Computer-assisted frameless stereotaxy in transsphenoidal surgery at a single institution: review of 176 cases

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Object. In this study the authors address the efficacy and safety of frameless stereotaxy in transsphenoidal surgery.

Methods. One thousand transsphenoidal operations were performed at the authors' institution between June 2000 and July 2005. This series consists of a retrospective review of 176 patients entered in a prospectively obtained database who underwent frameless stereotactic transsphenoidal surgery in which magnetic resonance (MR) imaging, computerized tomography (CT) scanning, or fluoroscopic guidance was used. Of the 176 patients, 104 (59%) had suprasellar extension of their tumor, 70 (40%) had involvement of the visual apparatus, and 65 (37%) had cavernous sinus involvement. All patients underwent detailed pre- and postoperative neurological, endocrinological, radiographic, and ophthalmological follow-up evaluations. Records were reviewed retrospectively for intraoperative and postoperative complications related to the surgical approach.

No instances of visual deterioration, carotid artery (CA) stenosis, or stroke were observed following transsphenoidal surgery. Only one patient sustained damage to the CA intraoperatively, and this was controlled in the operating room. Five patients (3%) required an intensive care unit stay postoperatively. Intraoperative cerebrospinal fluid leakage was encountered in 112 patients (64%) and was more frequently observed in tumors with suprasellar involvement.

Conclusions. Frameless stereotaxy is a safe and effective modality for the treatment of recurrent or invasive sellar masses. All three frameless stereotaxy modalities provided accurate information regarding the anatomical midline and the trajectory to the sella turcica. The MR imaging, CT scanning, and fluoroscopic stereotaxy modalities all have unique advantages as well as specific limitations.

KEY WORDS • pituitary adenoma • diagnostic imaging • stereotaxy • fluoroscopy

A SURGICAL intervention remains the mainstay of diagnostic and therapeutic management for many types of pituitary and sellar lesions.^{6,7} It provides the means of obtaining at least a biopsy sample for pathological assessment, a mechanism for effective cytoreduction, and a way of reducing mass effect of large tumors.²

Because sellar lesions are often deep-seated masses arising close to the optic apparatus, vital neurovascular structures, and eloquent parenchyma, the need for precision intraoperatively is vital. This need is further underscored in patients with recurrent or residual sellar masses treated via the transsphenoidal approach, because the normal anatomical landmarks of the sphenoid, nasal sinuses, and anterior skull base may be damaged, obliterated, or obscured by postoperative scars.^{8,22}

The concept of stereotaxy for the extirpation of sellar lesions dates back to the early twentieth century.¹³ In 1908, Horsley and Clarke defined the key components needed for stereotaxy as the following: a headholder frame for fixing the skull rigidly, a mechanism for directing the instrument to a defined intracranial target point, a stereotactic da-

ta acquisition unit, and a probe or surgical instrument that could be directed to a target point through a stereotactic frame. As detailed by Pollock, et al.,¹⁷ Horsley and Clarke used these principles to design a stereotactic device that was used to target deep structures accurately in the brain of a cat.

A renaissance in stereotactic procedures was brought about by the advent of 3D digitizers or "neuronavigators." Neuronavigator arms are passive intraoperative position-sensing systems whose main tasks are to encode the six-dimensional position of a surgical tool and to register the coordinates of a position sensor into an intraoperative 3D or 2D image. This provides a display of the real-time location of surgical tools on intraoperative or preoperative images.¹¹

The use of fluoroscopic neuronavigation (FluoroNav; Medtronic Sofamor Danek, Inc., Memphis, TN) in many centers is a mainstay in repeated transsphenoidal surgery. It has been proposed that fluoroscopy is an economical and ergonomic way of displaying the osseous anatomy of the sphenoid sinus and the anterior cranial fossa,⁸ even though it does not provide the 3D view of CT-guided stereotaxy and the visualization of neurovascular structures supplied by MR imaging. In this paper we describe our 5-year experience using frameless stereotaxy for the surgical treatment of sellar masses.

Abbreviations used in this paper: CA = carotid artery; CSF = cerebrospinal fluid; CT = computerized tomography; MR = magnetic resonance; 2D = two-dimensional; 3D = three-dimensional.

FIG. 1. Intraoperative photograph showing fixation of the patient's head in a three-point headholder; this is critical to allow mechanical accuracy for the Stealthsystem.

Clinical Material and Methods

Patient Selection

The cases in this retrospective review were obtained from a prospectively acquired database of 176 patients who underwent transsphenoidal surgery performed by a single surgeon (E.R.L.) at the University of Virginia Health System. Preoperatively, patients underwent general and specific neurological examinations, including a thorough history, physical examination, laboratory workup, and when relevant, special studies such as neuroophthalmological and radiological evaluations. The decision to use stereotaxy was the responsibility of the primary surgeon. Factors used in making the decision included (but were not limited to) lesion size, complexity, proximity to the optic apparatus and CAs, suprasellar extension, and whether the procedure was a first-time or repeated operation.

Postoperatively, patients were followed up by both a neurosurgical and neuroendocrine team. They were monitored closely for the presence of diabetes insipidus, ophthalmological changes, and the presence of new endocrinopathies (that is, hypocortisolemia).

Patient Characteristics

One thousand patients underwent transsphenoidal surgeries at our institution between June 2000 and July 2005. Of these patients, 176 underwent stereotactically guided operations. One hundred twenty-two patients (67%) underwent procedures with the FluoroNav system (Medtronic Sofamor Danek, Inc.), 15 (8%) underwent procedures with MR imaging guidance, and 39 (21%) had CT-guided procedures. The mean age at operation was 43 years (range 5–87 years). Ninety-eight patients were female and 78 were male.

Treatment Planning

System Setup. A necessary step before the actual opera-

tion is preparation of the imaging data on the workstation and subsequent treatment planning. Images are transferred easily via local ethernet connections directly from the imager to the workstation by using a File Transfer Protocol according to the Digital Imaging and Communications in Medicine–American College of Radiology/National Electrical Manufacturers Association image archiving standard. The workstation is located on a cart in the operating suite's treatment planning room. Because the system includes either a magnetic tape, CD, or DVD drive that is compatible with the image scanner archive drive, data can be imported from a tape or, in principle, historical images can even be used if a local area network has not been supported. Preoperatively, the imaging data are reformatted and background noise is reduced. Image fusion can also be performed when indicated.

Preoperative MR Imaging/CT-Guided Setup. The most important step in this preoperative routine is the identification of the fiducial markers on the images. The position is chosen in such a way that the marker on the images was identified just where it tangentially touched the skin. This position is thought to be identical to a tattooed spot on the scalp. For fiducial registration, any of the orthogonal slices can be used, leaving the other two for a control check. Interacting dynamically with the images already obtained at this point allows the surgeon to create a procedure plan consisting of an entrance point and a "navigational trajectory" to the lesion. The whole preparation process is usually accomplished within 30 or 45 minutes. Treatment planning is usually performed the day before surgery, after the imaging study has been completed, enabling the surgeon to begin surgery early in the morning without delay.

Fluoroscopic Setup. In setting up for fluoroscopically guided imaging, the patients' head is placed in a three-point headholder on a horseshoe headrest. A 2D, posterior–anterior, and lateral fluoroscopic view of the skull base is visualized in real time. The fluoronavigation system then generates a 2D matrix of the surgical target for each view based on the fluoroscopic projection. The StealthStation neuronavigational system (Medtronic Sofamor Danek, Inc.) system then creates a 3D matrix for the target, and the Stealth probe is used to confirm the accuracy of the system with respect to known external landmarks. All images in fluoroscopically guided surgeries were obtained after the patient was anesthetized, eliminating the need for additional CT or MR imaging scheduling.

Operative Technique

System Setup and Registration. The use of the Stealth system requires the establishment of a rigid transformation between image and physical space for both fluoroscopic and MR/CT images. Before the operation, the system is transferred into the operating room on its portable cart. After anesthesia is induced, the patient's head is fixed in a three-pin headholder in standard fashion (Fig. 1). In patients who receive fiducials, care is taken to ensure that all tattooed fiducial markers are reachable and properly distributed. The neuronavigator arm is fixed to the Mayfield headholder, always in the standard fashion on the left side of the patient, although many other positions could have been chosen if it had been necessary or desirable.

FIG. 2. Examples of fluoroscopic studies used to define the trajectory in repeated operations in which normal bone anatomy is disrupted.

Planning the Operation. The surgical planning process is an integral part of surgical preparation, can be performed quickly and efficiently, and provides valuable planned path information for all intraoperative localizations. The accuracy of the system can be visually checked by identifying a known reference point in surgical space and measuring the distance of the corresponding transformed point in image space. The primary surgeon is able to define the trajectory to the sphenoid sinus and sella turcica (Fig. 2). Different trajectories to the lesion can be examined. When the patient is draped, the neuronavigator arm is covered with a plastic bag, leaving a small part of its end segment uncovered. Intraoperatively, communication with the workstation is always possible by using a foot pedal; thus, there is no need to use a computer mouse or keyboard (Fig. 3). New landmarks can be established as reference points (that is, around the site of vomer or sphenoid ostium), enabling the surgeon to monitor whether accuracy is sustained. In patients in whom fluoronavigation is used alone, an ultrasound transducer is used in some cases before opening the dura mater to confirm location in relation to important vascular structures.

Statistical Analysis

Statistical analysis was performed using GAUSS 5.0 (Aptech Systems, Inc., Maple Valley, WA) and SAS 9.1 software (SAS Institute, Inc., Cary, NC). The level used to determine statistical significance was a probability value less than 0.05.

Results

Previous Operations

Of the 176 patients included in the study, 46 (26%) were

undergoing their first transsphenoidal operation; 105 (60%) had undergone at least one previous operation via this approach; and 25 (14%) had been treated with transsphenoidal operations twice or more in the past. Of those who had been treated previously, the mean number of operations per patient was 1.21. Approximately half of the patients (62) underwent their first operation at our institution, whereas in the remainder, the operations were performed elsewhere.

Tumor Characteristics

One hundred two patients underwent surgery for pituitary adenomas (46 for Cushing's disease, 43 for nonfunctional adenomas, seven for acromegaly, and three each with thyroid-stimulating hormone- and prolactin-secreting tu-

FIG. 3. Photograph of the operating room setup that allows the surgeon to see real-time images intraoperatively. Imaging data can be updated using a foot switch, making a keyboard or mouse unnecessary.

FIG. 4. Bar graph showing the breakdown of disease distribution. Pituitary adenomas and craniopharyngiomas were the most common lesions encountered. The numbers on the y axis denote the number of patients with the disease. GH = growth hormone; TSH = thyroid-stimulating hormone.

mors). Twenty-four patients harbored craniopharyngiomas, and eight had Rathke cleft cysts. Less common lesions included chordomas and fibrous dysplasia (one each) (Fig. 4). One hundred forty-three patients (81%) had masses larger than 3 cm (measured at their greatest diameter), and 104 (59%) had suprasellar extension, 70 (40%) had involvement of the visual apparatus, and 65 (37%) had involvement of either cavernous sinus.

Postoperative Complications

There were no instances of visual deterioration following stereotactically guided transsphenoidal surgery. Only one patient had damage to the CA after fluoroscopic neuronavigation surgery. This patient had a nonfunctioning pituitary macroadenoma with CA extension. The CA bleeding was stopped intraoperatively, and the patient was discharged from the hospital on postoperative Day 4 with no neurological deficit. No instances of CA insufficiency or stroke were encountered in any of the patients. Only five patients (3%) required a stay in the intensive care unit postoperatively. The overwhelming majority of patients (99%) were discharged home by postoperative Day 3.

An intraoperative CSF leak was encountered in 112 (64%), and in all instances an abdominal fat graft was used for primary repair (Table 1). Seven (46%) of the 15 patients who underwent MR imaging-guided stereotaxy experienced a CSF leak, as did 30 (77%) of the 39 who un-

derwent CT-guided stereotaxy, and 75 (61%) of the 122 who had fluoroscopy (Table 2).

Thirty-three (72%) of 46 patients who underwent first-time transsphenoidal surgeries required a fat graft, whereas 79 (61%) of 130 patients who underwent repeated surgeries experienced an intraoperative leak (Table 3).

Statistical Analysis

No statistically significant relationship was found between tumor type and the Stealth modality used, or between first-time or repeated operations and the incidence of complications. Furthermore, there was no statistical difference in the need for a fat graft between the patients who had previously been treated surgically and those undergoing their first transsphenoidal procedure. The use of MR imaging with stereotaxy appeared to result in a lower rate of intraoperative CSF leaks ($p = 0.032$).

Discussion

There are two basic, common surgical approaches to the sellar region; these are transsphenoidal and transcranial.²³ The transsphenoidal route is used to approach most pituitary adenomas.⁹ Through either an endonasal or sublabial (gingival mucosa) incision, dissection is extended to the front of the sphenoid sinus. The front of the sphenoid sinus is opened, and the sella turcica and its junction with the clivus and tuberculum sellae is then identified. The sella can then be opened, thereby exposing the dura mater, which is subsequently coagulated and incised, exposing the normal gland and/or tumor.^{1,18,21}

The entry into the sphenoid sinus and sella turcica during repeated transsphenoidal operations can be challenging because much of the normal sellar anatomy can be disrupted and scarred. Furthermore, in many cases there is no identifiable midline, making an approach to the sella

TABLE 1

Summary of intraoperative fat graft use during procedures

Fat Graft	No. of Patients (%)
no	64 (36)
yes	112 (64)

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TABLE 2

Incidence of CSF leaks in patients who underwent frameless stereotactic transsphenoidal surgery

CSF Leak	Op Guided w/			Total
	Fluoroscopy	MRI*	CT	
no	47	8	9	64
yes	75	7	30	112
all groups	122	15	39	176

* Statistically significantly fewer fat grafts were used in these cases ($p < 0.05$).

potentially dangerous, because the CAs lie just lateral to the midline and are at risk. Most transsphenoidal operations performed at our institution are guided by simple intraoperative fluoroscopy, but frameless stereotaxy was the preferred modality in cases of recurrent tumor and prior surgery, in which anatomical landmarks are obscured and/or absent.

The goal in using neuronavigational instrumentation during transsphenoidal surgery is to increase the accuracy of the approach, thus making it less invasive and more safe, while simultaneously decreasing the time needed for surgery and preoperative planning.^{4,10,20} The StealthStation intraoperative navigation computer system has been demonstrated to be an effective technique for stereotactic guidance during endoscopic endonasal interventions.¹⁶ The use of computer navigation enhances the performance of a radical operation without damage to anatomical structures at the base of the skull.^{12,14,15}

In many cases in our series, surgical interventions were salvage procedures in patients who had undergone previous unsuccessful transsphenoidal or/or transcranial operations, and were designed to reduce the tumor burden and preserve the patients' quality of life as safely as possible. From this standpoint, frameless stereotaxy enabled us to remove much of the tumor burden with minimal adverse effects related to the surgical approach.

Although the rate of CSF leakage appeared to be higher in our series compared with the nonstereotactically guided resections that were performed at our institution (range 20–30% intraoperatively, depending on the tumor type), it is important to note that the majority of the extirpated lesions were large, aggressive tumors, often with suprasellar and/or cavernous sinus extension, which frequently required the surgeon to reach the suprasellar region by intentionally incising the diaphragma sellae. This factor contributes to the higher rate of CSF leakage intraoperatively. We advocate the early repair of postoperative CSF leaks with packing.

The decision regarding which stereotactic imaging modality to use during frameless transsphenoidal navigation surgery remains controversial.⁵ Although modern MR imaging and CT studies are capable of providing exquisite detail of bone and vascular structures, intraoperatively they rely on preoperative images to provide information, and cannot provide true real-time intraoperative images.¹⁹ Furthermore, these modalities require patients to arrive early for a preoperative scan performed with fiducial markings in place, resulting in additional expense and time for patients. Fluoroscopically guided navigation avoids some of these

TABLE 3

*Comparison of the use of fat grafts in patients with previous surgery and in first-time patients**

Fat Graft	No. of Previous Ops			Total
	0	1	≥2	
no	13	43	8	64
yes	33	62	17	112
all groups	46	105	25	176

* No statistical difference in the incidence of the need for fat grafts between patients who had undergone previous surgery and those having their first transsphenoidal procedure ($p = 0.18$ according to the chi-square test).

pitfalls, but it does not allow the surgeon to visualize the important neurovascular and soft-tissue structures of the brain.

In our series, we noted no statistically significant relationship between the incidence of intraoperative complications and morbidity among the different modalities used. Fluoroscopy is associated with shorter operating times and less expense to the patient,³ but the decision regarding which imaging modality to use should depend on the patient's anatomy, the tumor characteristics, and the comfort level of the surgeon.

Conclusions

Frameless stereotaxy can provide a safe and effective method of extirpating sellar lesions that would otherwise be inaccessible. The use of MR imaging, CT scanning, and fluoroscopically guided resection all provide potential advantages as well as limitations. Intraoperative CT and MR imaging as well as functional MR imaging are emerging modalities that may provide a way of treating these masses even more safely.

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