Anterior clivectomy: surgical technique and clinical applications

Clinical article

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Object. Midline clival lesions, whether involving the clivus or simply situated anterior to the brainstem, present a technical challenge for adequate exposure and safe resection. The authors describe, as a minimally invasive technique, an anterior clivectomy performed via an expanded transsphenoidal approach coupled with the use of a neuronavigation on mobile head and endoscopic-assisted technique. Wide and direct exposure, with the ability to resect extra- and intradural tumors, was achieved without mortality and with a low rate of complications.

Methods. Cadaveric dissections were performed to outline the landmarks and measure the window that is created by resecting the clivus anteriorly. The technique was used in 43 patients to resect tumors located at or invading the clivus. The initial exposure of the clivus was obtained via the sublabial transsphenoidal approach. The wall of the anterior maxilla, often on 1 side, was removed to allow a wide side-to-side opening of the nasal speculum. Using neuronavigation, the authors made clivectomy windows by drilling the clivus between anatomical landmarks. Bilateral intraoperative neurophysiological monitoring was used (somatosensory evoked potentials, brainstem auditory evoked responses, and cranial nerves VI–XII).

Results. Of the 43 patients, 26 were female and 17 were male, and they ranged in age from 3.5 to 76 years (mean 41.5 years). Thirty-eight patients harbored a chordoma and 5 a giant invasive pituitary adenoma.

Gross-total resection of the tumor was achieved in 34 cases (79%). Nine patients (21%) had residual tumor unreachable through the anterior clivectomy, and this required a second-stage resection. Four patients developed new transient extraocular movement deficits. One patient developed a permanent cranial nerve VI palsy. Twenty-seven patients with chordoma underwent postoperative proton-beam radiotherapy. Tumor recurred in 19% of these cases. In 3 patients a cerebrospinal fluid leak developed during hospitalization and was treated successfully. Two other patients presented with a delayed cerebrospinal fluid leak after radiotherapy. Only 1 patient, who had previously undergone Gamma Knife surgery, experienced postoperative hemiparesis.

Conclusions. A complete anterior clivectomy via a simple extension of the transsphenoidal approach allows the surgeon access to different lesions involving the clivus or situated anterior to the brainstem. The exposure is similar to that provided by more extensive transfacial approaches. Instrument manipulation is easy. Neuronavigation, endoscopy, and intraoperative monitoring are easily incorporated and enhance the capability and safety of this approach.

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KEY WORDS • chordoma • clivus • maxillotomy • neuroendoscopy • neuronavigation • pituitary tumor • transsphenoidal approach

The merit of the anterior approach to the clivus has been convincingly stated by Laws et al.: “The concept of extended transsphenoidal–skull base approach for a variety of midline lesions is sound…The trajectory afforded by this approach allows the surgeon to work along the axis of the tumor and permits removal of tumors with minimal displacement or distortion of surrounding structures.”43 An anterior approach to the clivus for resection of lesions involving it or using it as a window to access intradural pathological entities has been described and utilized by pioneers and contemporary authors.14,19,20,22,26–28,48,53,61–63 Widening the exposure by including the maxillary antrum was reported as early as 1917 by Beck48 and has been well presented and studied by several authors.6,11,23,58,71

Today an extensive menu of anterior approaches is available for exposure of clival lesions: transoral, transsphenoidal, transmaxillary, transfacial, transbasal, and infratemporal.1–3,5,6,9–12,15–17,21,24,27,29,30,32–34,40–48,50–52,54–56,58–61,64,66,70 Some of the approaches involve extensive dissection of facial, cranial, oral, and nasal structures. Couldwell et al.,11 in a scholarly work, have demonstrated and estab-

Abbreviations used in this paper: CN = cranial nerve; CSF = cerebrospinal fluid.
lished the advantage and the limitation of each approach. For lesions located on the clivus in the midline and above the hard palate (extra- and/or intradural), we describe a minimally invasive anterior clivectomy that has been used in 43 patients. The anterior clivectomy is performed via a sublabial transsphenoidal approach, and the anterior wall of the maxilla usually on 1 side is removed. We use a neuronavigation system that is applied to a mobile head and an endoscope to achieve maximal exposure, visualization, and resection of the clival lesions. Because the incision is sublabial and the nasal septum is preserved, there have been no visible cosmetic defects or scars.

Methods

The clinical, radiological, and outcome data of 43 patients were retrospectively reviewed. The patients harbored tumors involving the clivus and underwent anterior clivectomy via an expanded transsphenoidal approach. Surgery was performed at the University of Arkansas for Medical Sciences by the senior author (O.A.) between April 1997 and January 2006. Floating-head stereotactic navigation was used for intraoperative localization and to assess the extent of resection. An endoscope was used routinely to assist in visualizing the area behind the clivectomy edges. We included only cases in which wide resection of the clivus was required. Because of their large, lateral extension or because they involved the condyle and created craniovertebral junction instability, several tumors required additional approaches to allow complete resection or stabilization. In these cases the procedures were staged. The anterior approach was used first.

Perioperative Management

Patients underwent a comprehensive clinical, ophthalmological, and endocrinological evaluation. Preoperatively we obtained high-resolution axial CT scans, with coronal and sagittal reconstructions and bone algorithm of the head. Multiplanar MR imaging with and without contrast administration, MR angiography, and MR venography were also conducted.

Neuronavigation was used in all cases. Intraoperative neurophysiological monitoring was undertaken in all patients and included somatosensory evoked potentials, brainstem auditory evoked responses, and electromyography of CNs VI, VII, X, XI, and XII as required by the tumor extension. If manipulation of the sellar contents was anticipated, 100 mg of hydrocortisone was administered at the beginning of the surgery, and the patient was started on a course of steroids, which were tapered during the postoperative period.

Follow-up CT and MR images were obtained during the first postoperative days.

Neuronavigation on Floating Head

After the induction of general anesthesia, the face and the nasal and oral cavities are prepared with povidone–iodine. The patient’s head is kept mobile on a foam headrest. We then use a facemask tracer for registration and navigation. In the past we applied the Mayfield 3-pin head tongs to the patient’s head to hold the tracer. The Mayfield frame, however, is not secured to the operative table. Instead the patient’s head rests on a C-shaped, foam headrest. Early in the series we fixed a post to the skull by screws via a small precoronal incision. The fiducial points are registered and the surgical planning ensues. This allows the patient’s head to be “floated,” and it is therefore easy to maneuver in the sagittal and lateral planes to achieve maximum exposure of the entire clivus; at the same time one can still use accurate neuronavigation for localization and verification of structures.

Surgical Technique

The patient is placed supine and the head is kept mobile. Neuronavigation registration is obtained. We use C-arm fluoroscopy if needed to confirm accurate localization intraoperatively. A sublabial incision is made for the transsphenoidal approach and extended further laterally on the side of the intended maxillotomy, which is the contralateral side if the tumor extends laterally in 1 direction to allow better exposure of the tumor’s lateral extension. Subperiosteal dissection is carried out to expose the nasal mucosa adjoining the pyriform recess. The dissection continues up the frontal process of the maxilla just below the inferior aspect of the orbit. The most superior aspect of the exposure is the infraorbital foramen containing the infraorbital nerve, which is spared to avoid a postoperative paraesthesia of the cheek. A B-5 bit of the Midas Rex drill is used to create a rectangular opening of the anterior maxillary wall (Fig. 1). Alternatively, an oscillating/reciprocating saw can be used. The osseous gap created by the drilling is minimized. The height of the osteotomy of the anterior wall of the maxilla must be large enough to accommodate the blades of the transsphenoidal retractor so that they can extend into the maxillary cavity as the retractor blades are spread. The maxillotomy incorporates the medial and anterior walls of the maxilla. Any bone left at the medial wall of the maxilla and the lateral aspect of the pyriform opening is removed using a bone rongeur. The cartilaginous nasal septum is disarticulated from the hard palate and the vomer, and it is then swung contralateral to the side of the maxillotomy. The self-retaining retractor blades are opened maximally to push the nasal mucosa laterally, thereby widening the exposure (Fig. 2). The sphenoid sinus is opened widely. The mucosa along the anterior aspect of the clivus is dissected inferiorly to gain maximal caudal exposure. If needed, part of the superior aspect of the hard palate can be removed using a high-speed drill to gain visibility of the caudal clivus. In this fashion, the entire length of the clivus is exposed from the dorsum sella to the foramen magnum. Occasionally, the pituitary fossa floor is cut using a rongeur, and the sella dura and the gland are pushed upward to facilitate removal of the dorsum sella. If a chalve chordoma is suspected, maneuvers are used to avoid surgical seeding—the walls of the operative bed are coated with fibrin glue and large cotton patties before removing the tumor. After the tumor is completely excised, the cotton patties along with the fibrin glue are carefully removed and all contaminated drapes, towels, gloves, and instruments are replaced.
Anterior clivectomy

**Clivectomy**

A clival window between the anatomical landmarks can be drilled with ease, exposing the tumor (Fig. 3). The clivus is then drilled using the diamond bit by angulated high-speed drill from the floor of the sphenoid sinus downward. Care is taken with the lateral borders as they are limited between the optic canals, the petrous and the cavernous segments of the internal carotid artery, and the abducent nerve, limiting the opening of the upper clivus to 16 mm. This widens as one moves caudally on the clivus with the distance between the 2 hypoglossal canals at 34 mm and between the abducent nerves at 20 mm. The vertical distance between the floor of the sella and the inferior margin of the clivus is 30 mm, and the thickest part of the clival bone is 18 mm rostrally and 8 mm inferiorly (Fig. 4). Table 1 details the distance measurements that we obtained in 4 dry skulls and 6 cadavers. Once that window is created, access to the planum sphenoidale, tuberculum sella, sella turcica, the posterior clinoid, the interpeduncular cistern, and the entire clivus down to the anterior lip of the foramen magnum is attainable and safe.

Even reaching laterally to the apex of the petrous bone can be accomplished with the assistance of the neuronavigation system. Extradural and intradural tumor resection is performed and carried out with suction, curette, and rongeur. Bleeding from the cavernous sinus or the basilar venous plexuses, even though it is bothersome, is easily controlled using gel foam and fibrin glue. If the tumor extends intradurally, it is followed through its dural penetration. The dural opening can be extended, as needed, in different directions (Fig. 5). The 30° and/or 70° endoscope is used to assist in the visualization and removal of the tumor that lies behind the dural opening and is not visible under the microscope (Fig. 6). The complementary endoscopic technique had added value to the resection in 18 patients (42%). If intradural dissection is performed, a fascia lata graft is applied intradurally, wider than the defect, and secured to the dural edges with small staples. The fascia graft is reinforced on the outside by fat and sealed with fibrin glue. Fat pieces harvested from the abdominal wall are used to fill the bone defect. The maxillotomy bone is placed with the aid of low-profile microplating.

**Results**

Between April 1997 and January 2006, 43 patients (26 females and 17 males) underwent the aforementioned expanded transsphenoidal procedure. The patients ranged in age from 3.5 to 76 years (mean 41.5 years). Thirty-eight patients harbored a chordoma and 5 an invasive pituitary adenoma. Ten patients with chordomas had previously undergone resection at other institutes; in 6 of these 10 an endoscopic approach had been used. The upper clivus was affected in 37 (86%) of the 43 cases; the middle clivus in 40 (93%); and the lower clivus in 19 (44%). In 19 patients (44%) the mass involved 1 cavernous sinus and in 7 patients (16%), the cavernous sinus was involved bilaterally. In 22 patients (51%) the pons was displaced posteriorly due to mass effect (Fig. 7). In 13 patients (30%) the tumor exhibited suprasellar extension (Fig. 8). Twenty-three patients (53%) had intradural extension confirmed during surgery (Fig. 9). Table 2 provides a summary of the area of involvement, tumor extension, clinical presentation, and surgical outcome.

Gross-total resection of the tumor was achieved in 34
Fig. 3. Artist’s illustration demonstrating chordoma exposure after the clivectomy. The wide opening allows ease of instrument introduction and good mobilization.

Fig. 4. Photographs of an anatomical model. Left: Outline of the maximal border of the clivectomy from its inner aspect: the vertical distance from the base of the posterior clinoid to the anterior surface of the foramen magnum (A); horizontal distance from both petrous apexes (B); horizontal distance from both petroclival sutures at the level of the internal acoustic meatus (C); horizontal distance from both jugular tubercles (D); horizontal distance from both hypoglossal canals (E); and horizontal distance from both anterior portions of the occipital condyle (F). Right: Outline of the maximal border of the clivectomy from its outer aspect: the lateral limit of the upper clivus (G); lateral limit of the lower clivus (H); and distance between carotid canals (I).
cases (79%), and residual tumors were present in 9 (21%). In 4 patients with residual chordoma a cranioorbitozygomatic approach was used, in 3 a transcondylar approach was used with 2 having occipitocervical fusion, and in 2 a transoral approach was used.

Nine of these patients underwent a second-stage procedure. In 4 patients with residual chordoma a cranioorbitozygomatic approach was used, in 3 a transcondylar approach was used with 2 having occipitocervical fusion, and in 2 a transoral approach was used.

In 4 of the 26 patients with CN VI deficits, function improved after surgery, regaining full ocular mobility. Improvement was documented in 2 of the 4 patients with visual field deficits secondary to chiasmal compression. Four patients developed new transient CN VI nerve deficits. One patient developed a permanent CN VI palsy, which required corrective surgery. One patient had transient diabetes insipidus. Three patients had CSF leak-

FIG. 5. Artist’s illustration of a wide dural opening showing the exposed neurovascular structures through the clivectomy. BA = basilar artery; PCA = posterior cerebral artery; SCA = superior cerebellar artery; III = oculomotor nerve.

age in the immediate postoperative course; 2 underwent lumbar drainage and in 1 repacking was required. In 2 patients, delayed CSF leakage occurred months after surgery and following high-dose radiotherapy. One patient developed right hemiparesis after suffering a stroke; this patient had previously undergone radiosurgery.

Because of the sublabial incision and the preservation of the nasal septum, there has been no visible cosmetic defect or scar.

FIG. 6. Intraoperative endoscopic images. A: A small residual intradural tumor is visible using a 30° angled endoscope. B: The tumor is removed from the cerebellopontine angle.

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Fig. 7. Preoperative and postoperative T1-weighted MR images. A–C: Preoperative coronal, sagittal, and axial images showing a chordoma involving the entire clivus, with bilateral cavernous sinus involvement and impressive suprasellar and posterior displacement of the brainstem. D–F: Postoperative axial, sagittal, and coronal images demonstrating the adequate removal of the tumor located at the midline, and the lateral limitation of the approach.

Fig. 8. A and B: Preoperative coronal and sagittal MR images revealing a large chordoma with suprasellar extension that will be grossly removed through the anterior clivectomy. C and D: Postoperative coronal and sagittal T1-weighted enhanced MR images depicting tumor.
Radiotherapy was performed in 26 of the 38 patients with chordoma. The recurrence rate in these patients after surgery and radiotherapy was 15%.

Discussion

All Old Roads Lead to the Clivus

The clivus has been divided into 3 subparts to facilitate the selection of the surgical approach.11,47,58 The upper clivus corresponds to the basisphenoid bone, the region of the dorsum sella, which extends from the posterior clinoid process to the plane of the Dorello canal; the middle clivus extends from the Dorello canal to the pars nervosa of the jugular foramen; and the lower clivus extends from the pars nervosa of the jugular foramen to the foramen magnum. These divisions are evident in the inner aspect of the clivus.57 The outer aspect only displays the division between the middle and the lower clivus. The upper clivus corresponds to the posterior wall of the sphenoid sinus.

Based on these 3 parts and how the tumor involves the clivus, different surgical approaches can be selected and used to resect the tumor. These approaches can be grouped into 2 main categories: anterior and lateral. Anterior approaches to the clivus are the transoral,1,12,15, 29,40,50,60,65 transmaxillotomy, transmaxillotomy,1,10,11,27,28,41–44,47 Le Fort I with maxillary drop down,1,2, 9,15,30,52,60 transfacial,5,32,41,46,55,56,68 and transcranial–transbasal.1,16,47,65 Accessing the clivus anteriorly dates back to 1919 when the transoral approach was used to remove a bullet.38 This approach was later advocated by Scoville and Sharman63 in 1951 and used extensively by Fang and Ong20 for the treatment of infection of that area. Mullan et al.53 were the first to describe the transoral–transclival approach for the treatment of an extraaxial tumor in 1966.

For removal of chordoma, Stevenson et al.56 have described a transcervical approach made by entering the upper retropharyngeal space through a right upper cervical submandibular incision. Fox52 has described the transcervical approach to basilar artery aneurysms. In 1987, Archer and colleagues3 advocated the use of a Le Fort I maxillotomy as an approach to distal vertebral and midbasilar artery aneurysms, whereas Loyo et al.49 used a maxillotomy to approach the cavernous sinus. All of these studies confirmed the appeal and the long-standing development of the anterior approaches. Our technique is a matter of steps toward its refinement in the era of minimally invasive surgery.
TABLE 2

Preoperative clinical characteristics, clival involvement, tumor extension, & surgical outcome in 43 patients who underwent anterior clivectomy for tumor resection via an expanded transsphenoidal approach

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs), Sex</th>
<th>Location at the Clivus</th>
<th>Extension of Tumor</th>
<th>Preop Clinical Presentation</th>
<th>Approach-Related Complications</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>38, M chordoma</td>
<td>upper, middle, lower</td>
<td>lt cav sinus, SSS</td>
<td>headache, lt VI n</td>
<td>none</td>
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<td>2</td>
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<td>headache</td>
<td>none</td>
</tr>
<tr>
<td>3</td>
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<td>rt cav sinus</td>
<td>rt III n, rt VI n</td>
<td>none</td>
</tr>
<tr>
<td>4</td>
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<td>upper, middle</td>
<td>brainstem compression, sphenoid sinus</td>
<td>visual loss (lt), lt III, IV, VI &amp; VIII</td>
<td>none</td>
</tr>
<tr>
<td>5</td>
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<td>bilat cav sinus, SSS</td>
<td>visual loss (lt)</td>
<td>none</td>
</tr>
<tr>
<td>6</td>
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<td>none</td>
</tr>
<tr>
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<td>headache, visual loss (lt), lt IV, VI, IX, &amp; X n</td>
<td>CSF leak</td>
</tr>
<tr>
<td>8</td>
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<td>none</td>
</tr>
<tr>
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<td>none</td>
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</tr>
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<td>lt V &amp; VI n</td>
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</tr>
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<td>lt V n</td>
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<tr>
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<td>condyle, brainstem compression</td>
<td>condyle, brainstem compression</td>
<td>lt VI, IX, X, &amp; XII n</td>
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<td>37</td>
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<td>upper, middle</td>
<td>lt cav sinus</td>
<td>lt cav sinus</td>
<td>lt VI n</td>
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(continued)
Anterior clivectomy

Expanded Transsphenoidal–Skull Base Approach

Since its revival and refinement by Guiot and Thibaut, Hardy and Wigser, the microsurgical transsphenoidal route has become the favored route to pituitary lesions and recently has been used in association with endoscopic techniques. Early on, Hardy and colleagues and Laws recognized the advantage of the anterior approach of the transsphenoidal route and promoted its use for suprasellar lesions other than pituitary lesions. Such use inspired the development of the extended transsphenoidal approach by the removal of the bone of the tuberculum sella and posterior planum sphenoidale between the optic canals with opening of the dura mater above the diaphragma. As delineated in 1987 by Weiss, this approach and several innovative variations have been used to gain added exposure to cranial base and juxtasellar lesions. The transsphenoidal approach has been used to remove clival chordomas by Guiot and Thibaut, Hardy and Wigser, Laws, and Weiss. Lesions arising from or involving the clivus such as chordoma are most often confined to the midline and frequently remain extradurally. They tend to extend in the anteroposterior direction.

Therefore, accessing these lesions via an anterior route has been correctly advocated. The transsphenoidal route allows the surgeon to look around blind anatomical corners that complement to the microscope, mainly because it allows the senior author (O.A.) has routinely used the endoscope as a senior author (O.A.) has routinely used the endoscope as a

Table 2 (continued)

Preoperative clinical characteristics, clival involvement, tumor extension, & surgical outcome in 43 patients who underwent anterior clivectomy for tumor resection via an expanded transsphenoidal approach

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs), Sex</th>
<th>Dx</th>
<th>Location at the Clivus</th>
<th>Extension of Tumor</th>
<th>Preop Clinical Presentation</th>
<th>Approach-Related Complications</th>
</tr>
</thead>
<tbody>
<tr>
<td>38</td>
<td>75, M</td>
<td>chordoma</td>
<td>upper, middle, lower</td>
<td>suprasellar cav sinus bilateral, bilat occipital condyle</td>
<td>III n</td>
<td>none</td>
</tr>
<tr>
<td>39</td>
<td>76, M</td>
<td>chordoma</td>
<td>upper, middle, lower</td>
<td>cav sinus bilat</td>
<td></td>
<td>none</td>
</tr>
<tr>
<td>40</td>
<td>3.5, F</td>
<td>chordoma</td>
<td>upper, middle, lower</td>
<td>brainstem compression</td>
<td>VI n</td>
<td>CSF leak</td>
</tr>
<tr>
<td>41</td>
<td>29, M</td>
<td>chordoma</td>
<td>upper</td>
<td>suprasellar rt cav sinus, sphenoide sinus</td>
<td></td>
<td>none</td>
</tr>
<tr>
<td>42</td>
<td>44, F</td>
<td>chordoma</td>
<td>middle, lower</td>
<td>brainstem compression</td>
<td>rt cav sinus, rt petrous apex sphenoid sinus</td>
<td>rt V, VI, IX, &amp; X n</td>
</tr>
<tr>
<td>43</td>
<td>65, M</td>
<td>chordoma</td>
<td>upper, middle</td>
<td>suprasellar, rt cav sinus, rt petrous apex sphenoid sinus</td>
<td></td>
<td>none</td>
</tr>
</tbody>
</table>

* cav = cavernous; n = nerve; RT = radiotherapy; SSS = suprasellar sphenoid sinus; UE = upper extremity.

A CSF leak and subsequent meningitis are the main risk factors of the procedure. The absence of a vascularized tissue flap and the difficulty in obtaining a watertight dural closure are the underlying causes for these complications. Surgeons use any combination of the following: fascia lata, dural substitute, fat graft, fibrin glue, and/or placement of lumbar drain. To alleviate serious complications, we emphasize the placement of the graft intradurally, and then support it using an extradural fat and fibrin sealant. The integrity of intact nasal mucosa provides a vascularized support to the graft. We believe this has an advantage over transnasal disruption of the mucosa by a purely endoscopic approach, particularly because many of these patients will be subjected to radiotherapy that devascularizes the area tissue and is associated with delayed CSF fistulas.

Mobile-Head Neuronavigation

The absence of intraoperative shift has been a recognizable factor in the accuracy and reliability of neuronavigation in skull base surgery. Early in the treatment of patients in this series we realized the need to mobilize the head to provide different trajectories. Fixing the tracker to the skull or using the facemask tracer allows the surgeon to fully move a patient’s head in various directions, thus achieving a better exposure of the entire region while maintaining the neuronavigation-based accuracy for localization and verification of structures.

Endoscopic-Assisted Techniques

Endoscopic surgery has flourished in the last decade with application beyond pituitary tumors. Numerous reports have addressed its advantages. The senior author (O.A.) has routinely used the endoscope as a complement to the microscope, mainly because it allows the surgeon to look around blind anatomical corners that
cannot be visualized directly with the microscope and because it affords a wide panoramic view, hence taking full advantage of the endoscope as an “eye” in the depth of the field. We believe that with such tumors as described in this article and those that require extensive drilling and dissection, the combination of the microscope and endoscopic technique enhances the safety of the procedure and facilitates its undertaking.

Conclusions

A clivectomy via the expanded transsphenoidal approach—combined with the application of neuronavigation system to the mobilized head and the use of the endoscope—allows the surgeon to access different lesions involving the clivus and those situated anterior to the brainstem effectively and with minimal invasiveness.

The exposure and the surgical window created by this technique, to some extent, provide a similar window and wide exposure to the more extensive approaches such as the transfacial and Le Fort I techniques with maxillary drop-down. Although it employs the full benefit of endoscopic technique, it maintains the advantage of wide binocular exposure and the benefit of microsurgical techniques.

Disclaimer

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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