TECHNICAL NOTE doi: 10.2176/nmc.tn.2014-0266

Neurol Med Chir (Tokyo) 55, 766–772, 2015 Online September 4, 2015

The Effectiveness of the Stereotactic Burr Hole Technique for Deep Brain Stimulation

Keisuke TOYODA,[1] Eiichirou URASAKI,[1] Tetsuya UMENO,[1] Waka SAKAI,[2] Akiko NAGAISHI,[2] Shunya NAKANE,[2,3] Takayasu FUKUDOME,[2,3] and Yuzo YAMAKAWA[1]

Departments of [1]Neurosurgery, [2]Neurology, and [3]Clinical Research, National Hospital Organization, Nagasaki Kawatana Medical Center, Kawatana, Nagasaki

Abstract

Deep brain stimulation (DBS) is performed by burr hole surgery. In microelectrode recording by multi-channel parallel probe, because all microelectrodes do not always fit in the burr hole, additional drilling to enlarge the hole is occasionally required, which is time consuming and more invasive. We report a stereotactic burr hole technique to avoid additional drilling, and the efficacy of this novel technique compared with the conventional procedure. Ten patients (20 burr holes) that received DBS were retrospectively analyzed (5 in the conventional burr hole group and 5 in the stereotactic burr hole group). In the stereotactic burr hole technique, the combination of the instrument stop slide of a Leksell frame and the Midas Rex perforator with a 14-mm perforator bit was attached to the instrument carrier slide of the arc in order to trephine under stereoguidance. The efficacy of this technique was assessed by the number of additional drillings. Factors associated with additional drilling were investigated including the angle and skull thickness around the entry points. Four of the 10 burr holes required additional drilling in the conventional burr hole group, whereas no additional drilling was required in the stereotactic burr hole group ($p = 0.043$). The thicknesses in the additional drilling group were 10.9 ± 0.9 mm compared to 9.1 ± 1.2 mm ($p = 0.029$) in the non-additional drilling group. There were no differences in the angles between the two groups. The stereotactic burr hole technique contributes to safe and exact DBS, particularly in patients with thick skulls.

Key words: burr hole, deep brain stimulation, stereotactic, trepanation, trephination

Introduction

Deep brain stimulation (DBS) is a surgical technique for treating several neurological diseases and involuntary movements, such as Parkinson's disease and dystonia, and generally uses the burr hole method. The burr hole technique is an easy procedure, in which a burr hole is made in a coaxial trajectory of the DBS lead. Recently, intra-operative microelectrode recording (MER) by multi-channel parallel probe (the so-called Ben's Gun)[1)] has been widely used to find the ideal target point in DBS. In this method, all microelectrodes must fit into a burr hole. However, because trepanation of the skull is generally performed using a non-stereotactic technique, it is possible that not all the microelectrodes and DBS leads will initially fit in the first burr hole. In such a case, additional drilling to enlarge the burr hole is required, and this procedure is often time consuming and more invasive. Here, we introduce a novel surgical procedure for a stereotactic burr hole technique using a Leksell stereotactic system to avoid additional drilling of the burr hole. Moreover, we report on the efficacy of this novel burr hole technique compared to the conventional procedure.

Received July 31, 2014; Accepted March 30, 2015

Materials and Methods

I. Patient population

Ten patients with Parkinson's disease (20 burr holes) who received DBS treatment in our institution between January 2013 and December 2014 were retrospectively analyzed for this analysis. The first five consecutive patients (10 burr holes) had undergone surgery using the conventional burr hole technique, while the following five patients (10 burr holes) had undergone surgery using the stereotactic burr hole technique. All patients had received first-time surgery and bilateral electrode implantation. Written informed consent was obtained

from the patients, and the study was performed in accordance with the institutional ethical policies.

II. Surgical procedure

All planning and procedures were carried out by the same operators. Preoperative magnetic resonance imaging (MRI) was conducted the day before surgery in all patients. Following placement of the Leksell stereotactic frame (Model G; Elekta Instrument, AB; Stockholm, Sweden), computed tomographic (CT) data were fused to pre-operative MRI using FrameLink 5 software (Medtronic, Inc.; Minneapolis, Minnesota, USA). Target points were based on the anterior commissure (AC)-posterior commissure (PC) line calculations and refined in gadolinium (Gd)-enhanced T1-weighted MRI. On the MR console, approximate anatomical targets of the subthalamic nucleus (STN) were chosen bilaterally at a point 12 mm lateral, 4 mm posterior, and 4 mm inferior to the midcommissural point. Entry points were not always at the same position because they were chosen to avoid the lateral ventricles, cortical veins, and deep sulci. The patient was placed in the supine position under local anesthesia. After making a C-shaped skin incision, a 14-mm perforator bit (Codman & Shurtleff, Inc.; Raynham, Massachusetts, USA) was used to make the burr hole, which accommodates the base ring of the Stimloc burr hole-mounted anchoring ring (Medtronic, Inc.; Minneapolis, Minnesota, USA). For the conventional burr hole technique, a burr hole was created coaxial with the trajectory based on the operator's speculation. For the stereotactic burr hole technique, a combination of the instrument stop slide of the Leksell stereotactic frame and the Midas Rex perforator (Medtronic Inc., Minneapolis, Minnesota, USA) with a 14-mm perforator bit was used (Fig. 1A). It was possible to place this perforator just within the instrument stop slide (Fig. 1B). By attaching it to the instrument carrier slide of the arc, an exact burr hole was created coaxial with the trajectory under its guidance (Fig. 1C). After the burr hole was made, bipolar forceps were used to make a small incision for the dural opening. Bipolar arachnoidal opening was performed directly prior to micro electrode placement using the MicroDrive device (Medtronic, Inc.; Minneapolis, Minnesota, USA). Immediately following the microelectrode placement using the multi-tract recording method with an array insertion tube, the burr hole was air- and fluid-tight closed using fibrin glue. MER started at 10 mm above the target point and 0.5 mm steps were taken. The exact implantation site was chosen based on both the MER and awake macrostimulation testing for motor symptoms and adverse side effects. The final electrodes (DBS Lead 3389; Medtronic Inc., Minneapolis, Minnesota, USA) were implanted under fluoroscopic control. Finally, the clip and cap of the Stimloc burr hole-mounted anchoring ring were used for DBS lead fixation. A pulse generator was implanted the following day under general anesthesia.

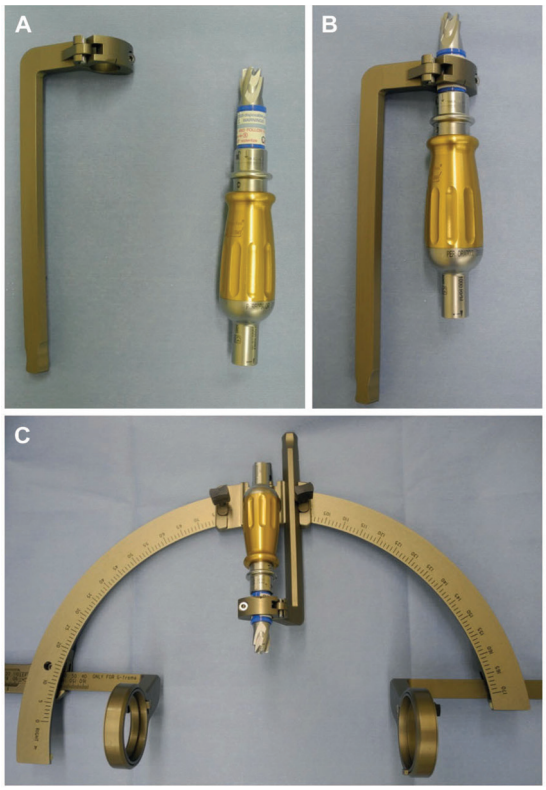

Fig. 1 Photographs of the stereotactic instruments. A: The instrument stop slide of the Leksell stereotactic frame is shown on the left, and the Midas Rex perforator with a 14-mm perforator bit is shown on the right. B: The perforator is placed just within the instrument stop slide. C: The combination of the perforator and the instrument stop slide is shown on the instrument carrier slide of the arc.

III. Assessment of stereotactic burr hole technique efficacy

The efficacy of the stereotactic burr hole technique for DBS was assessed by the presence or absence of additional drilling required to enlarge the burr hole. Factors associated with additional drilling were investigated, including the angles (mid-sagittal plane angle, axial plane angle from the AC-PC plane [i.e., angle of elevation subtending the AC-PC plane], and axial plane angle from the Leksell frame [i.e., angle of elevation subtending the horizontal plane of the Leksell frame]), which were based on the planning image using the FrameLink

5 software and the intraoperative lateral X-ray image, and the thickness of the skull at the entry points, which was based on the bony images from the postoperative CT scan from 1.25-mm slices. The thickness of the skull at the entry points was defined as the length from the external cortical bone in the center of the burr hole to the internal cortical bone, and the line of length was defined as being perpendicular to the external cortical bone in the center of the burr hole.

IV. Statistical analysis

Statistical analysis was performed with commercially available software (Excel; Microsoft Inc., Redmond, Washington, USA). Data are presented as the mean ± standard deviation (SD). The values were compared using analysis of variance followed by Fisher's exact probability test, Student's *t*-test, or Welch's *t*-test. Probability (p) values of less than 0.05 were considered statistically significant.

Results

No surgical complications were observed in the study group and no adverse stimulation effects were observed during surgery. All patients that underwent DBS had Parkinson's disease, and bilateral STN-DBS was performed. In the conventional burr hole group, three patients were men and two patients were women, and the mean age was 55.2 ± 8.1 years. In the stereotactic burr hole group, two patients were men and three patients were women, and the mean age was 68.8 ± 7.5 years. The baseline characteristics of all patients are shown in Table 1. There was no significant difference in the mid-sagittal plane angle, axial plane angle from the AC-PC plane, and axial plane angle from the Leksell frame in the entry points between the conventional burr hole group and the stereotactic burr hole group (p = 0.101, 0.058, and 0.223, respectively; Student's *t*-test and Welch's *t*-test). The thickness of the skull at the entry points was slightly higher in the stereotactic burr hole group compared to the conventional burr hole group, but the difference was not statistically significant (p = 0.110; Student's *t*-test). Four (40%) of the 10 burr holes in the conventional burr hole group required additional drilling to enlarge the burr hole, whereas no additional procedures were required in the stereotactic burr hole group, showing a statistically significant difference (p = 0.043; Fisher's exact probability test).

The characteristics of the cases requiring additional drilling in the conventional burr hole group are shown in Table 2. In the additional drilling group, 1 (25%) of the 4 burr holes was on the right side and 3 (75%) of the 4 burr holes were on the left side. The mid-sagittal plane angle, axial plane angle from the AC-PC plane, and axial plane angle from the Leksell frame in the entry points did not differ significantly between the additional drilling group and the non-additional drilling group (p = 0.375, 0.352, and 0.304, respectively; Student's *t*-test and Welch's *t*-test). The skull at the entry points in the additional drilling group was significantly thicker than that of the non-additional drilling group (p = 0.029; Student's *t*-test).

Representative Cases

I. Case 1: Standard thickness of the skull

A 79-year-old woman with Parkinson's disease had STN-DBS performed using the stereotactic burr hole technique. The thickness of her skull in the right burr hole was 9.1 mm, which was the standard length in this study. The entry points of the skin and skull were confirmed using the verifiable probe, and the trajectory was marked by crystal

Table 1 Comparison of patient characteristics for deep brain stimulation performed using the conventional burr hole technique or the stereotactic burr hole technique

	Conventional burr hole group (n = 5)	Stereotactic burr hole group (n = 5)	p value
Age*	55.2 ± 8.1	68.8 ± 7.5	
Sex (male/female)	3/2	2/3	
Mid-sagittal plane angle (°)*	24.2 ± 2.0	21.9 ± 3.8	0.101
Axial plane angle from the AC-PC plane (°)*	54.1 ± 8.6	60.2 ± 3.3	0.058
Axial plane angle from the Leksell frame (°)*	55.3 ± 10.2	60.2 ± 7.0	0.223
Thickness of the skull at the burr hole site (mm)*	9.8 ± 1.4 (range, 7.8–12.2)	11.1 ± 1.9 (range, 7.9–14.2)	0.110
Additional drilling of burr holes (No. of burr holes [%])	4/10 [40]	0/10 [0]	0.043

AC: anterior commissure, PC: posterior commissure, *Values are presented as the mean ± standard deviation.

Table 2 Comparison of factors associated with additional drilling in the conventional burr hole group

	Additional drilling required (n = 4)	No additional drilling required (n = 6)	p value
Burr hole side (right/left)	1/3	4/2	
Mid-sagittal plane angle (°)*	23.5 ± 1.2	24.7 ± 2.3	0.375
Axial plane angle from the AC-PC plane (°)*	50.8 ± 8.8	56.3 ± 8.5	0.352
Axial plane angle from the Leksell frame (°)*	49.8 ± 14.6	59.1 ± 4.6	0.304
Thickness of the skull at the burr hole site (mm)*	10.9 ± 0.9 (range, 10.3–12.2)	9.1 ± 1.2 (range, 7.8–11.2)	0.029

AC: anterior commissure, PC: posterior commissure, *Values are presented as the mean ± standard deviation.

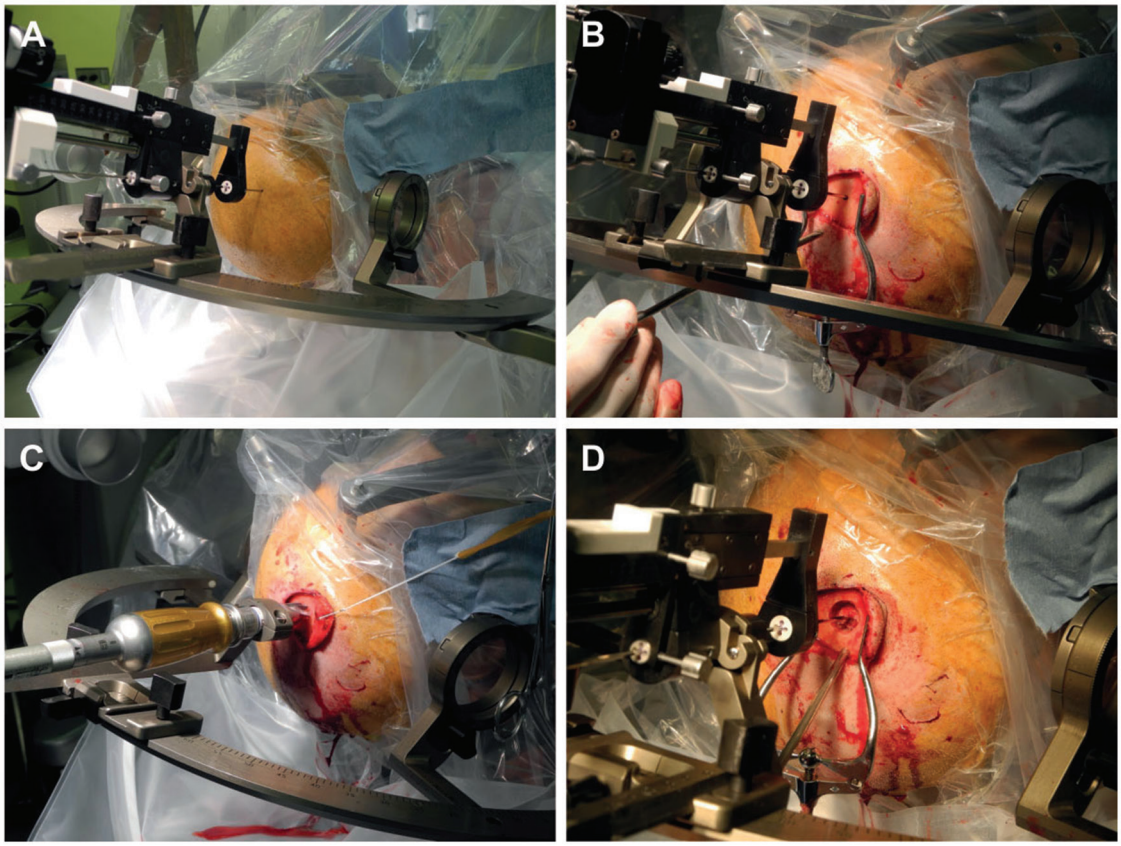

Fig. 2 Surgical procedures for the stereotactic burr hole technique. A: The entry point of the skin confirmed by the verifiable probe and marked by Crystal violet. B: The entry point of the skull confirmed by the verifiable probe after making the C-shaped skin incision and marked by Crystal violet. C: The combination of the instrument stop slide and the Midas Rex perforator with a 14-mm perforator bit is attached to the instrument carrier slide, and the tip of the perforator is just contacting the entry point. The burr hole is created under its guidance. D: The tip of the verifiable probe is shown in the center of the burr hole.

violet staining (Fig. 2A, B). After removal of the MicroDrive device from the instrument carrier slide of the arc, the combination of the instrument stop slide and the Midas Rex perforator with a 14-mm perforator bit was attached to the instrument carrier slide, and the burr hole was created under its guidance (Fig. 2C). After the burr hole was made, the tip of the verifiable probe was visible in the center of burr hole (Fig. 2D).

II. Case 2: Thick skull

A 70-year-old woman with Parkinson's disease had STN-DBS performed using the stereotactic burr hole technique. The thickness of her skull in the

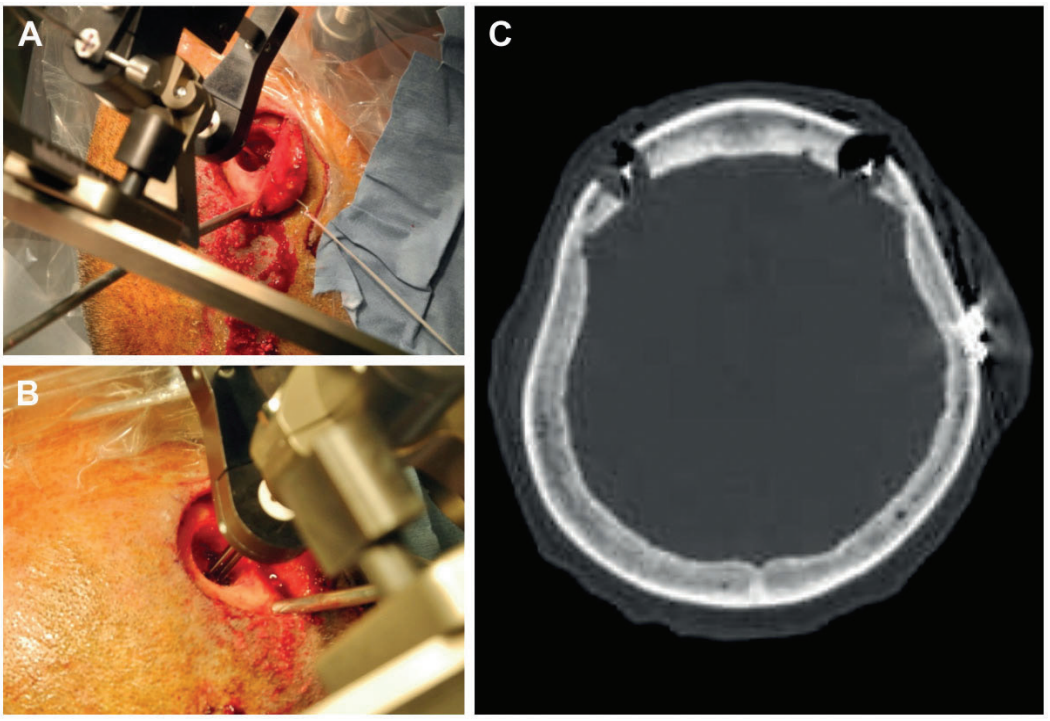

Fig. 3 Stereotactic burr hole technique in a thick skull. A: The tip of the verifiable probe is shown in the burr hole of a patient with a thick skull. B: The tips of 5 array insertion tubes used to guide the microelectrode are also shown in the burr hole without additional drilling. C: Postoperative computed tomographic image showing the thickness of the skull.

right burr hole was 13.7 mm, which was considered very thick in this study (Fig. 3A, C). However, all five of the array insertion tubes used to guide the microelectrode fit inside the burr hole without requiring additional drilling (Fig. 3B).

Discussion

The use of a small-sized trephination by a 0.25-inch twist drill under stereoguidance to insert a single DBS lead has been reported previously.[2] However, to our knowledge, this is the first report of stereotactic trephination by a 14-mm perforator bit, which is the bit size that is commonly used in the burr hole surgery. In this study, the cases with thick skulls tended to require additional drilling of the burr hole (Table 2). If the skull at the entry points is thick, a slight deviation of the burr hole from the planned trajectory in the external cortical bone may become a large deviation in the internal cortical bone. In such a case, when the array insertion tube used to guide the microelectrode is placed in the center of the burr hole on the external cortical bone, the tip of the array insertion tube may hit the edge of the burr hole on the internal cortical bone. Conversely, when the tip of the array insertion tube is placed in the center of the burr hole on the internal cortical bone, the array insertion tube may hit the edge of the burr hole on the external cortical bone (Fig. 4). In these circumstances, additional drilling to enlarge the burr hole becomes necessary. The enlargement of the burr hole may extend the length of the dural incision, which would increase cerebrospinal fluid (CSF) loss and intracranial air collection. These intraoperative changes are unfavorable factors for brain shift that can impede exact DBS lead placement.[3–6] Techniques to prevent intraoperative CSF loss have been reported.[7,8] In addition, it is noteworthy that no additional drilling is required in this stereotactic burr hole technique. Furthermore, this technique avoids a situation in which the DBS lead cannot be implanted in the same microelectrode tract to hit the bone edge or the dural incision edge because it is thicker than the microelectrode, even if the microelectrode can be implanted in the correct position.

As the thickness of the skull at the entry points did not differ between the conventional burr hole group and the stereotactic burr hole group (Table 1), it is suggested that the latter technique is extremely useful to avoid additional drilling,

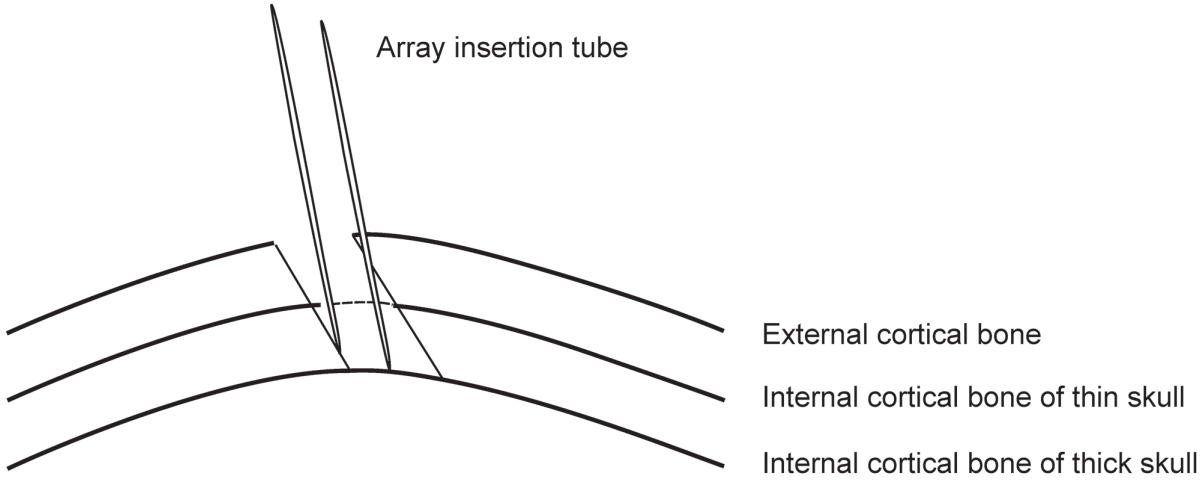

Fig. 4 Illustration showing a deviation of the burr hole for trajectory. In the case of a thick skull, if the tip of the array insertion tube used to guide the microelectrode (*left*) is placed in the center of the burr hole on the external cortical bone, it hits the edge of the burr hole on the internal cortical bone. However, this does not occur in thin skulls. Alternatively, if the tip of the array insertion tube (*right*) is placed in the center of the burr hole on the internal cortical bone, it hits the edge of the burr hole on the external cortical bone.

regardless of the bone thickness. As a result, this technique shortens the operative time and relieves patient stress.

We also investigated the relationship between the entry point angles and the requirement for additional drilling. The mid-sagittal plane angle and the axial plane angles from the AC-PC plane and the Leksell frame in the entry points of the conventional burr hole group were not different from those of the stereotactic burr hole group (Table 1). This result suggests that the entry point angles may not influence the need for additional drilling. Indeed, even in the comparison within the conventional burr hole group, there was no statistically significant difference of the entry point angles between the additional drilling group and the non-additional drilling group (Table 2).

Particular attention should be paid to several factors before adopting our stereotactic burr hole technique for safe clinical application. First, it is important to prevent the transmission of vibration from the perforator to the stereotactic frame because the vibration may distort the fine structure of the frame. Attachment between the perforator and the stop slide, as well as between the stop slide and the carrier slide of the arc should be sufficiently loose to minimize the transmission of vibration. Moreover, such a loose attachment enables easy removal of the perforator from these instruments in the case of an emergency event. When the angle between the perforator and the skull is very steep, small drilling on the external cortical bone would be useful to avoid slipping of the perforator from the skull. In addition, attention should be paid to the perforator to avoid injury of the dura matter and brain parenchyma. Recently, in the conventional burr hole technique using an automatic-releasing perforator, the incidence of the perforator plunging into the intracranial space has been reported to be 0.54%.[9] Since the perforator does not always trephine to the external cortical bone perpendicularly in the stereotactic burr hole technique due to the great difference in skull curvature between individuals, the dura matter and brain parenchyma may be injured when the internal cortical bone is trephined obliquely. Dural injury during trepanation tends to occur in elderly patients because of adhesion between the cranium and the dura mater.[10] No surgical complications were observed in the stereotactic burr hole technique; however, caution should be taken to avoid such complications, especially in elderly patients.

Conclusion

The stereotactic burr hole technique is a simple procedure, and contributes to safe and exact DBS, particularly in patients with thick skulls.

Acknowledgments

The authors would like to thank Editage (www.editage.jp) for English language editing.

Conflicts of Interest Disclosure

The authors have no personal, financial, or institutional interest in any of the drugs, materials, or devices described in this article. The authors who are members of the Japan Neurosurgical Society (JNS) have registered online self-reported COI Disclosure Statement Forms through the JNS website.

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Address reprint requests to: Keisuke Toyoda, MD, PhD, Department of Neurosurgery, National Hospital Organization, Nagasaki Kawatana Medical Center, 2005-1 Shimogumigo, Kawatana-machi, Higashisonogi-gun, Nagasaki 859-3615, Japan.
e-mail: enzokun7@yahoo.co.jp