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# Shift of the Brain during Functional Neurosurgery

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**Objective :** The study investigates the extent of brain shift and its effect on the accuracy of the stereotaxic procedure.

**Methods :** Thirty-five patients underwent 40stereotactic procedures between June 2002 and March 2004. There were 26 males, mean age 59years old. There were 34procedures for Parkinson's disease, 2 for essential tremor, 3 for cerebral palsy, 1 for dystonia. Patients were divided in four groups based on postoperative pneumocephalus : under 5cc (9 procedures), between 5~10cc (13procedures), between 10~15cc (11procedures) and more than 15cc (7procedures). The coordinates of the anterior commissure(AC), posterior commissure(PC), and target were defined in pre-and intraoperative magnetic resonance image scans and the amount of air volume was measured with @Target (BrainLab, Heimstetten, Germany).

**Results :** The mean AC-PC was 26.5mm for patients with less than 5cc, 26.9mm for 5~10cc, 25.8mm for 10~15cc and 26.2mm for more than 15cc. The length of AC-PC line and coordinates of AC, PC was also not statistically different, Euclidean distance as well as $\triangle x$, $\triangle y$, $\triangle z$ of AC, PC, and target were also not statistically different among the groups ($p>0.1$). There was a variance in target of 0.7~7.6mm, Euclidean distance of 2.5mm, related to electrophysiology but not to brain-shift.

**Conclusion :** The amount of air accumulated in the intracranial space and compressing the cortical surface has no effect on the localization of subcortical stereotactic target and landmarks.

**KEY WORDS :** Parkinson's disease · Stereotactic target · Air volume · Brain shift.

## Introduction

Great effort in stereotactic surgery for movement disorders has focused on the accuracy necessary to safely reach a clinically effective result. However, there is no consensus among the centers regarding the optimal technique. Theoretically, after optimizing frame placement and anatomic targeting, it would be tempting to conclude that anatomic targeting is sufficient for optimal electrode placement. Unfortunately, a number of factors limit the precision of anatomic targeting based upon historical image sets. The accuracy of any stereotactic system, regardless of the modern imaging modality with fusion technique, is limited by the mechanical properties of the frame and by slice thickness in computed tomography(CT)-or MRI-based stereotaxy[3,11,28)]. The application accuracy of standard frame based stereotactic systems, with 1mm thick CT slices, has been measured to be approximately 1.5mm at the 95% confidence limit[1,18,19,22)]. In practice, the theoretical maximum application accuracy of a stereotactic system is rarely achieved, since many other factors in a given case can further decrease the accuracy of anatomic targeting. These factor include; (1) image distortion of MRI; (2) imperfect visualization of the target structure that precludes the ability to compensate for anatomic variability in an individual; (3) brain shift that occurs after preoperative imaging is complete, and (4) a specific physiological function may not always coincide with the same anatomic location.

In a number of studies that have examined physiological refinement of an anatomical target for surgery in movement disorder, physiology also makes a significant (2mm or greater) deviation from the initial anatomic target in 25~50% of cases[6)]. Herewith, we studied the brain shift during surgery.

After trephination of skull, surgeons can easily observe the brain surface is compressed by trapped air between cortex and subdural surface. This leads neurosurgeons to respect that such displacement of the brain might be a source of inaccurate targeting. Using intraoperative MRI we tried to identify if cortical compression during surgery led to subcortical target movement.

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**Table 1.** Magnetic resonance parameters for pre- and post-operative functional neurosurgery planning

| | Pre-operative XYZ planning | | | Post-operative electrode localization | |
|---|---|---|---|---|---|
| Scanner | Siemens | Siemens | Siemens | Siemens | Siemens |
| Field Strength (Tesla) | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 |
| Pulse Sequence | T1 MPRAGE | T2 | T2 | T1 Flash 3D Vol. | T2 for bleed |
| Scan Region | Whole brain | Area of interest | Area of interest | Whole brain | Whole brain |
| Slice plane | Axial | Axial | Coronal | Axial | Axial |
| TR | 2050 | 4000 | 4000 | 56 | 1500 |
| TE | 4.4 | 96 | 96 | 25 | 60 |
| Flip Angle | 15 | 180 | 180 | 40 | 40 |
| FOV (mm) | 280 | 280 | 280 | 280 | 230 |
| Slab | 1 | | | 1 | n/a |
| Slab Thickness | 160 | 160 | 160 | 96 | n/a |
| Partitions | 160 | n/a | n/a | 32 | n/a |
| Slice Thickness (mm) | 1 effective | 2 | 2 | 3 effective | 6 |
| Slice gap | None | None | None | None | None |
| No of slices | 160 | 20 | 20 | 32 | 15 |
| Matrix | 256*256 | 252*256 | 252*256 | 256*256 | 224*256 |
| Matrix (%) | 100 | 98 | 98 | 100 | 88 |
| Rect/FOV | 8 of 8 | 8 of 8 | 8 of 8 | 8 of 8 | 8 of 8 |
| Voxel size Ht*Wd*Thick | 1.09*1.09*1.0 | 1.11*1.09*2 | 1.11*1.09*2 | 091*1.09 | 1.03*0.90 |
| Averages | 1 | 2 | 2 | 1 | 2 |
| Special | | Swap phase enc L->R | | Swap ph enc L->R | |
| Scan Time (min:sec) | 16:52 | 4:53 | 4:53 | 7:42 | 11:16 |

*TR = transverse relaxation, TE = transverse excitation, FOV = field of view, Ht = height, Wd = width

# Materials and Methods

## Patient population

We reviewed 35patients who had a DBS procedure and two patients who underwent 2pallidotomies in the MRI operating room at University of California, Los Angels(UCLA) from June 2002 to March 2004, for total 40procedures in 35patients. There were 34operations for Parkinson's disease (29patients), 2 for essential tremor (2patients), 3 for cerebral palsy (3patients), 1 for dystonia (1patient). There were 26males and 9females with a mean age of 59.1years, ranging from 6.9 to 78.2years. The target was the subthalamic nucleus(STN) in 19patients (23 operations), the globus pallidus internus(GPi) in 11patients (12 operations), the nucleus ventralis intermedius of the thalamus(VIM) in 3 patients, and 2 pallidotomies in 2 patients. DBS-surgery was performed bilaterally in 5 patients and one patient underwent 3 operations because the wound was infected. Three of these patients were implanted in two stages, two were implanted in one stage. Microelectrode recordings were performed in 37 surgeries including 23 STN, 12 GPi, and 2 VIM cases. 2 pallidotomy cases and 1 VIM case used 2-mm exposed tip and 1.8-mm diameter radiofrequency thermocouple electrode macrostimulation for electrophysiological confirmation (Radionics, Inc., Burlington, MA).

We reviewed the moving target with brain shift during the procedure and naturally resulted in having a question about the brain shift. In this work we compared the coordinates of target, anterior, and posterior commissure including the length of AC-PC line intraoperatively and simultaneously measured the amount of air volume, depth of air, and the distance which are from the midpoint of the dura to the anterior portion of the anterior horn of the lateral ventricle, as well as the mean Euclidean distance of changed targets.

## Frame placement and Magnetic Resonance Imaging studies

A Leksell stereotactic frame (Leksell series G, Elekta, Atlanta, GA., USA) was attached to the patient's head under sterile conditions in the anteroom of the MRI suite. It was adjusted parallel to the infra-orbito meatal line (Reid's line) to approximate the axial plane of the stereotactic frame to the AC-PC plane. The eyes and mouth remained unencumbered by the frame, so as to allow visual testing and airway access. Preoperative 1.5Tesla MRI (Magnetom; Siemens, Erlangen, Germany) series were obtained using the parameters listed in Table 1. These images were transferred into the targeting software (@Target, BrainLAB, Heimstteten, Germany) for computer-assisted target determination. Definition of the AC-PC line and outline of the cortical mantle permitted transfer between the MRI volumes of the patient and both the Shaltenbrand-Warren and Talairach atlas.

For both STN and GPi as previously described[9], our procedure for defining the initial anatomic target adjusts a hybrid of two methods: (1) indirect targeting, using fixed distances or from the midpoint of the line between the AC-PC line, and (2) direct visualization of the target nucleus on MR images optimized for the target structure.

The globus pallidum target was lies from 0 to 2mm anterior to the midcommissural point, 21mm to 22mm lateral to the AC-PC line, and 4mm ventral to the AC-PC axial plane[2]. The subthalamic target was located 3mm posterior to the midcommissural point, 11.6mm lateral from the midline and 6mm ventral to the AC-PC axial plan. Adjustment of the initial target was accomplished by visualizing the anatomical landmarks related to the target such as the substantia nigra,

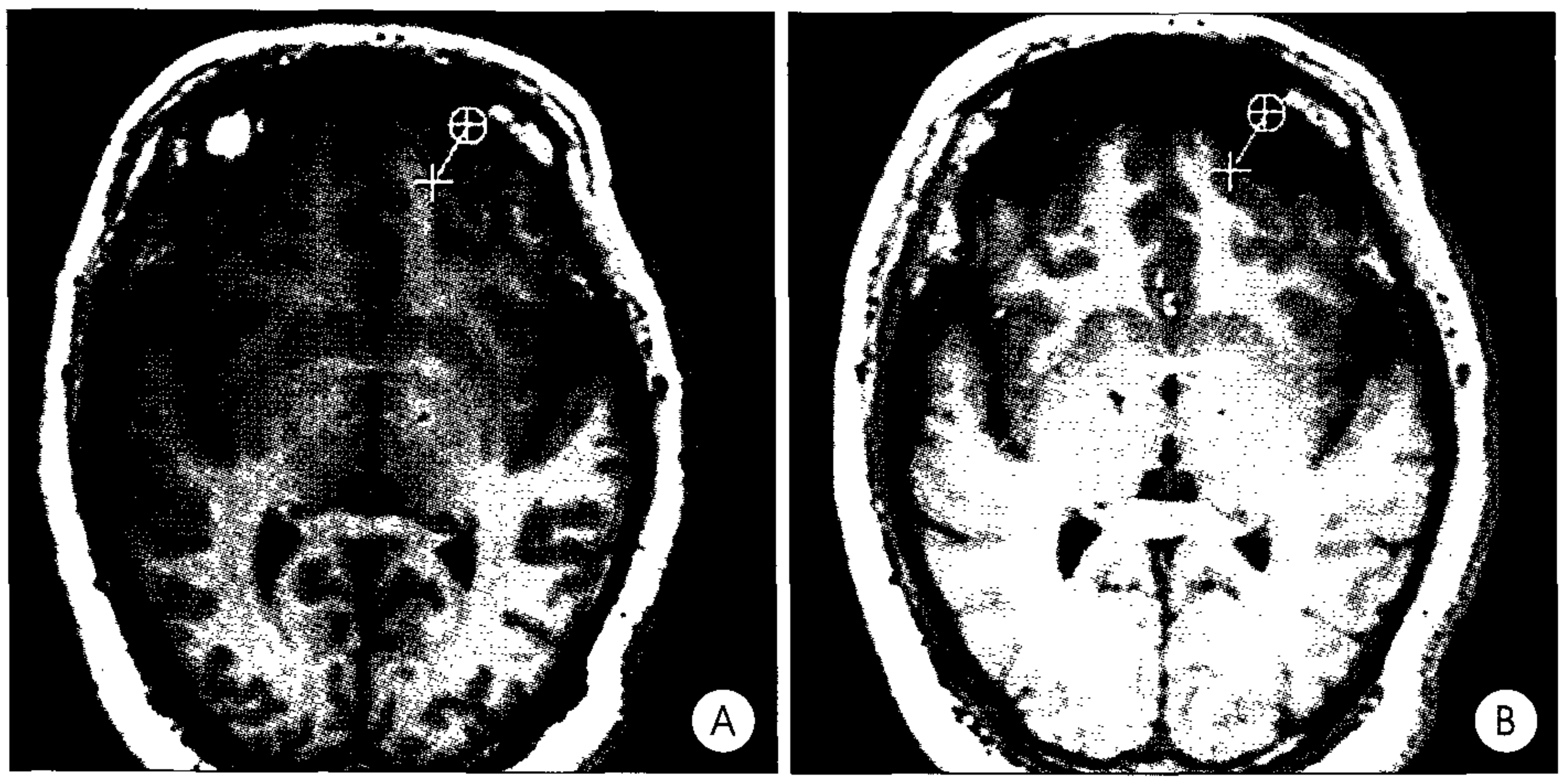

**Fig. 1.** Demonstration of the compressed cortical surface of the brain by the pneumocephalus during the deep brain stimulation-subthalamic nucleus procedure. A : The magnetic resonance image is overlaid as a drawing of pneumocephalus on the intraoperative T1WI at the level of anterior commisure-posterior commisure plane. B : The air thickness is 16mm and the deep brain stimulation is shown on the right side.

red nucleus, internal capsule, thalamus, and mamillary bodies. Frequently, direct visualization of the anatomical target was possible, notably for the GPi and STN[5,6,8]. Direct visualization of nuclear boundaries is helpful to make fine adjustments in the indirect coordinates and to compensate for individual variation in nuclear locations.

The thalamic target was located at one fourth of the AC-PC distance anterior to the PC, 11mm lateral to the wall of the third ventricle and the at the level of the AC-PC axial plane[7,23,26]. In the DBS procedures, the tip of the electrode was placed in the most ventral portion of the target, allowing the length of the four leads to span the target in the dorsal direction. Postoperatively, the chosen target vectors were compared with the position of the electrode seen on the images obtained in the 1.5Tesla iMRI unit during the operation. Sagittal, coronal, and axial T1 weighted images 3mm thick provided the position of the electrode. Measurements of the target and actual electrode position were taken from the fusion of pre-operative and intraoperative images. After checking the electrode position and ruling out hemorrhage, electrodes were fixed using the Navigus device (IGN, Melbourne, FL). Fusion of operative images with high-resolution 1.5 T pre-operative scans and multi-planar image acquisition circumvents the error of each MRI. The fusion was performed during the operation using @Target software (Brainlab, Heimstteten, Germany). Fusion is based on a volumetric mutual information algorithm with automatic process.

We measured the amount of air volume contained from the bottom of the brain to the level of the dorsal surface of the corpus callosum, as well as the length of AC-PC, the distance from dura to the anterior horn of the lateral ventricle (fronto-anterior horn line : FA line), coordinates of anterior commissure and posterior commissure and targets intraoperatively (Fig. 1). We also compared the mean Euclidean distance between planned target coordinates X(dx), Y(dy), Z(dz) and the actual position of the electrode in the intraoperative MRI (d3xyz) between each groups. The distance was calculated with absolute count and square root and angle of the axis of x, y, z with Euclidean method.

### Surgical procedure with electrophysiology

Patient was semi-sitting with the head frame fixed to the Mayfield headrest at approximately 30°. Intravenous sedation (profopol) was used for opening and closing. The burr hole was maintained open but related with surgical wax and Tissell (Baxter, Austria) to decrease leaking of cerebrospinal fluid(CSF). Microelectrode recording was performed using a Neurotrek system (Alpha-Omega, Nazareth, Israel), as previously reported[9]. Single-unit neuronal microrecordings were performed from 25mm above to 2mm beyond the the-oretical target or to a point beyond the target that showed a patterning unequivocally suggestive of the substatia nigra during the STN-DBS, or loss of recording in the thalamus and GPi targets. The final implantation site of the electrode placed for stimulation was guided by discharge frequency, neuronal pattern, and presence of the sensory receptive field as well as by clinically positive or adverse effects induced by the stimulations.

### Statistical analysis

Mean changed coordinate location and Euclidean distance of each target and the coordinates of anterior and posterior commissure as well as the factor of age were compared using Mann-Whitney U-test. The level of statistical significance was set at a probability value of less than 0.05. Statistical analyses were performed using commercially available software (SPSS, Inc., Chicago, IL).

## Results

The volume of air in the intracranial cavity had no significant influence in the position of the lateral ventricle (Table 2A). The intracranial air had also no significant influence in the position of planned target (Table 2B). It also had no influence in the position of AC, PC and the length of AC-PC. It had a minor influence in the coordinate z of the PC ($p<0.05$) (Table 2C). The number of insertion of DBS,

**Table 2.** Influence of intracranial air volume in the subcortical anatomy

| | Table 2A | | | Table 2B | | | Table 2C | | | | | | Table 2D | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean air volume (cc) | Mean air thickness (mm) | Mean FA line (mm) | Mean △ coordinate of target<br>Medio- lateral | Antero- posterior | Supero- inferior | Mean △ coordinate (mm)<br>Anterior commissure<br>△x | △y | △z | Posterior commissure<br>△x | △y | △z • | $dxyz^2$ | dAC−PC** | No. of insertion of DBS, macro- electo- de*** | No of micro- elec- trode recor- ding |
| Group I (9 procedures) | 2.4 | 1.9 | 41.5 | −0.8 | −1.4 | −1.3 | 0.1 | −0.1 | −0.1 | 0 | −0.1 | −0.3 | 3.2 | 0.3 | 1 | 1 |
| Group II (13 procedures) | 7.9 | 4.5 | 43 | −0.6 | −0.5 | −0.5 | 0.1 | 0.3 | 0 | −0.2 | −0.1 | 0.2 | 2 | 0.05 | 1.2 | 1.2 |
| Group III (11 procedures) | 12.5 | 6.9 | 43.5 | −0.7 | −0.4 | −0.2 | 0 | 0.1 | 0.2 | 0.5 | −0.3 | 0 | 2 | −0.01 | 1.3 | 1.2 |
| Group IV (7 procedures) | 22.3 | 9.4 | 45.5 | −0.5 | −0.7 | −0.1 | −0.2 | −0.1 | 0.2 | −0.3 | −0.1 | 0.6 | 3.1 | −0.6 | 2.3 | 1.6 |
| Mean | 11.3 | 5.7 | 43.4 | −0.65 | −0.75 | −0.53 | 0 | 0.05 | 0.08 | 0 | −0.15 | 0.13 | 2.58 | −0.07 | 1.4 | 1.2 |
| P−value | 0.000 | 0.000 | 0.590 | 0.481 | 0.370 | 0.277 | 0.114 | 0.815 | 0.481 | 0.673 | 0.963 | 0.002 | 0.888 | 0.481 | 0.008 | 0.139 |

*△z • and No. of insertion of DBS, macro−electrode*** have a statistical difference between each groups ($p<0.002$, $p<0.008$). dAC−PC** means difference between the pre− and postoperative i MRI. $dxyz^2$ means mean Euclidean distance between planned target coordinates and postoperative position of electrode in the intraoperative MRI, which were calculated with the absolute value of each coordinate and the square root of three dimensional moved distance. Group I ; V < 5cc, Group I ; 5cc < V < 10cc, Group III ; 10cc < V < 15cc, Group IV ; 15cc < V (V means air volume). △ means the difference of coordinate between planned target, commissures on preoperative MRI and actually achieved target, commissures on intraoperative MRI. * FA line = fronto−anterior horn line, AC−PC = anterior commisure−posterior commisure, DBS = deep brain stimulation

**Table 3.** Comparison of the coordinate of anterior, posterior commissure, and change of the target on the AC-PC plane including target of nucleus, age and Euclidean distance

| | | | Table 3A<br>Mean △ coordinate of target (mm) | | | Mean Euclidean distance(mm) | Table 3B<br>Mean △ coordinate of commissure (mm) | | | | | | Table 3C | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Target of nucleus | No.of procedure | mean age | Medio- lateral | Antero- posterior | supero- inferior | Anterior commissure<br>dxyz | △ x | △ y | Posterior commissure<br>△ z*** | △ x | △ y | △ z | *Air− thickness (mm) | No. of DBS,macro− elctrode | No. of micro− elctrode | △AC−PC Distance | **FA line<br>right | left | *Air− volume (cc) |
| Gpi | 12 | 58.1 | −0.9 | −0.2 | −0.2 | 2.1 | 0 | 0.2 | 0.3 | 0.4 | 0 | 0.2 | 6.7 | 1.2 | 1 | −0.25 | 44 | 43.5 | 12.3 |
| STN$^+$ | 23 | 62.2 | −0.4 | −0.8 | −0.7 | 2.5 | 0 | 0 | −0.1 | −0.2 | 0 | 0.2 | 5 | 1.3 | 1.4 | 0.04 | 44 | 43.5 | 10.5 |
| VIM | 3 | 71.2 | −2.8 | −2.3 | −0.7 | 4.7 | 0.3 | 0.3 | 0.3 | 0.1 | −0.3 | −0.2 | 4.1 | 1.5 | 1 | 0.3 | 41.1 | 41.8 | 5.4 |
| PAL | 2 | 12 | 0.3 | 0.6 | 0.4 | 1.9 | 0.2 | 0.2 | 0.1 | −0.1 | −1.1 | 0 | 7.4 | 3 | 0 | −0.25 | 45.3 | 47.6 | 11.6 |
| Age | | | | | | | | | | | | | | | | | | | |
| Under 50years old | 8 | 33.9 | −0.5 | −0.5 | 0.7 | 2.6 | −0.2 | −0.2 | −0.2 | −0.4 | −0.4 | 0.4 | 6.6 | 1.2 | 1.2 | 0 | 44.7 | 44.8 | 13 |
| Over 50years old | 32 | 65.5 | −0.7 | −0.7 | −0.8 | 2.5 | 0.1 | 0.1 | 0.1 | 0.1 | −0.1 | 0.1 | 5.2 | 1.9 | 0.9 | −0.03 | 43.8 | 43.1 | 10 |
| dxyz | | | | | | | | | | | | | | | | | | | |
| Over 4mm dxyz | 8 | 62 | −1.4 | −2.1*** | −2.3*** | 5.4 | 0.0 | −0.1 | 0 | −0.3 | −0.2 | 0.4 | 6.8 | 1.5 | 1.3 | −0.7 | 45.6 | 44.6 | 11.5 |
| Under 1mm dxyz | 9 | 65.4 | 0.1 | −0.4*** | −0.1*** | 0.9 | 0.1 | 0.2 | 0.2 | 0.4 | −0.2 | 0.3 | 4.7 | 1 | 1 | 0.2 | 42.7 | 41.9 | 11 |

*Air−thickness determined the maximum depth from dura to cortical surface. **FA line determined the distance from the midline of frontal dura to the most uppermost point of anterior horn of lateral ventricle.***statistical difference ($p> 0.05$), △= difference between planned target and position of electrode in the operative MRI sacn. dxyz= Euclidean distance, +STN = subthalamic nucleus, VIM = nucleus ventralis intermedius of the thalamus, Gpi = globus pallidus internus

macroelectrode was statistically related with the intracranial air volume ($p<0.008$) (Table 2).

The nucleus targeted did not influence the position of the electrode in relation to the planned target. The magnitude of the Euclidean distance between planned and achieved target was not significant. The same was found for young and elderly patients. Comparison of groups with large discrepancies in target (4mm × 1mm) suggests that major discrepancies occur in anterior-posterior position and superior-inferior direction (Table 3A). The same was found regarding anterior commissure and posterior commissure (Table 3B). The amount of intracranial air was not different for different target, or age group (Table 3C). Large differences between pre-and post-operative target, coordinates of AC-PC or ventricular position were not

**Table 4.** Influence of intracranial air volume in the subcortical anatomy on patients undergoing DBS- STN

| Air – volume. | Medio– lateral | Antero– posterior | Supero– inferior | dxyz | Anterior commissure △x | △y | △z | Posteior commissure △x | △y | △z | Air– thickness | FA line Right | Left |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Group I | −0.4 | −0.8 | −1.8 | 3.1 | 0.05 | −0.25 | −0.13 | −0.17 | 0.17 | 0.17 | 1.8 | 42.7 | 42.5 |
| Group II | −0.2 | −0.7 | −0.7 | 1.6 | 0 | 0.27 | 0.02 | −0.17 | 0.17 | 0.37 | 4.2 | 43.9 | 42.5 |
| Group III | −0.5 | −0.9 | −0.2 | 1.4 | 0.04 | 0.08 | 0.08 | −0.14 | −0.26 | −0.14 | 5.9 | 43.2 | 43.2 |
| Group IV | −0.5 | −0.7 | 0 | 3.7 | −0.18 | −0.08 | −0.18 | −0.35 | 0 | 0.55 | 7.9 | 46.6 | 45.7 |
| Mean | −0.4 | −0.775 | −0.675 | 2.45 | 0 | 0 | −0.1 | −0.2 | 0 | 0.2 | 5 | 44.1 | 43.5 |

dxyz means mean Euclidean distance between planned target coordinates and postoperative position of electrode in the intraoperative MRI, which were calculated with the absolute value of each coordinate and the square root of three dimensional moved distance. Group I; V < 5cc, Group II; 5cc<V<10cc, Group III ; 10 cc<V<15cc, Group IV; 15cc<V (V means air volume). △ means the difference of coordinate between planned target, commissures on preoperative MRI and actually achieved target, commissures on intraoperative MRI

**Table 5.** Comparison of targets and coordinators of anterior and posterior commissures as well as air volume between over 4.0 mm dxyz and under 1.0mm dxyz groups

| | | Coordinator of target on AC–PC plane | | | | | Coordinators | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| dxyz | Target | Air volume | AC–PC distance | Lateral | Antero– posterior | Supero– inferior | Anterior commissure △x | △y | △z | Posterior commissure △x | △y | △z | DBS No. of insertion | Microelectrode No. of insertion |
| Over 4.0mm | | | | | | | | | | | | | | |
| dxyz | STN | 3.35 | 0.6 | −1.6 | −5.0 | −1.5 | 0 | 0.4 | −0.2 | −0.5 | −0.3 | −0.4 | 1 | 1 |
| | STN | 3.51 | −1.0 | 0.3 | −1.2 | −7.5 | 0.1 | −0.2 | 0.3 | −0.1 | 0.3 | −0.1 | 1 | 1 |
| | VIM | 2.5 | 0.5 | −2.5 | −2.7 | −0.4 | 0.6 | 0.6 | 0.6 | 0.4 | −0.8 | −0.4 | 1 | 0 |
| | VIM | 7.52 | 0.9 | −2.9 | −4.2 | −1.4 | 0.2 | 0.3 | −0.3 | −0.2 | −0.7 | 0.4 | 1 | 1 |
| | GPi | 12.48 | −0.6 | −1.1 | 1.1 | −3.2 | 0 | −0.1 | 0 | 0.2 | 0.1 | 0.3 | 1 | 1 |
| | STN | 17.29 | 0.3 | −0.3 | −1.7 | 0 | −0.3 | −0.6 | −0.1 | −2.6 | 0.4 | 3.1 | 2 | 2 |
| | STN | 27.8 | −4.7 | −0.5 | 0.2 | −3.9 | −0.2 | −0.3 | −0.1 | 0.9 | −0.2 | −0.1 | 4 | 1 |
| | STN | 17.63 | −1.4 | −2.6 | −3.2 | −0.2 | −0.1 | −0.5 | −0.5 | −0.5 | 0 | 0.4 | 1 | 3 |
| Average | | 11.5 | −0.7 | −1.4 | −2.1 | −2.3 | 0.0 | −0.1 | 0.0 | −0.3 | −0.2 | 0.4 | 1.5 | 1.25 |
| Under 1.0mm | | | | | | | | | | | | | | |
| dxyz | STN | 3.87 | −0.6 | 0.8 | −1.8 | −0.4 | 0.6 | −0.7 | −0.3 | 0 | 0.1 | −0.4 | 1 | 1 |
| | STN | 4.35 | 1.7 | −0.8 | −0.4 | −0.7 | −0.5 | 0.4 | −0.5 | 0.3 | 0 | −0.3 | 1 | 1 |
| | STN | 7.24 | −0.7 | 0.9 | −0.8 | 0.3 | 0.2 | 0.2 | −0.7 | −0.3 | −0.2 | 0 | 1 | 1 |
| | STN | 9.01 | 0 | 0.3 | −0.1 | −1 | 0 | 0.5 | −0.2 | −0.1 | −0.1 | 1.1 | 1 | 1 |
| | GPi | 7.08 | −0.2 | 0.3 | −0.5 | 0.7 | −0.2 | 0.6 | −0.2 | −0.2 | −0.2 | 0.5 | 1 | 1 |
| | GPi | 33 | −0.3 | −0.5 | −0.5 | −0.7 | 0 | 0.1 | 1.5 | −0.5 | −0.1 | 1.7 | 1 | 1 |
| | STN | 11.37 | 1.2 | 0.0 | −0.5 | 0.2 | 0.5 | 0.3 | 0.4 | −0.7 | −0.2 | −0.6 | 1 | 1 |
| | GPi | 13.67 | 0.6 | −0.4 | 0.8 | 0 | 0.2 | 0.6 | 1.4 | 4.8 | −0.4 | 0.3 | 1 | 1 |
| | STN | 9.75 | 0.4 | −0.1 | 0.1 | 0.7 | 0 | −0.2 | 0.4 | 0 | −0.7 | 0.5 | 1 | 1 |
| Average | | 11 | 0.2 | 0.1 | −0.4 | −0.1 | 0.1 | 0.2 | 0.2 | 0.4 | −0.2 | 0.3 | 1 | 1 |

related to the amount of intracranial air (Table 3, 4, 5). Table 5 shows that large discrepancies in the target planned and achieved were not occurred by the amount of intracranial air ($p < 0.5$). Considering over 4.0mm dxyz group, the target changed 1.4mm medially, 2.1mm posteriorly, 2.3mm inferiorly

## Discussion

The result of this study shows that the compression of cortical brain during the open stereotactic neurosurgery was not related with the moving target under the modern technologic environment. Anecdotally, functional neurosurgeons anticipated some brain movement to occur between intraoperative scans with ventriculography as well as brain shifting with inevitable loss of CSF during a long operation[8,11,12,14,19,21]. According to review of literatures, the air ventriculography may cause slight anterior displacement of the third ventricle which may alter the anatomical position of the stereotactic target[20]. Recently, interventional MRI can acquire presurgical images for planning and intraoperative images for direct images guidance compensating for brain shift after dural opening[10]. As the matter of fact, all functional neurosurgeons have mainly tried to obliterate the trephination opening with bone wax and Tissell (Baxter, Austria) to avoid any leaking of CSF, reduces the risk of air emboli, and dampens pulsation artifact in the MER[8,11]. Some neurosurgeons insisted on it that the patient should be operated on in the sitting position for moving of stereotactic probe toward the same direction as shifted brain, namely vertically[29]. They also might trust that in this way, it is possible to catch up with the target simply by advancing the electrode or cannula further down along its trajectory even though the sinking of the brain is minor relevance since the final placement of the lesion is carried out according to functional stimulation and intraoperative MR images. Furthermore, there have been some differences of targets demonstrated in individuals who have a significant variation in the position of STN and topographically depended on the most critical factor to be the width of third ventricle in nucleus of VIM and GPi[5,8,11,13,24].

Our data shows that the centers of anterior and posterior commissure did not move anymore intraoperatively and the length of AC-PC line also was not influenced by pneumocephalus. There was not statistically difference of amount of air volume between over 4mm and less than 1mm distance of Euclidean distances of target. Actually the one case of DBS-GPi, which was performed for cerebral palsy, had 32.4cc of the air volume, 16.8mm of the air thickness and 52.2mm of the average distance from the midline of the dura to the most anterior point of the anterior horn of lateral ventricle. The patient had three times insertions of macroelectrode to identify the internal capsule and then DBS was inserted at the planned target but the dxyz still is defined under the average level. Otherwise, the large discrepancy over 4mm dxyz group is also unpredictable because the side effect of electrophysiologic stimulation is different between the each target, for example, the internal capsule relatively locates at the different position between GPi, STN and VIM. There were no statistical differences between the each target and the number of insertion of electrode.

It seems to be that the changed target in functional stereotaxic surgery for movement disorder is mainly depended on electrophysiology and the stage of determination of AC-PC line as well as other mechanical factors. This phenomenon is natural that the Euclidean distance (dxyz) of target also is resulted in the changed of the target on the AC-PC plane which might be also determined manually by neurosurgeon who always make an effort to place the distal contact (lead 0) to the bottom of the motor territory of STN and the anterolateral part of the motor territory of the GPi just 1mm superior to the optic tract with electrophysiologic response. There were no differences between the DBS-STN and GPi. Our results showed that the inferiorly moving of targets could not be related with pneumocephalus. In other word, there was no evidence of shifted brain in stereotactic functional neurosurgery for movement disorder.

Recently, most neurosurgeons use electrophysiological guidance to localize lesions or electrodes correctly in the thalamus, subthalamus, or GPi. According to review of literatures of the DBS-STN, most neurosurgeon used to determine the functional optimal target, which is defined by the best contact of the definite electrode implanted under electrophysiological and clinical guidance because it is impossible to be sure that the preoperative anatomical location of the STN is the functionally optimal target[4,5,8,11,13,17,25,27]. Specialists correct the initial target by using electrophysiological guidance, thereby increasing the efficiency of positioning[15,16]. There is a mean difference of 2mm between the initial target and electrophysiologically determined targets, and the axially acquired image data sets may contribute to this pattern error, since the spatial resolution will be most limited perpendicular to the scan plane. We always used the fused sagittal image to identify the tip of electrode. They were able to employ only one track of electrode insertion in the majority of cases by directly targeting the STN (75%) and most corrections were made in the vertical direction, which is achieved simply by advancing or withdrawing the DBS electrode within the same track. We were able to employ only one track of electrode in the majority of cases by hybrid technique of targeting (80%) with 1.5-tesla iMRI and the usage of fused images. According to the literature, success rate with one time passage of electrode was between 70% to 80% among all procedures[28].

In the review of the DBS-GPi, it could be concluded that volumetric MR imaging analysis has revealed that pallidotomy of GPi for Parkinson's disease are distributed along an anteromedial-to-posterolateral axis with the posteroventral GPi, parallel to the obliquely oriented border of the GPi with the internal capsule[15]. This was resulted from third ventricle variation in the absence of reliable neurophysiological indicators of mediolateral location. These findings emphasize the importance of anatomical and physiological factors in determining correct lesion placement. In our DBS of GPi the coordinators of the target was mostly determined by anatomical targeting and physiological stimulation with one time pass of microelectrode recording and test stimulation. Our data also showed the variation of targets on the AC-PC plane had 5mm on the axis of medial-lateral direction of target and the variation of this distance was each 1.4mm and 0.5mm bigger than the axis of anterior-posterior and inferior-superior. However, actually in point of view of the difference between the planned target and achieved target during procedures it was mainly influenced by moving the electrode more on the axis of anteroposterior as well as superoinferior direction rather than mediolateral direction during the each pass of electrode. It is always decided by electrophysiologic guide.

Partly because of high age and the disease itself, Parkinsonian patients tend to have atrophic brains. This atrophy allows the brain to be displaced more readily than in younger patients[29]. But our data showed that the Euclidean distance (dxyz) and the difference of distances of target on the AC-PC plane as well as the coordinators of anterior and posterior commissure had no statistical difference between over 50 and under 50years old group. However, although there was no statistical difference of intracranial air volume and the number of insertion of electrode between two age groups, the target on the AC-PC plane inferiorly moved 0.8mm in over 50years old patients, 0.7mm superiorly moved in young age group. It could not be explained how some amount of air in subdural space could move the young brain superiorly, so it cannot be the evidence that the atrophy allows the brain to be displaced more readily than in younger patients.

As a result, we can suggest that the shifting brain during operation does not imply a real situation and the cortex of brain was only compressed by the volume of the air. There might be existed with errors between pre-and intraoperative images, and mechanical problems during procedure. The changed of targets could be resulted from contributors of functional data with microelectrode recording and electrophysiological stimulation.

## Conclusion

The amount of air accumulated in the intracranial space and the depressed cortical surface apparently has no effect on the localization of subcortical stereotactic target and landmarks. The changed target in functional stereotaxic surgery for movement disorder is related with electrophysiologic response.

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