Accuracy of Surgeon's Estimation of Sella Margins during Endoscopic Surgery for Pituitary Adenomas: Verification Using Neuronavigation

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ABSTRACT

We assessed the accuracy of a surgeon's localization of sella margins during endoscopic transsphenoidal surgery for pituitary adenomas, as verified using a neuro-navigational system, and we identify types of pathology in which neuronavigation is of most benefit. We performed a prospective cohort study of 32 consecutive patients undergoing image-guided endoscopic transsphenoidal surgery for pituitary adenomas. We assessed the margin of error in the surgeon's localization of the superior and inferior margins of the sella and the lateral margins as determined by the medial border of left and right carotid arteries, using a magnetic resonance-based neuronavigational system. The overall mean error of localization of sella margins by the surgeon was 4.5 ± 3 mm. Localization of the inferior sella margin was more accurate (3.1 ± 2 mm mean error) compared with localization of the left (4.8 ± 3 mm) or right carotid arteries (4.6 ± 3 mm). Giant adenomas (> 2.5 cm), more invasive adenomas (Hardy grade IV), and those with parasellar extension (Hardy grades D and E) were associated with larger errors in localization of the carotid arteries. There was no significant difference when stratifying for recurrent surgery, nostril of approach, and sella morphology. During endoscopic transsphenoidal surgery, the margin of error in the surgeon's estimation of the sella margins for adenomas less than 2.5 cm located predominantly within the sella is relatively small. The margin of error increases for giant adenomas, with greater invasiveness and parasellar spread, and the use of neuronavigation can be especially useful in such cases.

KEYWORDS: Endoscopic transsphenoidal, pituitary adenomas, neuronavigation

Endoscopic transnasal transsphenoidal surgery is rapidly gaining acceptance as the approach of choice for sella and suprasellar lesions.^{1,2} The endoscope enables improved visualization through a combination of better

illumination and a wider field of view.^{3,4} Reduced nasal trauma and improved optics that could theoretically aid tumor resection have been reported as some of the benefits.^{5–7} Although extended endoscopic approaches

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are also described to treat several para- and suprasellar lesions,⁸ the pituitary adenoma remains by far the most common pathology tackled by the transsphenoidal route.

In all forms of transsphenoidal approaches to the pituitary, the identification and subsequent avoidance of the adjacent vascular and neural structures is paramount to prevent inadvertent damage. Although several useful anatomic landmarks can guide the surgeon to the pituitary fossa, anatomic variations are common and the normal anatomy may also be distorted following previous surgery.⁹ Thus, some form of intraoperative guidance can be helpful for the surgeon to target the pituitary fossa with the transsphenoidal approach.

Traditionally, most surgeons undertaking transsphenoidal pituitary surgery using an operating microscope have relied on intraoperative fluoroscopy in the lateral view to determine the trajectory in the sagittal plane to the pituitary fossa.¹⁰ Anteroposterior views are less commonly utilized, in part due to the technical difficulties in obtaining a useful fluoroscopic view in the coronal plane. Given that injury to the carotid artery is one of the most devastating complications of pituitary surgery, intraoperative guidance in the coronal or axial planes is also likely to be helpful. Frameless stereotactic neuronavigation has been a useful adjunct in this respect and provides a virtual intraoperative image in the sagittal, coronal, and axial planes.¹¹ First described in the early 1990s, the usefulness of neuronavigation has also been reported for both microscopic and endoscopic pituitary surgery.^{5,7,12} Navigation may be performed using either computed tomography (CT) or magnetic resonance (MR) images and allows confirmation of the margins of the pituitary fossa and the location of important surrounding structures.^{13,14}

To date, studies describing the usefulness of neuronavigation in endoscopic pituitary surgery have been generally qualitative in nature.^{5,6,15,16} In this report, we attempt to quantitate the accuracy of the

surgeon's localization of sella margins during endoscopic transsphenoidal surgery and verify this using a neuronavigational system.

PATIENTS AND METHODS

Consecutive patients undergoing endoscopic transsphenoidal surgery for pituitary adenomas over a 10-month period were included in the study. The surgery was performed by one surgeon, who had performed more than 100 pituitary surgeries previously. For each patient, the nature of the clinical presentation, endocrine profile, visual field changes, MR findings, operative details, complications, and tumor pathology were noted. In particular, the tumor size, degree of extrasellar extension and invasion (Hardy grade¹⁷), and sphenoid sinus configuration (i.e., sellar, presellar, or conchal) were recorded.

Operative Technique

The endoscopic transnasal transsphenoidal approach utilized has been described in detail previously.¹⁸ The surgeon, who was right-handed, stood at the head of the patient, with the neuronavigational system to the right and the endoscope stack to the left (Fig. 1). In general, a uninostrial approach was preferred, and the side of access was chosen following visual identification of the more capacious nasal passage or by the laterality of the lesion (e.g., left nostril approach for a right-sided lesion and vice versa). After gentle deflection of the middle turbinate laterally, a modified direct Griffith's technique was used to access the sphenoid fossa.

Surgery was performed with the aid of the BrainLAB VectorVision version b neuronavigational system (BrainLABTM USA, Moorestown, NJ). Preoperatively, all patients underwent a fine cut (1-mm contiguous slices) volumetric MR study in the axial plane. These

Figure 1 View of the operative setup during endoscopic transsphenoidal surgery.

images were uploaded to the workstation in the operating room and co-registered to the patient's head, which was secured in rigid three-point cranial fixation allowing intraoperative registration via a high-resolution laser scan of the patient's face. Validation of the accuracy of the registration was performed visually by identification of external landmarks. In the event of failure of registration, the process was repeated up to a maximum of four times. Time taken to set up and register the neuronavigational system was also recorded.

Localization of Sella Margins

The surgeon did not have sight of the neuronavigational monitor until after the position of sella margins had been estimated. After adequate exposure of the sphenoid sinus, the operating surgeon was asked to localize the following margins of the sella using the navigational probe: superior and inferior sella margins and the medial edge of the left and right carotid bulges (Fig. 2). The perpendicular distance between the tip of the navigational pointer used by the surgeon to localize the sella margins and the actual anatomic landmarks as identified using the frameless neuronavigational system were then measured by an independent surgeon (Fig. 2).

Statistical Methods

All data were entered and analyzed on the SPSS statistical package (Statistical Programs for the Social Sciences, Chicago, IL). Differences between groups were assessed using analysis of variance (ANOVA) and post hoc Bonferroni tests for parametric data and using the chi-square tests for nonparametric data.

RESULTS

Of the 37 consecutive patients recruited into this study, 5 (14%) patients had to be excluded due to failure of the neuronavigational system to register ($n=2$) or because of grossly inaccurate readings during intraoperative navigation due to presumed movement of the reference frame ($n=3$). There were missing data in one or more categories for four patients. The mean time for setup of the neuronavigational system was 3.6 ± 1.2 minutes (range 3 to 8 minutes; $n=32$). The intraoperative registration accuracy of the system was calculated to be 0.97 ± 0.2 (range 0.6 to 1.4; root mean square values).

Patient Demographics

For the 32 patients included in the study, the average age was 54 ± 17 years (range 23 to 82), with a female preponderance (19 women, 13 men). All had pituitary adenomas with 18 nonfunctioning adenomas and 14 functioning adenomas (six acromegalies; six prolactino-

mas intolerant of medical treatment; one Cushing's disease; one thyrotropin-secreting). Six patients had undergone previous transsphenoidal surgery. The transnasal surgical approach was undertaken via the right nostril in 14 cases and via the left nostril in 13, and a binostril approach was performed in five cases.

Review of the preoperative MR images confirmed that 24 were sellar and eight were presellar types. The majority of tumors were macroadenomas ($n=27$), and the overall mean vertical height of tumors was 17.7 ± 9.3 mm (range 0 to 35) and the mean transverse width was 16.2 ± 7.4 mm (range 0 to 29). Based on the maximum tumor dimension, the tumors were grouped as micro (< 1 cm; $n=4$), macro (1 to 2.5 cm; $n=17$), or giant (> 2.5 cm; $n=7$).

Degree of cavernous sinus invasion and parasellar extension was assessed using the Hardy grading system (Table 1).¹⁷ Seven tumors were categorized as Hardy grade IV, denoting invasion outside of the sella margins, and eight were categorized Hardy grade D or E, demonstrating parasellar extension.

Localization of Sella Margins

The overall mean error of localization of sella margins by the surgeon as compared with the neuronavigational system was 4.5 ± 3 mm (range 0.1 to 17 mm). The mean error in the surgeon's localization of the inferior margin of sella floor was the lowest; it was lower than when compared with localization of the left and right carotid arteries ($p < 0.05$ and $p < 0.01$, respectively; one-way ANOVA and post hoc Bonferroni test; Table 1). The error of localization of the superior margin of the sella was caudal in 24 cases and rostral in eight cases. The error of localization of the inferior margin of the sella was caudal in 16 cases and rostral in 16 cases. The error of estimation of the right carotid was medial in 31 cases and lateral in one case. The error of estimation of the left carotid was medial in 30 cases and lateral in two cases.

With respect to the maximum dimension of the tumor, micro- (< 1 cm) and macroadenomas (1 to 2.5 cm) had lower mean error in the surgeon's localization of the carotid arteries compared with giant adenomas (> 2.5 cm; $p < 0.01$; one-way ANOVA and post hoc Bonferroni test; Table 1). There was no significant difference in this respect between tumor size and mean error in estimation of the superior or inferior sella margins (Table 1).

Using the Hardy classification, more invasive adenomas (Hardy grade IV) and those with parasellar extension (Hardy grades D and E) were associated with larger mean errors in localization of the left and right carotid arteries ($p < 0.05$; one-way ANOVA and post hoc Bonferroni test; Table 1). There was no significant difference in this respect between the Hardy grade and the mean error in estimation of the superior or inferior

Figure 2 Example of the intraoperative view obtained with the endoscopic (A) and a line diagram (B) clarifying the anatomic landmarks. Neuronavigation screenshots (C–F) obtained when the surgeon was asked to identify with the pointer (green line) the inferior margin (+1; C), superior margin (+2; D), medial aspect of left carotid (+3; E), and the medial aspect of the right carotid artery (+4; F). Note that the intraoperative endoscopic view is upside down as annotated. The margin of error in localizing the sella margins was calculated as the perpendicular distance between the tip of the pointer and the sella margin (orange line; e.g., yellow line in D). LCA, left carotid artery; RCA, right carotid artery.

Table 1 Estimation of Error in the Surgeon's Localization of Sella Margins as Verified by Intraoperative Neuronavigation (One-Way Analysis of Variance and post hoc Bonferroni Test)

	<i>n</i>	Superior Sella Margin (mm)	Inferior Sella Margin (mm)	Medial Edge of Left Carotid (mm)	Medial Edge of Right Carotid (mm)
All patients (range)	32	4.6 ± 3 (0.1–17)	3.1 ± 2 (0.3–8)	4.8 ± 3* (0–13)	5.6 ± 3 [†] (2–11)
Tumor size (maximum dimension)					
Micro (< 1 cm)	4	3.2 ± 1	2.0 ± 1	3.9 ± 2 [‡]	4.8 ± 2
Macro (1–2.5 cm)	17	5.2 ± 4	2.7 ± 2	3.7 ± 2 [‡]	4.3 ± 2 [‡]
Giant (> 2.5 cm)	7	4.3 ± 2	3.8 ± 2	9.0 ± 2	8.0 ± 2
Hardy grade					
Suprasellar (A–C)	22	4.9 ± 4	2.6 ± 2	4.1 ± 2 [§]	4.9 ± 2
Parasellar (D–E)	8	3.7 ± 2	3.9 ± 2	7.3 ± 4	6.8 ± 2
Noninvasive (0–III)	23	4.8 ± 4	2.6 ± 2	4.1 ± 2 [¶]	4.8 ± 2 [¶]
Invasive (IV)	7	3.9 ± 2	3.9 ± 2	7.6 ± 4	7.4 ± 2
Previous surgery					
No	26	4.7 ± 3	2.8 ± 2	4.8 ± 3	5.5 ± 3
Yes	6	4.2 ± 2	4.3 ± 2	5.0 ± 3	6.5 ± 3
Sinus morphology					
Sellar	24	4.7 ± 4	2.8 ± 2	4.9 ± 3	5.4 ± 3
Presellar	8	4.2 ± 2	3.8 ± 2	4.6 ± 2	6.2 ± 3
Nostril of approach					
Right	14	4.5 ± 3	3.0 ± 2	4.9 ± 2	5.9 ± 3
Left	13	5.0 ± 4	3.4 ± 2	4.7 ± 4	4.8 ± 3
Both	5	3.6 ± 1	2.5 ± 1	5.0 ± 2	6.9 ± 2

**p* < 0.05.[†]*p* < 0.01 versus inferior margin value.[‡]*p* < 0.001 versus giant size tumors.[§]*p* < 0.01 versus parasellar group (Hardy grade D–E).^{||}*p* < 0.05 versus parasellar group (Hardy grade D–E).[¶]*p* < 0.01 versus Invasive group (Hardy grade IV).

sella margins (Table 1). There was also no significant difference in the mean error of localization of the sella margins when considering the sella morphology (i.e., sellar versus presellar type of sphenoid sinus), previous surgery, and nostril of approach (Table 1).

DISCUSSION

In transsphenoidal pituitary surgery, the identification of the pituitary fossa margins is vital to avoid accidental injury to adjacent structures. With endoscopic pituitary surgery, the improved optics and the wider field of view can help the surgeon identify several anatomic landmarks that might aid in the localization of the sella margins.¹⁹ Thus, on approach to the sphenoid, identification of important anatomic landmarks such as the choana, middle turbinate, and the sphenoid ostium is helpful in delineating the opening into the sphenoid sinus. Once within the sphenoid sinus, the superior (i.e., planum sphenoidale) and inferior (i.e., pituitary fossa floor) sella margins can be identified in most cases (Fig. 2). When recognizable, the left and right carotid prominences and superiorly the opticocarotid recesses are key bony landmarks that mark the lateral margins of the sella.

Such anatomic detail can be more difficult to visualize with the microscopic transsphenoidal approach (unpublished observations). The present study examines the accuracy of the surgeon in identifying the margins of the pituitary fossa during endoscopic surgery for pituitary adenomas, and verifies this using an intraoperative neuronavigational system.

For a consecutive series of pituitary adenomas, our results demonstrate that localization of the inferior margin of the pituitary fossa was the most accurate, probably related to the relative ease of recognition of the curved shape of the sella floor in most patients. Localization of the carotid arteries was the least accurate, with a tendency for the surgeon to be more medial in almost all cases. Although this may reflect "surgical caution," it is also likely to compromise the degree of side-to-side dural exposure obtained for tumor resection. Moreover, the error of localization of the carotid arteries was greater for giant adenomas (i.e., > 2.5 cm) and those with greater invasiveness and parasellar spread as assessed by the Hardy classification. Giant adenomas especially with lateral invasion into the cavernous sinuses may flatten the contours of the carotid bulges, resulting in difficulty identifying the lateral margins of the sella. This further highlights the value of intraoperative guidance notably

in the coronal or axial planes to confirm the lateral extent of surgery for pituitary adenomas.³

Neuronavigation in transsphenoidal surgery has been especially advocated in cases where the anatomy of the sphenoid sinus may be distorted, such as in patients with previous pituitary surgery and abnormal nasal or sphenoid sinus anatomy.^{12,13,16} Somewhat surprisingly, in the present study there was no significant association between the accuracy in identification of sella margins and previous transsphenoidal surgery nor for that matter the configuration of the sphenoid sinus (i.e., sellar and presellar types). Intuitively, it may have been expected that the inferior margin of the sella floor would be more difficult for the surgeon to identify in presellar-type sphenoid sinus, due to flattening of the clival-sella margin. Failure to observe this may be due in part to the relatively low number of cases in each subgroup. The sample size was also relatively small to be able to undertake a multivariate analysis to consider the complex interactions between various factors that could potentially affect surgeon's accuracy in estimating sella margins (e.g., tumor size, shape, invasiveness; abnormal sella anatomy, etc.). Moreover, in this study the localization of the sella margins was undertaken by a single surgeon. This will introduce operator bias, especially given that there will also be inherent variability between surgeons and there is also an operative learning curve with pituitary surgery.¹⁸ Thus, the errors in estimating the sella margins may be greater for the surgeon at the beginning of the learning curve for the procedure.

The present study further highlights the usefulness of neuronavigation in pituitary surgery. We found that the MR-based neuronavigation to be relatively straightforward to undertake with minimal setup time. Previous reports have also observed that neuronavigation can help to reduce the overall operative times for the surgeon.¹⁴ When successfully registered, the system was found to have a good intraoperative registration accuracy that compares well with previous studies.^{20,21} However, this is only an estimate of the point-to-point error and not the actual error of the navigational system as determined by testing on a phantom target. Our study did identify a 14% failure rate in using the neuronavigational system, due to registration failures as well as movement of the reference frame intraoperatively. Frameless neuronavigation can be based on MR or CT images.²² CT-based studies are reported to have a higher degree of registration accuracy.²² Although CT images give better details of the bony landmarks, one of its disadvantages is the radiation exposure to the patient and the reduced detail with respect to soft tissue anatomy. Merging of CT and MR images in neuronavigation can provide the benefits of both modalities of imaging, which is useful in more complex pathology and for extended transsphenoidal approaches.

Although there is a role for neuronavigation in pituitary surgery, its routine use does necessitate additional resources including the expense of the navigational system and the need for a preoperative scan. Despite its limitations, preoperative images are not required with fluoroscopy, which also provides a "live" image as opposed to the virtual image of the neuronavigational system. Others have also highlighted the benefits of intraoperative Doppler ultrasound probes in localizing the carotid arteries during pituitary surgery.^{23,24}

CONCLUSION

The present study suggests that in reasonably experienced hands, the margin of error in the surgeon's localization of the sella margins during endoscopic pituitary surgery for uncomplicated micro- and macro-adenomas is relatively small. Indeed, it has been ours and other's observation that in relatively uncomplicated cases where the pituitary adenoma is located within the sella, with normal sphenoid sinus anatomy, endoscopic pituitary surgery can be undertaken without the aid of fluoroscopy or neuronavigation (unpublished observations). Guidance from a neuro-navigational system becomes more useful for larger pituitary adenomas with significant parasellar extension and in extended approaches. However, in all pituitary surgery, the neuronavigational system can add another level of surgical confidence without significant increases in operative times.

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