Anatomical analysis of transoral surgical approaches to the clivus

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Object. The authors conducted a cadaveric anatomical study to quantify and compare the area of surgical exposure and the freedom available for instrument manipulation provided by the following four surgical approaches to the extracranial pericilval region: simple transoral (STO), transoral with a palate split (TOPS), Le Fort I osteotomy (LFO), and median labioglossomandibulotomy (MLM).

Methods. Twelve unembalmed cadaveric heads with normal mouth opening capacity were serially dissected. For each approach, quantitation of extracranial pericilval exposure and freedom for instrument manipulation (known here as surgical freedom) was accomplished by stereotactic localization. To quantify the extent of extracranial clival exposure obtained, anatomical measurements of the extracranial clivus were performed on 17 dry skull bases.

The values (means ± standard deviations in mm²) for pericilval exposure and surgical freedom, respectively, for the surgical approaches studied were as follows: STO = 492 ± 229 and 3164 ± 1900; TOPS = 743 ± 319 and 3478 ± 2363; LFO = 689 ± 248 and 2760 ± 1922; and MLM = 1312 ± 384 and 8074 ± 6451. The extent of linear midline clival exposure and the percentage of linear midline clival exposure relative to the total linear midline exposure were as follows, respectively: STO = 0.6 ± 4.9 mm and 7.8 ± 11%; TOPS = 8.9 ± 5.5 mm and 24.2 ± 16.7%; LFO = 32.9 ± 10.2 mm and 85.0 ± 18.7%; and MLM = 2.1 ± 4.4 mm and 6.7 ± 11.1%.

Conclusions. The choice of approach and the resulting degree of complexity and associated morbidity depends on the location of the pathological entity. The authors found that the MLM approach, like the STO approach, provided good exposure of the craniocervical junction but limited exposure of the clivus. The TOPS approach, an approach attended by a lesser risk of morbidity, provided adequate exposure of the extracranial inferior clivus. Maximal exposure of the extracranial clivus proper was provided by the LFO approach.

KEY WORDS • clivus • Le Fort I osteotomy • mandibulotomy • maxillotomy • transoral approach • transpharyngeal approach

EXTRACRANIAL clival exposure via anterior approaches is becoming commonplace for the treatment of clival pathology because it provides the most direct route to the ventral CCJ. Use of a posterior approach to the clivus has fallen out of favor as a result of the difficulty of access to the ventral CCJ for irreducible atlantoaxial abnormalities. With regard to extracranial clival exposure, however, there is a paucity of literature related to the efficacy of various transoral procedures for access to the extracranial clivus.

Historically, anterior transoral approaches were developed and used for obtaining extradural exposure to the ventral CCJ for irreducible atlantoaxial abnormalities. With regard to extracranial clival exposure, however, there is a paucity of literature related to the efficacy of various transoral procedures for access to the extracranial clivus. The object of our cadaveric anatomical study was to quantify and compare analytically the extent of pericilval exposure provided by different anterior transoral approach-
es. Four approaches were selected for study: STO, TOPS, LFO, and MLM. We performed all four approaches serially in each of the cadaveric heads, using established surgical techniques and taking care to avoid destructive interference between the dissections. We found that the LFO approach provided the best pericentral exposure centered on the clivus proper.

**Materials and Methods**

**Data Acquisition**

Materials used in this study included 12 unembalmed cadaveric heads, each with an oral cavity opening capacity comparable to that of a typical adult patient. A craniotomy was performed to remove the entire central nervous system. Then three divots were sequentially drilled into the intracranial surface of the clivus to define a two-dimensional representative clival plane. A single, midline inferior clival divot was placed 3 mm superior to the anterior FM, and two lateral clival divots were placed at the intersection of the jugular tubercle and the middle portion of the clivus proper bilaterally (Fig. 1) below the sphenoid petrosal synchondrosis. The representative clival plane defined by the three divots was then used as a backdrop onto which the anterior extracranial data points were projected for analysis. To eliminate movement during data collection, the cadaveric heads were secured in a head holder.

Data were acquired with the aid of a frameless stereotactic navigation system (StealthStation; Medtronic Navigation, Louisville, CO) as described previously. Data collection was initiated by defining a series of eight equidistant points, each separated by 45°, at the periphery of the surgical exposure. Computer-assisted overlay analysis of the relationship between the peripheral data points and the established clival plane facilitated quantitative computation of the following: 1) the maximum vertical and horizontal length of the exposed area; 2) the extent of clival exposure superior to the FM; and 3) the total area of pericentral exposure.

Data from a second series of points were then collected to determine the degree of surgical freedom (freedom for instrument manipulation). This was accomplished by pivoting a 10-cm probe, with the apex at the center of the exposed area, circumferentially at the most acute angle afforded by the exposure. Stereotactic measurements were marked at the distal tip of the pivot probe at eight equidistant points, each separated by 45°. Computer-assisted integral analysis of the inverted cone-shaped area created by the data points permitted calculation of the overall degree of surgical freedom. (Due to experimental error, information from data point 5 was not included in calculations for the pericentral area, superior exposure, and midline exposure for any of the approaches.)

**Dissections**

In each cadaveric head, the four surgical approaches—STO, TOPS, LFO, and MLM—were serially performed and analyzed. Established surgical techniques, an operating microscope, and standard microneurosurgical instruments were used for each surgical approach, and care was taken to avoid anatomical interference between approaches. The salient features of each approach are depicted in Fig. 2.

The STO approach was performed with the use of the Spetzler–Sonntag transoral retractor system (Aesculap Inc., Center Valley, PA), which elevates the soft palate into the nasopharynx and depresses the tongue inferiorly (Fig. 2A, left). A vertical incision was made in the posterior pharyngeal wall and was extended through the submucosa and the pharyngeal constrictor and longus colli muscles. The muscular and ligamentous attachments to the C3 were undermined and retracted with rake attachments on either side of the retractor system (Fig. 2A, right). Quantitative data acquisition was then initiated as described earlier.

For the TOPS approach, the soft palate was divided in the midline, starting at the junction of the hard and soft palates. The incision was then advanced inferiorly through the tip of the uvula (Fig. 2B, left). The retractor system was placed in the mouth with the divided soft palate splayed laterally and superiorly (Fig. 2B, right). The previously made posterior pharyngeal wall incision was then extended superiorly, and the fibrous and muscular layers were again retracted laterally with the rake attachments of the retractor system. Quantitative data acquisition was again conducted for the new exposure. The divided soft palate was repaired with sutures after data acquisition to minimize anatomical interference with subsequent dissections.

The LFO approach was initiated with an incision through the oral mucosa of the gingivobuccal sulcus of the upper lip down through the peristium of the maxilla. The peristium was then elevated superiorly, and a horizontal osteotomy was made bilaterally from the piriiform aperture laterally through the maxillary alveolus. Care was taken to ensure that the bone cuts were superior to the tooth roots. The fracture line was then propagated posteriorly with an osteotome through the lateral walls of the piriiform aperture and nasal vault bilaterally. The dissection continued posteriorly through the lower third of the pterygoid process. Next, the nasal septum was freed from the osseous spine along the floor of the nasal cavity, thereby allowing downward retraction of the entire upper alveolus (Fig. 2C, left). The remaining parts of the osseous nasal septum, including the vomer and perpendicular plate of the ethmoid, were then removed for full exposure of the posterior nasopharynx and oropharynx. A midline vertical incision was then made through the posterior pharyngeal mucosa and muscle. The soft tissue and ligamentous structures were retracted laterally to provide full exposure, and a new pivot point was established in the center of the area of exposure (Fig. 2C, right). Quantitative data acquisition was again performed for the new exposure. Finally, the maxilla was reattached to the craniofacial skeleton and fixed in place with wire to minimize possible anatomical interference during the subsequent dissection.

The MLM approach involved an initial midline vertical incision of the skin overlying the mentum, extending superiorly through the lower lip. Dissection was extended down to the subperiosteal plane in the midline. The peristium was elevated and retracted laterally. A vertical osteotomy was created through the midline of the mandible using an oscillating, high-powered saw. The tongue was divided down the middle from the tip posteriorly to the valleculae (Fig. 2D, left). Oral retractors were then positioned to displace the divided tongue laterally and to elevate the soft palate. Again, a midline vertical incision was made through the posterior pharyngeal mucosa and muscles. The soft tissue and ligamentous structures were retracted laterally to provide full exposure (Fig. 2D, right), and a third pivot point was established in the center of the new area of exposure, typically on C-2. Quantitative data acquisition was again performed.

**Extracranial Clival Measurements**

Because there is a paucity of information on the dimensions of the extracranial clivus, we performed anatomical measurements (Fig. 3) on 17 dry skull bases. The following measurements were taken: A) overall midline length of the extracranial clivus from the FM to the vomer; B) midline clival height from the FM to the pharyngeal tubercle; C) distances between the occipital condyles along the anterior rim of the FM; D) distance between the medial aspect of the extracranial apertures of the hypoglossal canal; E) distance between the intrapetrous carotid sulcus at a point midway between the FM and the vomer; and F) width between the vomerovaginal canal located inferior to the vomer on the clival surface (which is sometimes absent and in such cases a best approximation was performed). These measurements (Fig. 3) were used to determine clival dimensions for comparing quantitative clival exposures provided by the four surgical approaches under study.

**Statistical Analysis**

Statistical analysis was performed using repeated-measures analysis of variance, with the Bonferroni inequality used for post hoc detection of all pairwise differences. Each reported probability value for a given measurement has thus been adjusted for multiple comparisons.

**Results**

**Surgical Exposures**

The statistical data analysis is presented in Table 1. Data
are presented as means ± standard deviations. The results are also presented pictorially in Fig. 4 and graphically in Fig. 5. The periclival area in the data set refers to the area of surgical exposure within and around the clivus. This represents the area, observed through a microscope (with allowance for multiple changes in the position of the microscope as required), in which the stereotactic probe can be positioned around the periphery of the surgical exposure. Linear clival midline exposure lengths define the actual length of the exposed clivus within a given exposed periclival area. Surgical freedom was defined as a space through which surgical instruments could be inserted for manipulation at a target point while providing an unobstructed view of the target point for the surgeon. The different transoral approaches were quantified to define access to the extracranial middle and inferior clivus.

The STO exposure provides direct midline exposure of the distal CCJ (Fig. 5). The mean periclival exposure obtained via this approach was 492 ± 229 mm² and was centered to facilitate decompression of the upper cervical spine (Fig. 4) with a surgical freedom of 3164 ± 1900 mm². This approach does not, in general, provide adequate exposure of the clival tip (0.6 ± 4.9 mm), and it only represents a small fraction of the anterior aspect of the FM in most of the specimens in comparison to the total linear midline surgical exposure (7.8 ± 11%).

The TOPS approach, with the addition of the soft palate split, provided an additional increment of 50% in periclival exposure measured as 743 ± 319 mm² (Fig. 4), but the amount of surgical freedom (3478 ± 2363 mm²) associated with this approach was similar to that obtained with the STO approach. Unlike the STO approach (Fig. 5), the TOPS approach provided adequate exposure of the CCJ (eight of 11 specimens), involving both the upper cervical spine and the inferior clivus with a midline clival exposure from the FM of 8.9 ± 5.5 mm; this represented 24.2 ± 16.7% of the total linear midline surgical exposure. In addition, the pharyngeal tubercle (mean 9 ± 2.2 mm from the

**Fig. 1.** An intracranial view of the clivus depicting the locations of the one midline clival divot (placed 3 mm superior to the anterior FM) and the two lateral divots (placed at the intersection of the jugular tubercle and the middle portion of the clivus proper bilaterally).
FM), denoting the division between the inferior and middle clivus, is frequently accessible (six of 11 specimens).

Access via the LFO avenue provided the largest extent of midline clival exposure superior to the FM (32.9 ± 10.2 mm; Figs. 4 and 5) and represented 85.0 ± 18.7% of the total achievable midline exposure. The quantitated area of surgical freedom (2760 ± 1922 mm²) and the periclival exposure (689 ± 248 mm²) was the smallest, but it was centered on the extracranial inferior and middle clivus. Therefore, the LFO approach provided the most direct access to the extracranial clivus. Furthermore, it provided significant lateral exposure (11.0 ± 1.8 mm) on either side of the clival midline at a point 16 mm superior to the FM, which corresponds to the midpoint of the extracranial clivus from the FM to the vomer. This extent of bilateral exposure was adequate to access the lateral aspect of the body of the middle clivus without violating the internal carotid artery located within the intrapetrous carotid sulcus. The exposure of the

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**TABLE 1**

Quantitative measurements from various anterior approaches*

<table>
<thead>
<tr>
<th>Surgical Approach</th>
<th>Surgical Freedom (mm²)</th>
<th>Periclival Exposure (mm²)</th>
<th>Midline Exposure† (mm)</th>
<th>Superior Exposure from FM (mm)</th>
<th>Clival Exposure‡ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>STO</td>
<td>3164 ± 1900a</td>
<td>492 ± 229a</td>
<td>32.2 ± 9.8a</td>
<td>0.6 ± 4.9a</td>
<td>7.8 ± 11.0</td>
</tr>
<tr>
<td>TOPS</td>
<td>3478 ± 2363a</td>
<td>743 ± 319b</td>
<td>40.5 ± 9.2a</td>
<td>8.9 ± 5.5b</td>
<td>24.2 ± 16.7</td>
</tr>
<tr>
<td>LFO</td>
<td>2760 ± 1922a</td>
<td>689 ± 248ab</td>
<td>35.8 ± 11.1ab</td>
<td>32.9 ± 10.2c</td>
<td>85.0 ± 18.7</td>
</tr>
<tr>
<td>MLM</td>
<td>8074 ± 6451b</td>
<td>1312 ± 384c</td>
<td>51.5 ± 11.3c</td>
<td>2.1 ± 4.4c</td>
<td>6.7 ± 11.1</td>
</tr>
</tbody>
</table>

* Each value is expressed as the mean ± standard deviation. Values with dissimilar superscripts (a-c) within any given column differ according to the following probability values: 0.009 for surgical freedom (12 specimens); 0.010 for periclival exposure (11 specimens); 0.0152 for midline exposure (11 specimens); and 0.006 for superior exposure (11 specimens). Due to experimental error, no information from data point number 5 is included for periclival, midline, or superior exposure. Probability values are adjusted for multiple comparisons with the Bonferroni inequality.

† Linear exposure from the inferior-most point to the superior-most point at midline. For the LFO the inferior-most clival exposure did not reach the FM in six of 11 specimens.

‡ Clival exposure is given as a percentage of the total midline exposure.
extracranial superior clivus was not quantitated, as removal of the vomer and entry into the sphenoid sinus were not performed. For the LFO approach, six of 11 specimens showed an inferior-most clival exposure that did not reach the FM, and four of 11 specimens did not provide exposure of the rostral extracranial clivus (bounded by the alar of the vomer).

The MLM procedure, with the largest area of periclival exposure (1312 ± 384 mm²; Fig. 4) and surgical freedom (8071 ± 6451 mm²), principally exposed the upper cervical spine down to the third vertebral body with little or no clival exposure. The extent of midline exposure for the MLM procedure was substantial (51.5 ± 11.3 mm), but the actual exposure of the midline clivus proper (superior to the FM) was minimal (2.1 ± 4.4 mm) and represented only 6.7 ± 11.1% of the total midline exposure. In addition, the MLM procedure, like the STO and TOPS procedures, provided approximately 1.5 mm of bilateral exposure lateral to the midline in the horizontal plane without risk of trauma to adjacent neurovascular and soft-tissue structures.

**Extracranial Clival Measurements**

Anatomical measurements taken to define the dimensions of the extracranial clivus are summarized in Fig. 3. The data suggest that the extracranial clivus can be subdivided into the inferior, middle, and superior clivus, in a manner similar to the intracranial clivus. The inferior extracranial clivus extends from the FM to the pharyngeal tubercle in the midline, where the pharyngeal raphe is attached. The middle extracranial clivus extends from the pharyngeal tubercle to the alar of the vomer or the posterior end of the vomer, located just above the sphenocipital synchondrosis. The superior clivus, formed by the basisphenoid bone, is not visible extracranially as it contributes to the posterior wall of the sphenoid sinus. However, removal of the vomer and entry into the highly variable pneumatized sphenoid sinus will allow access to the superior clivus. We found the dimensions of the wedge-shaped clivus proper to be similar to those previously reported (length = 38–42 mm; width = 12 mm; thickness at the FM = 4 mm; thickness dorsal to the pituitary fossa = 20 mm).

**Discussion**

The resection of pathological clival lesions presents substantial challenges. Approaching via the most direct surgical route is imperative, and the merits of approaching anteriorly are manifold. First, anterior approaches are performed in a midline plane that is relatively avascular and parallels the course of the cranial nerves that are typically displaced laterally by the pathological condition at hand. Second, these approaches provide the most direct route to the osseous and soft tissue abnormalities that are ventral to the brainstem and therefore the shortest working distance for treatment of lesions. Third, important lateral structures, such as the internal carotid artery, muscles of mastication, the temporomandibular joint, the facial nerve, and the vestibulocochlear apparatus, are completely avoided.

The transoral approach, originally described more than 85 years ago, in the pioneering work of Scoville and Sherman and that of Southwick and Robinson, is well known today. The primary indication for this approach, which is called the STO approach in this paper, is an irreducible midline lesion that compresses the cervico-medullary junction. It is, however, inappropriate for intradural pathology because of the difficulty of achieving a watertight dural closure and the resulting significant risk of CSF leakage and meningitis due to oral contamination. A review of the literature suggests that the STO approach provides adequate exposure of the CCJ from the inferior clivus to the upper cervical spine. This is conditional on the patient’s ability to open the mouth widely, which may depend on the integrity of the temporomandibular joint, in addition to the anatomical constraints of the individual’s skull base. Does this suggest that the STO approach may not always be adequate for clival access? From this basic technique, several variations have been described with extensions superiorly via a transpalatal or transmaxillary avenue or inferiorly with a mandibulotomy and median glossotomy. The principle of all these technical variations is to use the empty anatomical spaces of the mouth and pharynx to provide a suitable surgical corridor for direct access to extradural ventral pathological conditions at the CCJ. However, with respect to clival access, insufficient information on these different approaches is available in the literature. The object of this report was...
to quantify the extent of clival exposure provided by microscopic procedures for four anterior approaches: STO, TOPS, LFO, and MLM.

The STO exposure is a relatively straightforward anterior approach to the CCJ associated with minimal risk of postsurgical complications. The procedure is performed through the mouth; the soft palate is elevated into the nasopharynx, exposing the arch of C-1 and—with some head extension—the rim of the FM. Unfortunately, this surgical corridor does not generally provide adequate exposure of the clivus superior to the FM (0.6 ± 4.9 mm), but it is an excellent surgical avenue for treating destructive or degenerative lesions of the atlantoaxial complex. Therefore, the technique of elevating the soft palate into the nasopharynx in the STO exposure adds little value to CCJ access. However, there are anecdotal reports that the inferior clivus, representing the portion from the FM to the pharyngeal tubercle, is surgically accessible with the STO. This is true on occasion (as reflected by data point 10, Fig. 5) and represents individual anatomical variation as noted by the authors and others in their anatomical measurements of the extracranial clivus. Furthermore, computed tomographic and magnetic resonance imaging studies of the skull base have also revealed individual variations of 3 to 7 mm in adults at the FM. Therefore, it behooves the clinician to review imaging studies to decide on the adequacy of an STO exposure for access to the inferior clivus.

When the TOPS approach was used, we found that at least an additional 8.3 mm (8.9 ± 5.5 mm) of the clivus was exposed. Qualitative observations about the increased exposure facilitated by the TOPS approach have been noted previously, and this avenue has been suggested as the anterior approach for microscopic procedures to the inferior clivus. However, superior alveolar margins have been found to limit the exposure laterally. De Divitiis and colleagues suggest in their anatomical study that the TOPS approach provides sufficient exposure of the extracranial clivus for an endoscopic transoral–transclival avenue to the brainstem and surrounding cisternal space, but they do not provide quantitative data. Also, they report that no additional procedures, such as a maxillotomy or a labiobulotomy, are required to increase the view either rostrally or caudally. This claim rests on the theoretical advantage that the endoscopic approach permits excellent visualization of inaccessible regions of the brain without the need for extensive skull base procedures. However, the pertinent question is what can be surgically accomplished with an endoscopy following visualization in this region? The utility of a strictly endoscopic transoral–transclival approach is yet to be clinically tested, but endoscope-assisted microscopic procedures in this region have been reported. Significant oropharyngeal morbidity from splitting the soft palate is associated with the TOPS approach; this ranges from transient velopharyngeal insufficiency in the majority of patients to occasional wound dehiscence of the soft palate following repair. Velopharyngeal insufficiency arises from the incompetence between the posterior pharyngeal wall and the soft palate due to wide clival defects and results in difficulties with swallowing and phonation.

The MLM procedure, originally described by Trotter, affords excellent exposure from the inferior aspect of the clivus, forming the anterior FM to the third cervical vertebral body, via a long and narrow corridor of the midline compartment. This procedure with its associated surgical morbidity (including a lip- and chin-splitting incision, a median glossotomy, and a mandibulotomy) does not satisfac-

**Fig. 5.** Graphs showing clival exposures obtained in each specimen via the four surgical approaches performed in relation to the total surgical exposure. Due to experimental error, information from data point 5 was not included for midline exposure data for each approach.
torily address principal clival pathology. The technique is more suited for inferior clival pathology with a significant inferior extension caudally along the cervical spine. In such cases, if required, access to the more superior portions of the clivus may be obtained by wider exposure of the nasopharynx through either soft palate retraction into the nasopharynx or additional soft and hard palate incisions. Nevertheless, surgical freedom is significantly limited by the narrow palatal corridor to the clivus. This lower transfacial procedure requires a mastery of surgical anatomy, the procedure is difficult, and its infrequent use prevents performance with genuine ease. Moreover, excellent technique and closure of the vermillion border of the lip is required because a notch in the vermilion border as small as 1 mm results in a conspicuous facial scar. A tracheostomy is mandatory for the MLM procedure but not for the others, except in the presence of paralyzed lower cranial nerves or brainstem dysfunction.

The maxillary LFO, Cheever’s operation,36 provides the single most important transoral–transclival exposure via a transmaxillary approach. Advantages of the LFO include: 1) wide passage to the extracranial clivus, particularly for both the middle and inferior clivus; 2) exposure of the lateral compartment for access to the medial aspect of the intrapetrous carotid sulcus bilaterally and the cavernous sinus at the superior lateral aspect of the exposure; 3) clear visibility of the resection margins; and 4) the lack of superficially visible scars. However, in six of 11 cadaveric specimens, the caudal aspect of the clivus contributing to the anterior FM was not identified secondary to the obstruction of the downwardly retracted fractured hard palate. In such cases, if exposure of the anterior FM is required, the hard and soft palate could be split to create an open-door maxillotomy.11 Surgical freedom will also be increased by this maneuver. The degloving procedure of the face performed by the LFO approach maintains innervation of the face, but at a price. Denervation of the maxillary dentition is unavoidable, because the nasopalatine and the anterior, middle, and posterior superior alveolar nerves are cut.36 Another disadvantage of the LFO approach is the high risk for disruption of the greater palatine nerve, due to surgical manipulation.30,36

Postoperative CCJ instability is an important consideration in any of these transoral procedures and causes concern if there is wide excision of the osteoligamentous components of the CCJ.15,32 This would be particularly true when addressing inferior clival pathological conditions that extend across the CCJ to involve the atlantoaxial complex. On occasion, pathological conditions involving the clivus may traverse the dura. In these cases, success with the transor- toral technique occurs at the risk of increased morbidity and death.13,14,35,38 In such instances, great care should be exercised in performing a repair, and CSF diversion should be performed to avoid subsequent CSF leaks and reduce the risk of meningitis.

Conclusions

The quantitative data presented in this paper suggest that a transoral approach is a reliable and technically sound method for gaining access from the middle clivus to the cervical spine. The exact location of the lesion in the clivus will dictate which variation of the different transoral procedures will be adequate. The results of our study indicate that the LFO avenue provides excellent exposure of the middle and the inferior clivus although, in some cases, it may be necessary to split the hard palate to reach the FM. Our findings further indicate that the TOPS or STO approaches, which are associated with substantially less morbidity than the MLM approach, may be adequate for exposure of the extracranial inferior clivus. The MLM technique is only recommended for pathological conditions that extend caudally from the inferior clivus for a significant distance.

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References
