage. The use of an endoscope makes it possible to eliminate blind manipulation throughout the surgical procedure. In addition, hemostasis can be achieved safely under direct visualization, and the possibility of postoperative hematoma formation can be reduced. The endoscope provides a sufficient field of view even under water, allowing for the entire extraction cavity to be observed and hemostasis to be confirmed by expanding the cavity with water pressure. Endoscopic biopsy using a small-diameter cylinder is an effective and safe biopsy technique that causes minimal damage to normal brain tissue. Thus, this method could be safe for biopsy, especially in cases where postoperative hemorrhage is expected.

**Declarations**

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**Competing Interests**

The authors have no conflicts of interest to declare.

**Author contributions**

KT and YN had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. Concept and design: KT, YA. Acquisition, analysis, or interpretation of primary data: FO, SM, TY. Literature Review: KT, AM, HS, HH. Drafting of the manuscript: KT. Critical revision of the manuscript for important intellectual content: All authors. Molecular analysis: FO, SM. Administrative, technical, or material support: All authors. Supervision: RS.

**Data availability**
The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

**Ethics approval**

This study was approved by the Institutional Review Board at Nagoya University.

**Consent to participate**

Not applicable.

**Consent to publish**

Not applicable.

**References**


Figures

![Figure 1](image-url)

**Figure 1**

Images of the instruments for cylinder insertion. a) The 6-mm diameter outer sheath (white arrow), 5.8-mm transparent test tap needle (black arrow) and a 2.7-mm 0-degree endoscope attached to an instrument adapter array. The tip of the endoscope was calibrated by a navigation system. b) The outer sheath, the test tap needle and the endoscope were inserted coaxially. c) A 5.8-mm transparent test tap needle with a 3-mm inner lumen. d) The translucent test tap needle was inserted toward the target area under navigation guidance and endoscopic view. e) Tissue sampling was performed with pituitary forceps. f) The thin bipolar coagulator designed for this surgical technique. This bipolar coagulator can be used even inside the narrow cylinder. g) Complete hemostasis was confirmed under water.

![Figure 2](image-url)

**Figure 2**

The trajectory scar was assessed by measuring the maximum diameter of brain edema around the scar on MRI, and postoperative hematoma formation was assessed on CT image. a) Grade 1 (less than 5 mm) trajectory injury (white arrow) b) Grade 2 (5 mm < 10 mm) trajectory injury (white arrow) c) Grade 3 (larger than 10 mm) trajectory injury (white arrow) d) A small hematoma was detected within the biopsy cavity (white arrow). e) No hematoma was detected in the biopsy cavity (white arrow).

**Supplementary Files**

This is a list of supplementary files associated with this preprint. Click to download.

- Video.mp4
- Supplementarytable1.docx