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Effect of cranial window diameter during deep brain stimulation surgery on volume of pneumocephalus

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Abstract

Background—Successful deep brain stimulation (DBS) surgery necessitates high accuracy in targeting specific intracranial nuclei. Brain shift due to pneumocephalus can contribute to decreased accuracy. Larger burr holes and dural openings may increase pneumocephalus volume due to a greater degree of communication between the subdural space and extracranial air.

Objective—To determine if there is a statistically and clinically significant difference in postoperative pneumocephalus volume related to burr hole and durotomy size.

Materials and Methods—DBS electrodes were surgically implanted through either large (14 mm) burr holes or small (4 mm) twist drillholes. Immediate postoperative computerized tomography (CT) scans of 165 electrode implantations in 85 patients from 2010–13 were retrospectively analyzed. Student's t test and Mann-Whitney U test were employed with a threshold of significance set at $p = 0.05$.

Results—No significant difference in pneumocephalus was identified between patients who had implantation of DBS electrodes through 4 mm twist drill holes ($n=71$ hemispheres, 12.84 ± 9.79 cm³) and those with large 14 mm burr holes ($n=87$, 11.70 ± 7.46 cm³, $p=0.42$). Volume of pneumocephalus did not correlate with duration of surgery or patient age. The groups did not differ significantly with respect to other aspects of surgical implantation technique or surgical duration.

Conclusion—While identifying factors that may reduce pneumocephalus volume may be critical to improving stereotactic accuracy and targeting, the current results suggest burr hole size may not alter the degree of brain shift.

Keywords

Brain shift; Deep brain stimulation; Pneumocephalus

BACKGROUND

Successful deep brain stimulation (DBS) surgery necessitates high targeting accuracy. Brain shift due to pneumocephalus is well recognized as a potential source of stereotactic inaccuracy.^{1–7}

Given that the degree of brain shift correlates with the volume of pneumocephalus,^{7–9} several strategies have been described to reduce the amount of CSF egress and resultant pneumocephalus. For example, Takumi et al. (2013) reported that using a polyethylene glycol sealant at the burr hole decreases postoperative pneumocephalus.⁵ Head position has also been discussed as a modifiable risk factor for pneumocephalus. Some have argued that elevating the head and burr hole site will reduce pneumocephalus, although at an increased risk of venous air embolism.^{2,10} Others have suggested that the supine position may result in decreased pneumocephalus due to the resulting decreased intradural to extradural pressure differential when compared with an elevated position. Moreover, when the head is supine, the brain may occlude the cranial window from the inside, further decreasing potential air invasion.^{2,10} Nazarro and colleagues (2010) also addressed other potential modifiable factors such as number of micro-electrode recordings and angle of electrode approach and found no associations with degree of pneumocephalus.¹⁰

One surgical technique that has not been systematically evaluated with respect to impact on degree of pneumocephalus is burr hole and durotomy size. It has been suggested that reducing the communication between the subdural space and external air is crucial in reducing the total pneumocephalus volume.² Some surgeons opt to use a small opening such as a twist drill (measuring 4 mm in diameter) rather than using a cranial perforator bit (14 mm diameter) on the assumption that CSF egress can be better controlled thereby minimizing pneumocephalus and brain shift.

Given that the relationship between brain shift and pneumocephalus volume has already been established in the literature,^{7–9} the goal of this retrospective study is to determine if there is a statistically and clinically significant difference in pneumocephalus volume on immediate postoperative CT imaging between patients undergoing stereotactic DBS implantation using large (14 mm) vs small (4 mm) skull perforations.

METHODS

Patient population

Postoperative CT scans of 165 consecutive image-guided stereotactic DBS electrode implantations performed at a single institution between 2010 and 2013 were retrospectively analyzed. 87 electrodes were implanted by a single neurosurgeon in 44 subjects using 14 mm “large” burr holes and 78 electrodes were implanted by a second neurosurgeon in 41 subjects using a 4 mm “small” burr holes. Details of the number of patients, hemispheres, and electrodes studied in this series are provided in Table 1.

Surgical Procedure

Besides difference in burr hole size, surgical procedures were done in an identical fashion. Prior to the surgery, application of a local anesthetic was followed by frame placement (Leksell model G stereotactic frame, Eletka AB), after which high resolution CT images were obtained. DBS electrodes were targeted at the globus pallidus internus (GPi) or subthalamic nucleus for patients with Parkinson's disease, the ventral intermediate nucleus (ViM) of the thalamus for essential tremor, the GPi for dystonia, and the periaqueductal gray/periventricular gray, ventral posteromedial nucleus of the thalamus, and/or ventral posterolateral nucleus of the thalamus for the treatment of chronic pain. Targeting was based on direct visualization of target on high resolution preoperative magnetic resonance imaging, except when targeting ViM in which case indirect targeting was used. Trajectories were selected in order to avoid sulci, ventricles, and vessels imaged on contrast-enhanced imaging. In all cases, patients were positioned in a semirecumbent position, with head-of-bed elevated at approximately 20–30 degrees. For large 14 mm burr holes, a 4.5 cm linear incision was made, a cranial perforator bit (14 mm) was used, and the burr hole edges were immediately waxed upon completion to minimize the risk of venous air embolism. Dura was opened widely to visualize cortex but was not opened until immediately prior to guide tube placement after which the cranial and dural opening were immediately sealed with Tisseal sealant. The sealant was left in situ during anchoring of the Stimlock (Medtronic, Inc). For small 4 mm burr holes, a 4 cm curvilinear incision was used and a twist drill bit was used. Dura was opened using monopolar cautery through the twist drill hole. The cranial opening edges were immediately waxed after completion of drilling and throughout the remainder of the procedure. The lead was anchored with a dog bone titanium cranial plate. In both groups, the size of the dural opening was equal to the size of the cranial window. Patients were maintained on propofol anesthesia during drilling and were awakened for the remainder of the surgical procedure for intraoperative microelectrode recording (MER) and neurophysiological testing. MER was always performed with a single microelectrode per pass.

CT Measurements

CT scans were acquired in the axial plane. The postoperative CT scan was taken within 8 hours following completion of the surgery. Postoperative CT scans were imported into iPlanStereotaxy™ (BrainLab, Munich, Germany). The volume of pneumocephalus was measured using a semiautomated approach with iPlan. The intracranial air was first identified visually. The object creation function was then used to encircle the region of interest. This was done in both the axial and sagittal views to span all slices with pneumocephalus. The region of interest was drawn around outer margins of air in an ellipsoid manner to best exclude extracranial air (eg: sinuses). The threshold option was then applied with an upper Hounsfield unit threshold of –250. Images were then manually reviewed by a single investigator for consistency slice-by-slice to exclude extraneous inclusions (eg: frontal sinuses, nasal cavity) (Figure 1A). Volumetric estimates were extracted from the iPlan software, expressed in cubic centimeters (cm³) (Figure 1B). For the scans of bilateral implants, the advanced manipulation function with the sagittal split option was then applied to divide total pneumocephalus volume into per-hemisphere volume, so as to allow comparison of bilateral surgeries with unilateral surgeries. Unilateral surgeries

included patients who underwent two staged procedures to implant the two hemispheres, with each surgery being analyzed separately.

Statistical Analysis

Student's t test (unpaired, two-tailed, equal variance) was employed to detect significant differences in pneumocephalus volume between patients with small burr holes and large burr holes. Since pneumocephalus volumes in both groups were not normally distributed, Mann-Whitney U (rank sum) test (two-tailed) was additionally used to perform nonparametric analysis. One-way ANOVA between the 4 main targets (GPi, subthalamic nucleus, ventral intermediate nucleus of the thalamus, and ventral posterolateral/medial nucleus of the thalamus) was employed to determine if there was a statistically significant difference in pneumocephalus volume based on target. Association between age and pneumocephalus volume was assessed via Pearson's correlation coefficient (R), with a two-tailed p value. The threshold level of significance for all analyses was set at $p = 0.05$.

RESULTS

The average age of patients with small 4 mm and large 14 mm burr holes were 61.8 ± 11.8 years and 60.8 ± 15.5 years, respectively ($p = 0.73$). No difference in surgery duration was found between patients implanted with either small (315 ± 67 mins) or large (327 ± 57 mins) burr holes (student's t test, $p = 0.41$). Furthermore, no correlation was found between surgery duration and pneumocephalus volume ($R = 0.027$, $p = 0.81$).

Amongst all patients, total postoperative pneumocephalus volumes ranged from 0 to 68.78 cm³, with an average of 21.49 ± 13.70 cm³ (mean $\pm$ standard deviation) (median: 19.42 cm³). Volume of pneumocephalus was not related to target (one-way ANOVA, $p = 0.6$). No statistically significant difference in total pneumocephalus was found between patients with large burr holes (20.78 ± 11.63 cm³, median: 19.37 cm³) vs small burr holes (22.35 ± 15.95 cm³, median: 19.52 cm³) (student's t test, $p = 0.60$; Mann Whitney U Test, $p = 0.83$). The average per-hemisphere pneumocephalus volume for all patients studied was 12.22 ± 8.58 cm³ (median: 11.07 cm³). Average per-hemisphere pneumocephalus volume in patients with small 4 mm burr holes ($n = 71$ hemispheres) was 12.84 ± 9.79 cm³ (median: 11.37 cm³) and in those with large 14 mm burr holes ($n = 87$) was 11.71 ± 7.47 cm³ (median: 11.07 cm³) (student's t test, $p = 0.42$; Mann Whitney U Test, $p = 0.76$) (Figure 2).

Due to possible differences in results for patients undergoing unilateral implants as opposed to patients undergoing simultaneous bilateral implantation of DBS leads, we performed additional analyses of each of these subsets of patients. For patients with simultaneous bilateral DBS implants, average total pneumocephalus volume was 22.23 ± 14.33 cm³ (range: 0.17 to 68.78 cm³, median: 20.62 cm³) and average per-hemisphere pneumocephalus volume was 11.08 ± 7.86 cm³ (range: 0 to 36.24 cm³, median: 10.32 cm³). Total pneumocephalus volume did not significantly correlate with age amongst patients in this subgroup ($R = 0.17$, $p = 0.17$). No statistically significant difference in total pneumocephalus volume was found between in those patients with large burr holes (20.31 ± 11.98 cm³, median: 19.46 cm³) and those with small burr holes (24.61 ± 16.69 cm³, median: 24.23 cm³) (student's t-test, $p = 0.24$; Mann Whitney U Test, $p = 0.31$) (Figure 2). Likewise,

no significant difference in per-hemisphere volume was found between patients with large burr holes ($10.15 \pm 6.45 \text{ cm}^3$, median: 10.11 cm^3) and those with small burr holes ($12.23 \pm 9.24 \text{ cm}^3$, median: 11.15 cm^3) (student's t test, $p = 0.14$; Mann Whitney U Test, $p = 0.20$). Finally, in this patient subset, total pneumocephalus volumes did not correlate with age neither with large burr holes nor with small burr holes (large burr holes: $R = 0.27$; $p = 0.06$, small burr holes: $R = 0.09$, $p = 0.58$).

Amongst patients with unilateral surgery, total pneumocephalus volume varied from 0.4 to 48.90 cm^3 , with an average of $19.33 \pm 11.7 \text{ cm}^3$ (median: 17.62 cm^3). Amongst these patients, pneumocephalus was seen only in the ipsilateral hemisphere in 18 out of 19 patients, with bilateral pneumocephalus seen in the remaining patient. The average per-hemisphere pneumocephalus in patients with unilateral implants was $18.57 \pm 9.78 \text{ cm}^3$ (range: 0.4 to 37.79 cm^3 , median: 18.19 cm^3). Total pneumocephalus did not significantly correlate with age amongst patients undergoing unilateral surgery (total pneumocephalus: $R = 0.21$, $p = 0.34$). No difference in total pneumocephalus volume was observed between those implanted with small burr holes ($16.20 \pm 12.33 \text{ cm}^3$, median: 12.00 cm^3) vs. large burr holes ($22.21 \pm 10.84 \text{ cm}^3$, median: 18.85 cm^3) (student's t test, $p = 0.23$; Mann Whitney U Test, $p = 0.19$). No significant difference in per-hemisphere volume was found between patients with small burr holes ($16.20 \pm 12.33 \text{ cm}^3$, median: 12.00 cm^3) and those with large burr holes ($20.58 \pm 6.86 \text{ cm}^3$, median: 18.94 cm^3) (student's t test, $p = 0.31$; Mann Whitney U Test, $p = 0.18$). In patients undergoing unilateral surgery, per-hemisphere pneumocephalus volumes did not correlate with age neither with large nor with small burr holes (small burr holes: $R = 0.47$, $p = 0.14$; large burr holes: $R = -0.19$, $p = 0.58$).

DISCUSSION

Intraoperative brain shift can significantly decrease targeting accuracy in stereotactic surgery. Several studies have focused on strategies to reduce pneumocephalus volume and subsequent brain shift. It has been suggested that minimizing the area of communication between the subdural and extracranial compartments reduces CSF egress and thus pneumocephalus,^{2,8} indicating that burr hole size may be a modifiable factor in controlling pneumocephalus volume. No prior study has focused directly on the role burr hole size plays in pneumocephalus volume. The current analysis suggests that burr hole size does not correlate with volume of pneumocephalus and that using small twist drill burr holes does not afford any advantage from this perspective.

Rationales exist beyond the degree of pneumocephalus to motivate the use of large vs small burr holes. Large 14 mm burr holes portend the advantage of direct visualization of the cortical surface which may lend increased safety to the procedure allowing avoidance of cortical vessels. The data suggests that using a larger burr hole to gain greater visual access would not increase pneumocephalus. Large burr holes are also compatible with commercially available electrode anchoring systems, which some surgeons may prefer. These anchors are however high profile. Small twist drill perforations may provide a more cosmetic closure without proven inferiority with respect to anchoring effectiveness.

The results of this study are in part confounded by different surgeons using different burr hole sizes. The potential impact of this limitation is thought to be minimized by the otherwise similar techniques, including anesthetic protocol, head-of-bed position, and duration of surgery. Head-of-bed was elevated at 20–30 degrees for all patients in the study, and in all cases the dura was not opened until immediately prior to guide tube placement after which the cranial and dural opening were immediately sealed with Tisseal sealant or bone wax. No difference in surgery duration was found between the two surgeons, and furthermore, surgery duration was shown to not be a contributing factor in the amount of post-operative pneumocephalus volume. Moreover, the current results do not even suggest a trend towards a difference in pneumocephalus volume, which makes it less likely that the confound of two surgeons has significantly skewed the results and introduced a type II error. While it is recognized that procedure duration does not directly reflect the duration of dural opening, this measure offers the best available surrogate for such a retrospective study. Other surrogates, such as number of electrode passes would be similarly flawed and are unlikely to be significant contributors given the similarity in procedure times. A future study could be prospective in nature, using a single neurosurgeon.

While ideally one would like to investigate the effect of burr hole size on the precise position of the deep brain target as well as the anterior and posterior commisures, this was not possible with the current data as only postoperative CT data was available, which was insufficient for such quantification. Still, given the established relationship between pneumocephalus and brain shift^{7–9} the current results are no doubt informative about the impact of burr hole size on stereotactic surgical technique.

CONCLUSION

It is widely agreed that minimizing pneumocephalus is not only optimal for ensuring stereotactic accuracy but also facilitating postoperative recovery. This study fails to identify a systematic difference in volume of pneumocephalus related to burr hole size, using the techniques described. Other factors affecting pneumocephalus volume, including the effect of head-of-bed position on pneumocephalus volume remain to be more fully elucidated. A systematic study with varying degrees of head elevation comparing their respective pneumocephalus volumes awaits further review, and may elucidate the role that a potential “ideal” head-of-bed elevation would play in reducing pneumocephalus. Despite preventative measures taken, some pneumocephalus and subsequent brain shift will still likely be present. The presence of brain shift argues for the continued use of intraoperative physiological testing and image guidance.

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Fig. 1.

A: Progressive (ventral to dorsal) axial CT scans from a representative patient with bilateral DBS implants, showing pneumocephalus outlined in red. **B:** iPlan 3-dimensional reconstruction of total pneumocephalus; generated volume 23.18 cm³.

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Pneumocephalus Volume

Fig. 2.

No statistically significant difference in per-hemisphere pneumocephalus volume between patients with small burr holes and patients with large burr holes. Further subdividing patients to observe total pneumocephalus volume yielded similar results: no significant difference in total pneumocephalus volume for bilaterally implanted patients with 4 mm and 14 mm burr holes. Whiskers indicate standard deviation.

Table 1**Patient Population**

Number of patients, hemispheres analyzed, and electrodes implanted for bilateral and unilateral surgeries through small and large burr holes.

		Patients	Hemispheres	Electrodes
Small 4 mm Burr Hole	Bilateral	30	60	61 [*]
	Unilateral	11	11	17 [*]
	Total	41	71	78
Large 14 mm Burr Hole	Bilateral	36	74 ^{**}	74
	Unilateral	8	13 [‡]	13 [*]
	Total	44	87	87

^{*} Discrepancies in number of hemispheres and number of electrodes correspond to patients that had more than one electrode implanted in a hemisphere, as was done in cases of DBS for pain.

^{**} One patient had an infection, was explanted and was reimplanted bilaterally, resulting in a disproportionate number of hemispheres relative to patients implanted.

[‡] In one patient with unilateral implant, bilateral pneumocephalus was noted.