Transoral Approach and Extended Modifications for Lesions of the Ventral Foramen Magnum and Craniovertebral Junction

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ABSTRACT

Objectives: To describe our method of performing the transoral approach and the extended approaches to the ventral foramen magnum and craniovertebral junction and review the technical aspects and operative nuances. **Design:** Review. **Results:** The transoral approach provides direct midline exposure to access extradural disease located at the craniovertebral junction and ventral foramen magnum. The corridor of exposure is generally limited by the extent to which the patient can open his or her mouth. The location of the hard palate relative to the craniovertebral junction limits superior exposure, whereas the mandible and base of the tongue limit the inferior exposure. In most cases, exposure can be obtained from the inferior clivus to the middle to lower C2 vertebral body. Extended transoral approaches can be performed to increase exposure if necessary. These approaches include transmaxillary (Le Fort I maxillotomy), transmaxillary with a midline palatal split (extended “open-door” maxillotomy), transpalatal, and median labiomandibular glossotomy (transmandibular split). **Conclusions:** The transoral approach effectively provides direct access to extradural midline lesions of the craniovertebral junction. A specialized retractor system can expose the inferior clivus to the C2 body. Extended approaches as described can access lesions that extend beyond these limits.

KEYWORDS: Craniovertebral junction, foramen magnum, skull base surgery, transoral approach

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Lesions of the ventral foramen magnum and craniovertebral junction present a difficult challenge. This complex region can harbor neoplastic, degenerative, or inflammatory lesions that can cause compression of the cervicomedullary junction and craniocervical instability. Treatment may require surgical decompression and subsequent craniocervical stabilization. Various midline anterior approaches have been developed to access lesions of the central cranial base and craniovertebral junction, including the transbasal, transnasal trans-sphenoidal, Le Fort I transmaxillary, transfacial, extended maxillotomy, transpalatal, transmandibular, and transoral approaches.¹⁻¹⁰ Each approach has its own advantages, disadvantages, and limitations of exposure. Surgeons should be familiar with the various midline anterior approaches and their modifications to select the most appropriate approach for the given lesion.

The location and extent of the lesion are the major determinants influencing selection of the appropriate cranial base approach. The transoral approach provides direct midline access to the craniovertebral junction and is most suitable for extradural lesions, such as chordomas, chondrosarcomas, giant cell tumors, and rheumatoid or degenerative pannus.^{6,11-15} This approach is best suited for strictly midline extradural lesions that occupy or are behind the inferior clivus down to the C2 vertebral body. Extensive lesions involving the sphenoid sinus and upper and middle clivus may require the more superior exposure offered by the transpalatal, transmaxillary (Le Fort I maxillotomy), or transmaxillary with a midpalatal split (extended "open-door" maxillotomy) approaches.^{5,8,16-20} If the lesion extends more inferiorly from C2 to C4, additional inferior exposure can be gained with a median labiomandibular glossectomy or a mandibular swing-transcervical approach.^{7,21-25} This article focuses on the technical aspects of the transoral approach for accessing lesions of the ventral foramen magnum and craniovertebral junction. The transmaxillary, transpalatal, and transmandibular extensions are also reviewed.

HISTORICAL OVERVIEW

Lesions of the craniovertebral junction have historically been challenging to remove surgically because of the difficulty in obtaining adequate exposure with minimal morbidity to the neural structures. Initial attempts at enlarging the foramen magnum were performed with posterior and posterolateral decompressive approaches, but the results were unsatisfactory.²⁶ Because of the limited exposure and increased risk of cerebrospinal fluid leakage and subsequent infection, the transoral approach was rarely used and, prior to the 1960s, was reserved primarily for accessing retropharyngeal abscesses. Beginning in 1962, the transoral approach was used to treat tuberculous lesions of the craniovertebral junction.²⁷ Despite this, criticism of transoral surgery continued because of its limited exposure, poor illumination, and lack of proper instrumentation.⁸ The advent of the operating microscope, microsurgical instrumentation, and specially designed transoral retraction systems contributed to the repopularization of the transoral approach. Currently, the transoral approach is used mostly for basilar invagination, compressive rheumatoid pannus, and extradural craniovertebral junction tumors. Previously described techniques of craniofacial osteotomies have been rediscovered and incorporated into modern cranial base surgery for increasing exposure of the transoral approach to access more extensive lesions.^{4,5,9,10,17,19,28} More recently, direct endoscopic approaches to the lower clivus and odontoid process have been described using an expanded endonasal endoscopic approach^{29,30} as well as an endoscopic transcervical approach.³¹

SURGICAL CONSIDERATIONS

The standard transoral approach primarily provides midline exposure of the inferior one third of the clivus, the anterior craniovertebral junction, and the C1-C2 complex. Its main advantage is that it

provides a direct extradural approach that does not require any brain retraction. This midline trajectory also accesses the lower pons, the medulla, the cervicomedullary junction, and the vertebrobasilar artery complex intradurally; however, we generally do not choose this approach for intradural lesions because it traverses a “contaminated” operative field, which is one of the main disadvantages of this approach. A watertight dural closure is difficult to achieve using a transoral approach, and a subsequent cerebrospinal fluid leak may result in life-threatening bacterial meningitis. The lateral limits of this exposure are defined by the mandible and the tonsillar pillars. The superior and inferior limits are usually the lower clivus and the middle to lower C2 vertebral body, respectively, although this will vary with each individual. If there is basilar invagination, exposure further down the spinal column becomes possible. Restricted jaw opening such as that which may occur in patients with rheumatoid arthritis may reduce the extent of exposure, especially inferiorly.

Carefully review radiographic images, including enhanced magnetic resonance imaging (MRI) and fine-cut 3D-reconstructed computed tomographic scans of the craniovertebral junction, before selection of the appropriate approach. It is important to determine initially whether the lesion is suitable for a midline cranial base approach and whether the lesion is situated intradurally or extradurally. Consider a transoral approach if the lesion is situated in the midline extradurally. If it extends more laterally or appears to be located intradurally, consider alternatives such as the far lateral or extreme lateral transcondylar approaches. To obtain adequate line of sight in the superior and inferior trajectories, the opening of the mouth should be at least 2.5 to 3 cm between the upper and lower teeth. Preoperatively, estimate the superior extent of the exposure by drawing an imaginary line in the plane of the hard palate toward the craniovertebral junction on a sagittal MRI. If the lesion is midline and is situated above this line, an extended trans-sphenoidal approach may be suitable. If, however, the lesion is situated below the

plane of the hard palate, a transoral approach alone may be sufficient. Alternatively, consider a Le Fort I maxillotomy with or without a palatal split if the lesion extends above and below the plane of the hard palate. If the lesion extends inferiorly beyond the line of sight of a standard transoral approach (roughly beyond the lower body of C2 to the C2–C3 disk space in most cases), a labiomandibular median glossotomy (transmandibular split) approach may be appropriate to gain more inferior exposure. Although these extended approaches provide increased exposure for more extensive lesions, these procedures increase morbidity and should be used judiciously.

Preoperatively, we obtain dynamic plain cervical radiographs in flexion and extension views to evaluate for pre-existing instability at the craniovertebral junction. In some cases, the expansion of the tumor has destabilized the occipitoatlantal or atlantoaxial joints, thus requiring a subsequent or prior stabilization procedure. Even if no instability is present, however, most cases will require stabilization after resection of the lesion and the involved ligaments because of postoperative iatrogenic instability. Either occipitocervical or atlantoaxial stabilization can be performed, depending on the level of instability. We generally obtain a high-resolution stereotactic computed tomography scan of the craniovertebral junction for preoperative planning.

If severe deformity or cranial settling is detected preoperatively, attempt reduction with cervical traction using Gardner-Wells tongs. In cancer patients with metastatic disease who do not have neural compression, a posterior occipitocervical stabilization to treat the instability may be appropriate palliative treatment given the patients' short life expectancy. If, however, there are compressive pathological conditions, if the lesion is a primary neoplasm, or if the patient's neck cannot be reduced to an anatomic position sufficient to decompress the neural elements, a transoral resection followed by a posterior stabilization is an effective strategy.

SURGICAL TECHNIQUE: TRANSORAL APPROACH

Positioning and Application of Transoral Retractor System

Place the patient in the supine position with the head resting on a doughnut pad. Slightly extend the neck to facilitate a direct line of sight to the craniovertebral junction. Apply cervical traction if it was implemented preoperatively for reduction. The patient is orally intubated. Consider awake fiberoptic intubation in patients who have marked spinal instability. Topical corticosteroid cream can be applied to the tongue to minimize postoperative tongue swelling. We do not use three-point skull fixation because the head is adequately secured once the transoral retractor system is set.

We apply the Spetzler-Sonntag transoral retractor system (available from Jarit Surgical Instrument Division, Integra LifeSciences Corporation, Hawthorne, NY), which is rigidly attached to the operating table to prevent the retractors from moving intraoperatively and to stabilize the patient's head (Figs. 1–3).³² Proper positioning of the transoral retractor maximizes exposure and obviates the need to incise the soft palate or uvula to gain the

needed exposure. Retract the patient's tongue inferiorly using a wide and rigid retractor blade. The endotracheal tube can be placed under the tongue retractor, but we prefer to route it along the side of the mouth to reduce tongue compression. It exits the corner of the patient's mouth and does not obstruct the surgical exposure. This provides adequate exposure and eliminates the need for a preoperative tracheostomy in most cases. We usually reserve a tracheostomy for those patients who have pre-existing bulbar or respiratory dysfunction or those who are undergoing a median labiomandibular glossectomy approach. Maximize exposure of the cephalad posterior pharynx by elevating the soft palate and uvula superiorly with a small retractor blade that attaches to the transoral retractor. This avoids injury to or incision of the soft palate, which can be difficult to repair and can result in dysphagia, dysphonia, and nasal regurgitation of fluids. Place teeth guards, which are attached to the retractor frame, around the upper teeth for protection. Use adjustable lateral retractors attached to the retractor frame to retract the pharyngeal soft tissues laterally. After the retractor system is in place, carefully inspect the tongue to confirm that it is free from compression between the retractor blade and the teeth. Failure to recognize this compression can result in necrosis or

Figure 1 Operative positioning. (A) The patient is placed in the supine position with the head resting on a doughnut pad. The neck is slightly extended to facilitate a direct line of sight to the craniovertebral junction. The patient is orally intubated. The Spetzler-Sonntag transoral retractor system is rigidly attached to the operating table with crossbars to prevent the retractor and the patient's head from moving intraoperatively. (B) Intraoperative fluoroscopy is used throughout the operation.

swelling of the tongue. After final positioning of the retractors, prep the mouth, oropharynx, and retractors with Betadine solution. The surgeon operates from the head of the patient, using an operating microscope to enhance magnification and illumination. Prophylactic antibiotics are administered intraoperatively. We do not perform preoperative bacterial cultures of the oropharynx.

Incision and Muscle Dissection

The posterior pharyngeal wall can be infiltrated with 0.5% lidocaine with 1:200,000 epinephrine

solution, but this step is usually not necessary for hemostasis if the monopolar cautery is used to open the pharynx as described below. Locate the midline by palpating the tubercle of C1; however, this anatomic landmark may be absent or distorted in patients who harbor tumors in this location. Using a fine-tip, shielded monopolar cautery (Colorado MicroDissection Needle, Stryker Leibinger, Portage, MI) set at low cutting power, incise the posterior pharyngeal wall longitudinally in the midline over the region that is to be resected (Fig. 2B). Carry the incision progressively through the mucosa, the midline raphe between the pharyngeal muscles, and the anterior longitudinal ligament down to

Figure 2 (A) Illustration shows placement of the Spetzler-Sonntag transoral retractor system. The patient is orally intubated and the endotracheal tube exits the corner of the mouth. The retractor is held between the anterior teeth superiorly and the tongue inferiorly. (B) Adjustable retractor blades are placed superiorly to elevate the soft palate and uvula and laterally from each side to maximize exposure of the posterior pharynx. The dotted line marks the posterior pharyngeal incision.

Figure 3 (A) Intraoperative photograph shows the surgeon's view of the transoral exposure after placement of the Spetzler-Sonntag transoral retractor system. The surgeon operates from the head of the patient. The tongue is retracted inferiorly by a wide and rigid retractor blade. The endotracheal tube is routed along the side of the mouth to reduce tongue compression. It exits the corner of the patient's mouth and does not obstruct the surgical exposure. The soft palate and uvula are elevated superiorly with a small retractor blade that attaches to the transoral retractor. Teeth guards, which are attached to the retractor frame, anchor the frame on the superior teeth or, if the patient is edentulous, on the maxillary alveolar ridge, and protect the upper teeth. (B) An enlarged view.

the bone using a regular monopolar cautery tip. The lateral retractors help to expose the tissues as the incision is deepened. Then use the tip of a regular monopolar cautery, bent to a near-right angle, in a sweeping motion to detach the ligaments from the bone in a subperiosteal fashion. This technique greatly reduces bleeding from these well-vascularized tissues. The longus colli and the longus capitis muscles are mobilized laterally and

held in place with tooth-bladed lateral pharyngeal retractors to expose the inferior clivus, C1 arch, and C2 vertebral body (Fig. 4).

Removal of C1 Arch and Odontoidectomy

The following section describes the removal of the arch of C1 and odontoid process in the absence of a tumor. Its purpose is to illustrate the anatomy of an intact craniovertebral junction that has not been destroyed by a neoplastic process. Clear all soft tissues with electrocautery before removal of the anterior C1 arch and the odontoid process. Using a high-speed drill, make bone cuts through the arch of C1 on both sides of the odontoid process (Fig. 4). Use rongeurs to remove the arch of C1 to expose the underlying odontoid process. Before performing odontoidectomy, clearly define the edges of the odontoid process and free them from any ligamentous attachments. Detach the apical and alar ligaments from the odontoid using sharp curettes. Use a right-angled curette to free the posterior cortex of the odontoid from the underlying soft tissues and ligaments. Using a high-speed drill and copious irrigation and suction, hollow out the center of the odontoid process, leaving an eggshell-thin layer of outer cortical bone. Remove the remaining eggshell-thin bone with either the drill or Kerrison rongeurs. By systematically detaching the odontoid from its associated ligaments before removing the odontoid, the surgeon can prevent upward retraction of the odontoid tip toward the clivus should the base of the odontoid be prematurely transected.

After the anterior arch of C1 and the odontoid process are removed, the transverse ligament can be identified. Removal of the transverse ligament, tectorial membrane, and any residual ligaments may be necessary to remove pannus. Resect the compressive pathology to decompress the underlying craniovertebral junction dura mater adequately. If necessary, remove the inferior clivus with a high-speed drill and rongeurs.

Figure 4 Removal of the arch of C1 and odontoid process. (A) Bone cuts are made through the arch of C1 on both sides of the odontoid process using a high-speed drill, and the arch is subsequently removed with rongeurs. (B) After the odontoid process is freed from its ligamentous attachments, the center of the odontoid is hollowed out with a high-speed drill, leaving an eggshell-thin layer of bone that is subsequently removed with Kerrison rongeurs or additional drilling.

Tumor Removal

In some cases, tumor may be encountered on opening the posterior pharyngeal mucosa and the anatomy of the craniovertebral junction may be distorted by the tumor. Use ringed curettes, rongeurs, bipolar cautery, and suction to remove tumor in a piecemeal fashion. If tumor has involved the ligaments, remove them with rongeurs. If the odontoid process is intact but will be resected to gain deeper access, detach the apical and alar ligaments to prevent upward retraction of the odontoid tip. Identify the plane between the tumor and dura mater to facilitate tumor removal.

Tumor that extends longitudinally into the clivus or the body of C2 is well visualized by this approach and can typically be removed using curettes and a high-speed drill until normal cancellous bone is identified. Tumor that has extended further laterally is more difficult to visualize and to remove. Tumor in these regions can be removed using angled curettes, pituitary rongeurs, and suction, while being careful not to injure the vertebral artery. A side-angle view endoscope may help with lateral

visualization as well. If the tumor has eroded the occipitoatlantal joints, the patient should undergo a posterior stabilization either before or after tumor removal, as should any patient in whom the arch of C1 or the odontoid is disrupted by the surgery. If the occipital condyle is drilled out because of tumor involvement, the surgeon should be mindful of avoiding injury to the hypoglossal nerves, which traverse this structure in the hypoglossal canal located in the anterior third of the condyle.

Tumor may be adherent or may have infiltrated the dura mater. If the dura mater has been violated by tumor, take care not to injure the intradural structures, such as the basilar artery, perforators, and brainstem. If there is an intraoperative cerebrospinal fluid leak, reconstruct the dura mater with autologous or allograft fascia lata, fat, and fibrin glue in several layers. Follow this with temporary lumbar drainage, which should be performed promptly at the end of the procedure. If, however, the dura mater is intact, evaluate the extent of decompression intraoperatively by injecting contrast into the epidural space and viewing this fluoroscopically.

Closure

Performing an adequate closure in a deep wound after a transoral operation can be challenging. It can be facilitated using long, thin needle holders with a curved tip and instrument-tying techniques (similar to those used in microvascular anastomosis). If the dura mater is intact, the wound closure proceeds in two layers (Fig. 5). First, approximate the muscle layer in a horizontal mattress with 3-0 Vicryl sutures. We use half-circle Lane cleft palate needles because they are small and stiff enough to resist bending forces. These benefits outweigh the inconvenience of not having a swedged-on needle. Then approximate the mucosal layer with simple interrupted 3-0 Vicryl sutures using the same needle. Take care not to pull the sutures too tightly because this can strangulate the delicate mucosal tissues. In cases in which the dura mater is intact, continue prophylactic antibiotics for 24 hours. We have not had any complications of wound dehiscence from the described two-layer wound closure. Reapproximation of the deeper pharyngeal muscle layer

provides added strength to the closure. The mucosal layer incision heals quite rapidly. If, however, wound dehiscence is encountered, perform an aggressive washout and reclosure of the wound and administer broad-spectrum antibiotic medications.

If the dura mater has been violated, either by the tumor or by the surgical approach, reconstruction of the cranial base followed by temporary lumbar drainage is paramount in preventing a cerebrospinal fluid leak. Because primary closure of the dura mater is usually not feasible, autologous fascia lata and fat are harvested from the thigh. Alternatively, allograft fascia lata supplemented with fat harvested from the abdominal wall or other suitable site has been used successfully. Reconstruct the dural defect by grafting a piece of fascia lata in an onlay fashion followed by fibrin glue, fat, Surgicel, and additional fibrin glue (Fig. 5). The placement of excessive fat may result in neural compression and should be avoided. Extend broad-spectrum antibiotic coverage for ~5 days. Close the pharyngeal muscles and mucosa as described above.

Figure 5 Closure technique. (A) Defects in the dura mater are reconstructed with autologous fascia lata, fat, and fibrin glue. (B) The pharyngeal muscles and mucosa are reapproximated in separate layers with interrupted absorbable sutures.

Posterior Stabilization

We prefer to perform a posterior stabilization immediately after the transoral resection (Fig. 6). This allows restoration of normal alignment that often is disrupted by the pathologic process as well as stabilization. If the patient is in good alignment initially, however, the option exists to perform this step before the transoral approach. In almost all

cases, the craniovertebral junction will be rendered unstable by the extent of pathologic destruction produced by the lesion, ligamentous weakening, and/or operative bone removal.^{33,34} The key stabilizing structures in the atlantoaxial region are the odontoid process of C2 held within the anterior ring of C1 by the very strong transverse ligament. Resection of the anterior arch of C1 or a transoral odontoidectomy disrupts this complex and renders

Figure 6 (A) Preoperative T2-weighted sagittal magnetic resonance image; (B) preoperative sagittal computed tomography scan. Both demonstrate severe ventral compression of the craniovertebral junction and posterior deviation of the spinal cord from a large degenerative pannus behind the odontoid process in a 81-year-old woman who presented with neck pain and early myelopathy. A transoral approach was performed to remove the large pannus at the craniovertebral junction followed by a posterior occipitocervical stabilization. (C) Postoperative sagittal computed tomography scan shows resection of the C1 arch, odontoid process, and pannus resulting in excellent decompression of the craniovertebral junction. (D) Postoperative lateral cervical spine radiograph shows occipitocervical stabilization construct at 6 months after surgery.

the spine very unstable because it allows a significant increase in the amount of translational and rotational motion.³⁵ If basilar invagination was present preoperatively, an occipitocervical stabilization is usually required.³² We rarely place anterior bone grafts into the transoral defect because they do not restore spinal stability and are difficult to fixate. They also become dislodged easily and are associated with a high rate of infection.³²

Carefully reposition the patient in the prone position with the head placed in three-point fixation for a posterior stabilization. We use a cervical collar to augment the stability while carefully turning the patient. Place the craniovertebral junction in anatomic alignment under fluoroscopic visualization for subsequent stabilization. The motion segments that require stabilization are definitively determined at the time of surgery because in the face of atlantoaxial instability it is difficult to determine whether there is atlanto-occipital instability. After the spine is exposed, place a towel clamp or Kocher clamp on the posterior arch of C1, and carefully apply force under fluoroscopic visualization. If C1 translates in the anteroposterior plane by more than 1 mm, the occipitoatlantal joint is unstable and the fusion construct is extended up to the occiput to perform an occipitocervical fusion. If, however, there is no translation of C1 relative to the occiput, only C1/2 stabilization is usually needed. This may be done with transarticular screws or a direct C1 lateral mass screw and C2 pars screw construct (Harms technique). If C1 and C2 cannot be fixated directly then the construct may need to be extended to achieve an instrumented occipitocervical stabilization, but in most cases the versatility of modern instrumentation systems allows a short segment fusion to be accomplished.

Postoperative Care

In most cases, we attempt routine extubation immediately after surgery unless we are concerned about a difficult airway. As described above, topical corticosteroids applied to the tongue minimize

postoperative swelling. We generally do not place a nasogastric feeding tube postoperatively, because it may cause irritation to the pharyngeal wound closure. We withhold oral feedings for 24 to 48 hours; however, we give the patient oral swabs or ice chips to moisten the mouth. After 24 to 48 hours, the patient starts on clear fluids and later advances to a mechanical soft diet as tolerated.

EXTENDED TRANSORAL APPROACHES

Lesions that extend beyond the exposure limits of a standard transoral approach may require an extended transoral approach (Figs. 7–10). The need for an extended approach can be determined preoperatively on radiographic images, as described earlier. Extended approaches involve additional incisions and facial osteotomies to mobilize structures that may be obstructing the surgeon's line of sight to the lesion. A detailed anatomic knowledge of the craniofacial bones, soft tissues, and blood supply is critical in executing these approaches. The assistance of an experienced craniomaxillofacial surgeon may be helpful. Accurate reconstruction of the maxillofacial osteotomies is paramount to achieving excellent cosmesis and avoiding malocclusion. The options for gaining more superior exposure of the upper and middle clivus and sphenoid sinus are the transmaxillary (Le Fort I maxillotomy) approach, transmaxillary palatal split (extended "open-door" maxillotomy) approach, or the transpalatal approach. To gain more inferior exposure from C2 to C4, a median labiomandibular glossectomy (transmandibular split) can be applied.

Transmaxillary Approach (Le Fort I Maxillotomy)

The transmaxillary approach involves a Le Fort I maxillotomy through a sublabial incision that allows inferior mobilization of the maxilla and hard palate, much like a trap door.^{5,17,18,36} Thus, it has often

Figure 7 Illustration shows the locations of the osteotomies for extended transoral approaches.

been referred to as a “drop-down” maxillotomy approach. This maneuver provides more upward viewing to the sphenoid sinus and upper and middle clivus and also provides a wider panoramic exposure of the posterior naso-oropharynx. Inferior displacement of the hard palate, however, obstructs inferior viewing of the inferior portions of the body of C2, which is the major limitation of this approach. The lateral limits of exposure are the carotid arteries. This approach is appropriate for midline extradural lesions that are wider and involve the sphenoid sinus, clivus, and odontoid process. The Le Fort I maxillotomy has advantages over the extended trans-sphenoidal approach in that it provides wider exposure as well as more inferior viewing past the plane of the hard palate. In summary, the Le Fort I maxillotomy approach is indicated for extensive lesions that are too wide and too inferior for an extended trans-sphenoidal approach and too cephalad for a standard transoral approach.³³

Make a sublabial incision along the upper alveolar margin extending from one maxillary tuberosity to the other. Elevate the gingival mucosa subperiosteally to expose the anterior maxilla up to the level of the infraorbital nerve. Once the piriform aperture is identified, elevate the nasal mucosa from the nasal floor and nasal septum up to the level of

the inferior nasal turbinates. The pterygomaxillary fissures on both sides must be exposed prior to the osteotomy. Mark the intended Le Fort I osteotomy on the maxilla with a sterile pen (Fig. 7). It is important to preregister the titanium miniplates and screws before performing the maxillotomy to ensure an exact fit when the maxilla is returned to its anatomic position at the time of closure. This technique reduces the risk of postoperative malocclusion.^{8,33,37} Secure the titanium miniplates and screws over both sides of the intended Le Fort I osteotomy line. Remove and carefully label them for subsequent replacement at the time of closure.

Using an oscillating saw, make bilateral Le Fort I osteotomies, staying above the roots of the teeth to avoid dental injury. Make another osteotomy to separate the bony nasal septum from the hard palate. Using a curved osteotome, disarticulate the maxillary tuberosities from the pterygomaxillary fissures bilaterally. Then down-fracture the hard palate and mobilize it inferiorly into the oral cavity. Readjust the transoral retractor to retract the down-fractured maxilla inferiorly. Inspect the tongue carefully to ensure that it is free from entrapment between the teeth. The remainder of the operation is similar to the transoral approach described earlier. At the time of closure, replace the maxilla and

Figure 8 Illustration shows the exposure gained by performing an extended transoral approach. The extended maxillotomy provides rostral exposure of the sphenoid sinus and upper clivus. The median labiomandibular glossotomy provides inferior exposure of the upper cervical spine down to C3 and C4.

fasten it with the preregistered titanium plates and screws. Reapproximate the gingival mucosa with interrupted 2-0 absorbable sutures.

Transmaxillary Palatal Split Approach (Extended Maxillotomy)

One major disadvantage of the Le Fort I maxillotomy is obstruction of inferior exposure by the down-fractured maxilla. This can be overcome by splitting the hard and soft palate and mobilizing the hemi-maxillae laterally (Figs. 7–9). Each hemi-maxilla maintains its own blood supply and innervation from its respective palatine artery and nerve. This modified approach is referred to as the transmaxillary palatal split approach, or extended “open-door” maxillotomy, and is essentially a Le Fort I osteotomy enhanced with an additional split of the hard and soft palate.^{8,33} This approach provides rostral exposure of the sphenoid sinus and upper and middle clivus while maintaining the inferior exposure provided by a standard transoral approach.

This is particularly useful for extensive lesions that involve the sphenoid sinus and clivus down to the body of C2. The lateral limits of this exposure are the cavernous carotid arteries, the occipital condyles, and the lateral masses of the C1–C2 complex. The major disadvantages of this approach are extended operating time and the complexity of reconstruction and wound closure.³³

A Le Fort I osteotomy is initially performed as described above. Incise the mucosa over the hard palate slightly off the midline, continuing posteriorly through the soft palate, staying on one side of the uvula. Using an oscillating saw, split the hard palate in the midline starting between the front incisors. The osteotomy traverses around the anterior nasal spine and continues posteriorly in the sagittal plane. Rotate each hemi-maxilla outward and retract them laterally into the cheek (Figs. 7–9). Make a midline incision in the posterior pharyngeal wall and continue the surgical resection as described previously.

At the time of closure, restore each hemi-maxilla to its anatomic location and fasten them

Figure 9 Illustration of surgical removal of a tumor involving the clivus, C1, and C2, using the transmaxillary palatal split approach (extended "open-door" maxillotomy).

with preregistered titanium plates and screws. Reapproximate the mucosa over the hard palate and the sublabial incisions with interrupted absorbable sutures. Close the soft palate in three layers with interrupted absorbable sutures.

Transpalatal Approach

The transpalatal approach provides increased rostral exposure of the upper and middle clivus through a standard transoral approach by excising the hard palate. This approach is useful for tumors of the craniovertebral junction that extend superiorly beyond the plane of the hard palate. In contrast to the transmaxillary approaches described earlier, this approach has the advantage of minimal facial disassembly.^{4,37}

To disarticulate the hard palate, you must obtain exposure above and below the hard palate through the nasal floor and oral cavity, respectively. Initially, make a sublabial incision and elevate the gingival mucosa subperiosteally to expose the piriform aperture. Perform the submucosal dissection to expose the nasal floor and nasal septum, similar to a sublabial trans-sphenoidal

approach. Make a midline incision through the mucosa of the inferior surface of the hard palate that continues through the soft palate, staying on one side of the uvula. Elevate the mucosa subperiosteally to the alveolar margin around the greater palatine foramen, and detach the levator muscle from the posterior margins of the hard palate. Use an oscillating saw to cut around the margin of the palate near the alveolar edge, staying medial to the greater palatine foramen (Fig. 10). Through the sublabial exposure, disarticulate the hard palate from the nasal septum and lateral nasal walls with an osteotome. Remove the bony hard palate from the oral cavity, thereby exposing the nasal septum, sphenoid sinus, and upper clivus (Fig. 10).^{4,37}

Incise the posterior pharynx and tumor removal proceeds as described previously. At the time of closure, use titanium microplates and screws to fasten the hard palate back into its anatomical position. Take care not to place screws into the tooth roots. Reapproximate the soft tissues of the soft palate and palatal mucosa with interrupted absorbable sutures. Also close the sublabial incision with interrupted absorbable sutures.

Figure 10 Illustration shows the transpalatal approach. (A) The dotted line marks the area of the hard palate to be removed. (B) Removal of the hard palate exposes the sphenoid sinus and upper clivus.

Transmandibular Approach (Median Labiomandibular Glossotomy)

The median labiomandibular glossotomy involves a lower lip and chin incision followed by midline split of the mandible and tongue. Trotter³⁸ first described this approach in 1929 and it is used by otolaryngologists for resecting midline tumors located at the base of the tongue and the posterior pharynx.^{39,40} It is also useful for accessing craniovertebral junction tumors and other lesions that extend inferiorly beyond C2 to about the C4 level if they are not accessible through a standard transoral approach.^{9,21-23} We perform a tracheostomy before performing this extended approach.

Make a vertical curvilinear incision in the lower lip, starting in the midline and curving around the skin crease of the chin, then continuing inferiorly in the midline to the hyoid bone. Elevate the

soft tissues and mucosa from the mandible laterally. Titanium plates and screws are contoured to the mandible and preregistered for later replacement. Using an oscillating saw, split the mandible in the midline between the two lower incisors (Figs. 7, 8). Removal of the teeth is not required in performing this osteotomy. Incise the tongue with monopolar cautery along the median raphe, a relatively avascular plane, posteriorly toward the median glossoepiglottic fold. Because the incision is in the midline, the innervation from the hypoglossal nerves to their respective halves of the tongue is preserved, as is the vascular supply to the tongue. Retract the halves of the mandible and tongue laterally (Figs. 7, 8). Split the floor of the mouth between the submaxillary ducts, and extend the incision inferiorly to the level of the hyoid bone. Incise the posterior pharyngeal wall in the midline, exposing the middle-to-inferior clivus down to the C3 and C4 vertebral bodies. Tumor removal and closure proceed as described earlier.

Restore the mandible to its anatomic position and reapproximate with preregistered titanium plates and screws. Reapproximate the tongue with interrupted absorbable sutures. Reapproximate the lip and skin incisions with 3-0 nylon sutures.

CONCLUSION

The transoral approach is effective in providing direct access to extradural midline lesions of the craniovertebral junction. Using a specialized retractor system, exposure can be obtained from the inferior clivus to the C2 body. Lesions that extend beyond the limits of exposure of a transoral approach can be accessed with extended approaches as described.

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Commentary

Liu et al present a “Transoral Approach and Extended Modifications for Lesions of the Ventral Foramen Magnum and Craniovertebral Junction.” Pathology at the ventral craniovertebral junction remains a technical challenge to remedy. The authors present a well-written review of the transoral approach and its extensions to access lesions from

the inferior clivus to the C2. The article is easy to read and the illustrations enable a visual understanding of the local anatomy; these attributes make this an excellent educational reference for neurosurgical residents and skull base neophytes.

Endoscopic endonasal techniques to expose this area have also been described as an alternative to the often morbid transoral, transfacial, and transmandibular approaches. Accessing the area and resecting the pathology appear quite feasible via the less invasive endoscopic approach. There are some technical tips that may assist in this approach. We prefer using a small pediatric feeding tube, and then using a 2-0 silk tie to attach the uvula to the pediatric feeding tube. This helps get the uvula out of the way and increases the level of exposure. We prefer to use the Codman Crockard Retractor (Randolph, MA), which has worked very well for our approaches. The major complications that we have encountered in our series of transoral approaches have involved rheumatoid arthritis patients, who were immunosuppressed and for whom healing is not optimal. We had one cerebrospinal fluid leak that resolved with lumbar drainage.

In conclusion, this is an excellent review article, with concise yet complete techniques and illustrations. The article will serve as an excellent reference for those who perform surgery in this area.

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