52 Endoscopic and Transnasal Approaches to the Craniocervical Junction

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SUMMARY OF KEY POINTS

- The endoscopic transnasal approaches provides a direct surgical trajectory to anteriorly located lesions at the craniocervical junction.
- Clinical series demonstrate low rates of postoperative infection after endoscopic transnasal approaches to intradural pathology despite nasal contamination.
- Endoscopic transnasal odontoidectomy allows preservation of the soft palate and patients can restart an oral diet on the first postoperative day.
- On sagittal imaging, a line drawn from the anterior inferior nasal bone through the posterior aspect of the hard palate—the nasopalatine line—can predict the caudal limit of exposure of the upper cervical spine with a transnasal approach.
- Lesions extending lateral to the lower cranial nerves cannot fully be treated via an endonasal approach.
- A vascularized nasoseptal flap has dramatically reduced the incidence of postoperative cerebrospinal fluid leak.
- We recommend a two-surgeon, four-hand approach with collaborative expertise in rhinology and neurosurgery.

Neoplasms, infections, trauma, and inflammatory and degenerative conditions can all affect the craniocervical junction. Lesions located anterior or anterolateral to the medulla and upper cervical spinal cord present a formidable challenge given the proximity of critical neurovascular structures. Early attempts to address these lesions via a posterior approach resulted in considerable morbidity and mortality due to retraction-related morbidity and poor visualization.[1,2] Various surgical approaches have been developed to treat these lesions more effectively while minimizing morbidity. These include the far lateral transcondylar, the extreme lateral, the lateral transatlantal or direct lateral, the transoral, and various endoscopic and transnasal approaches.[3-12] At the craniocervical junction, endoscopic and transnasal approaches have been utilized primarily to treat lesions located anterior to the brain stem and upper cervical spinal cord.[10-12]

Endoscopic and transnasal approaches were developed because they provide a direct surgical trajectory to anterior craniocervical junction pathologies with excellent operative visualization. The direct route reduces the need to manipulate surrounding neurovascular structures and can therefore reduce the risk of retraction-related morbidity. The benefit of the endoscope is that it increases illumination of the operative field, provides higher magnification with a wider angle of view, and increases depth of field. This chapter reviews common endoscopic transnasal approaches to the craniocervical junction and highlights important intraoperative and perioperative details.

PREOPERATIVE EVALUATION

Routine preoperative imaging includes thin slice (1-mm) computed tomography (CT) and magnetic resonance imaging (MRI). This is necessary to fully evaluate both the bony anatomy and the neurovascular relationships to the pathology. In addition, fusion of both the thin slice CT and the MRI is performed for intraoperative computer-assisted navigation. Finally, the addition of a high-resolution constructive interference in steady state (CISS) sequence can provide unparalleled detail of the relationship of cranial nerves to the pathology.[13] In addition to radiographic evaluation, a critical component of preoperative evaluation is dedicated bilateral sinonasal endoscopy in the office. This evaluation is performed by the participating otolaryngologist to identify any anatomic variations, such as septal deviation, spur formation, or perforation, which would affect the operative approach or reconstruction. In addition, screening for concurrent paranasal sinus disease is needed to determine if preoperative antibiotic treatment is necessary. For pathology affecting the lower cranial nerves, a preoperative swallow evaluation and direct laryngoscopy can be performed to provide baseline function and counsel patients on expected postoperative risks if preoperative dysfunction exists.

ENDOSCOPIC TRANSNASAL SURGICAL TECHNIQUE

Operating Room Setup, Patient Positioning, and Equipment

The patient is positioned supine and is placed near the edge of the right side of the operative table. The head is placed in a neutral position using a rigid three-point fixation device. This is particularly important when cervical instability is present or expected after surgery. For access to the odontoid process, the head is elevated slightly to align the surgical trajectory with the surgeon. Frameless stereotactic image guidance is used with all endoscopic transnasal cases. Most navigational systems have suctions that can be registered and navigated. Malleable suctions are also useful during the resection stage, as they can be manipulated to reach the surgical target and avoid conflict with the endoscope.

After nasal access is obtained, a two-surgeon approach is used for the remainder of the case. The endoscope is positioned at the apex of the right nostril and navigated by one surgeon. For a right-handed surgeon, a suction is placed underneath the endoscope in the right nostril and a dissecting instrument is placed in the left nostril. Endoscopes are 4 mm in diameter and the 0- and 30-degree lens angles are most commonly used for these approaches. An irrigation sheath on the endoscope can improve efficiency by reducing the time needed to clean the lens.

Anesthetic Considerations

The endotracheal tube is placed along the left side of the mouth. A nasogastric tube or a throat pack is placed to prevent the pooling of blood in the stomach, which can provoke postoperative emesis and disrupt the reconstruction. Neurophysiology monitoring is routinely used, including somatosensory evoked potentials (SSEPs), motor evoked potentials (MEPs), and lower cranial nerve electromyography (EMG). Electrodes may be placed in the trapezius muscle and tongue to monitor the accessory and hypoglossal nerves, respectively. In addition, a neural integrity monitor (NIM) electromyogram endotracheal tube (NIM 3.0, Medtronic, Minneapolis, MN) allows one to stimulate the vagus nerve and assess for motor response within the vocal cords. Local anesthetic gels must be avoided with this endotracheal tube. The use of nondepolarizing neuromuscular blocking agents should be avoided in addition to any local anesthetic gels when using the NIM EMG tracheal tube.[14] Lastly, arterial hypotension, which is often used to help control nasal mucosal bleeding, is avoided when entering the intracranial space or when brain stem or upper cervical spinal cord compression is present.

Nasal Approach

The nasal mucosa is injected with local vasoconstrictors. The inferior turbinates are outfractured and one or both of the middle turbinates are resected if necessary to provide a wider corridor for passage of instruments. In approaches to pathology limited to the craniocervical junction, resection of the middle turbinate is frequently not necessary unless significant platybasia is present. The posterior choanae can be visualized by following the nasal cavity floor back to the nasopharynx. The natural sphenoid ostium is identified medial to the superior turbinate. A nasoseptal flap, if required, is harvested by first identifying the pedicle of the flap, which contains the posterior septal artery, a branch of the sphenopalatine artery. Using needle-tip bovie electrocautery, an inferior cut is made from the posterior choanae extending inferior and anterior along the floor of the nasal cavity. A superior cut is then made from the natural os of the sphenoid extending superior and anterior along the nasal septum. Normally, the nasoseptal flap can be tucked down into the nasopharynx during most endoscopic endonasal cases, but when working in the region of the craniocervical junction, this becomes obstructive and can be easily damaged. Therefore, on the side of the nasoseptal flap harvest, a maxillary antrostomy is performed by removing the uncinate process, and the nasoseptal flap can be tucked into the maxillary sinus until it is needed at the time of reconstruction. Again, it should be noted that approaches for pathology limited to the craniocervical junction might not require initial nasoseptal flap harvest. Rather, an inferior posterior septectomy that spares the pedicle to the nasoseptal flap can be employed, allowing subsequent harvest if warranted by intraoperative findings.

Wide sphenoidotomies can then be performed if warranted by the pathology or at the discretion of the surgeon. The posterior nasal septum is disarticulated from the rostrum of the sphenoid sinus and the rostrum is removed with a 4-mm coarse diamond bur Kerrison rongeurs. Roughly 1 to 2 cm of the posterior septum is removed as well. Wide bilateral sphenoidotomies create a large, singular surgical cavity with adequate room for the passage of the endoscope and surgical instruments without conflict.

For access to the lower clivus and upper cervical spine, additional nasal work is required as follows. The floor of the sphenoid sinus is drilled down to create a wide communication between the sphenoid sinus and the nasopharynx. The nasopharyngeal mucosal and muscular layers along the midline are cauterized and lateralized. This exposes the buccopharyngeal fascia, which is also elevated off the clivus and lateralized. The longus capitus (lower clivus), longus coli (upper cervical spine), and anterior atlanto-occipital membranes are also cauterized at the midline and lateralized to provide access to the lower clivus, anterior ring of C1, and odontoid process.[12]

ENDOSCOPIC TRANSNASAL TRANSCLIVAL APPROACH

This chapter focuses on the transclival approach for access to the lower clivus and craniocervical junction. Common pathologies at this level include anteriorly located foramen magnum meningiomas and clival chordomas. Proper preoperative evaluation includes radiographic evaluation of the lesion pathology in relation to the lower cranial nerves and carotid arteries. Lesions extending lateral to the lower cranial nerves cannot fully be treated via an endonasal approach. The paraclival carotid arteries, or the segment of the carotid artery between the foramen lacerum and the cavernous sinus, is at risk during a midclival approach. The lacerum segment of the internal carotid artery (ICA) roughly corresponds to the pontomesencephalic junction. Therefore, the risk of carotid injury is lower in an approach to the lower clivus and foramen magnum. However, preoperative imaging should be carefully evaluated to rule out any major anatomic variation that may put the ICA at increased risk. In general, the ICA is lateral to the occipital condyle and the superior pharyngeal constrictor muscle. However, anatomic variations exist that may place the ICA at risk during this surgical approach, particularly in elderly patients and in patients with significant congenital bony deformity of the craniocervical junction.[12,15,16]

After appropriate nasal access has been carried out as previously outlined, the clivus is drilled with a 4-mm coarse diamond bur between the occipital condyles inferiorly and the lacerum segments of the ICA superiorly. Between the two layers of clival dura, the basilar plexus, which communicates with the inferior petrosal sinus and cavernous sinus, can often result in brisk bleeding that can be controlled with injectable hemostatic agents. When the basilar sinus has been invaded by tumor, the basilar plexus is often already thrombosed.

For lesions extending lateral to the occipital condyle, the anteromedial aspect of the occipital condyles may be drilled down to provide further lateral access. First, the rectus capitus anterior and the atlanto-occipital joint capsule are removed to expose the atlanto-occipital joint. The superior aspect of the condyle has a small groove, which estimates the level of the hypoglossal canal.[12] Below this groove is bone of the occipital condyle, and above this groove is bone of the jugular tubercle. The condyle can be removed down to the level of the hypoglossal canal. The inferior portion of the condyle with the alar ligament insertion is left intact as its resection provides little additional surgical exposure but can result in increased craniocervical instability.[17,18] Angled endoscopes can be used to help broaden the lateral extent of surgical exposure.[19,20] Inferior clivectomy, transection of the tectorial membrane, and resection of up to 75% of the anteromedial condyle for exposure of the anterior foramen magnum do not result in enough significant craniocervical instability to warrant fusion.[20]

CASE 52-1 Pediatric Clival Chordoma

A 10-year-old male with a history of bilateral severe to profound sensorineural hearing loss underwent an uncomplicated left cochlear implantation at 2 years of age. He subsequently represented for consideration of a right-sided implant, and during his preoperative evaluation, a history of intermittent epistaxis for approximately 2 years was noted. Given this report and the planned surgical procedure, a CT of the sinuses was obtained revealing a heterogeneous mass about the sella and clivus concerning for a clival chordoma (Fig. 52-1). An endoscopic endonasal resection was planned.

The patient was placed supine with the head in neutral position on a gel headrest. Stereotactic image guidance was utilized, and the nasal cavities were prepared with pledgets soaked with a topical vasoconstrictor. The inferior turbinates were then lateralized and the right middle turbinate was removed, allowing easy visualization of the sphenoid rostrum. A right-sided nasoseptal flap was then harvested with cold instruments, as monopolar cautery is contraindicated in the presence of a cochlear implant. Once harvested, a small right maxillary antrostomy was performed and the flap was tucked into the right maxillary sinus for future use. To facilitate a two-surgeon, four-handed approach, a posterior septectomy was performed. Wide bilateral sphenoidotomies were then performed to allow a panoramic view of the planum, tuberculum, sella, clival recess, and clivus.

With this view obtained, the mucosa of the sphenoid was stripped to improve visualization of the osseous anatomy. The bone of the inferior sella, clival recess, and clivus was progressively thinned using a 4-mm rough diamond bur until the dura was exposed. Given the location of the mass, the medial aspect of the right carotid canal extending from the posterolateral aspect of foramen lacerum to the paraclival segment was progressively drilled to expose the ICA (Fig. 52-2).

Given that the lesion extended to the dorsum sella, the posterior clinoids were removed. A dense osseous ring between the bilateral posterior clinoids was noted, thereby requiring midline transection of the dorsum sella to facilitate delivery of each posterior clinoid separately (Fig. 52-3). The sella and clivus were then reconstructed with the previously harvested right nasoseptal flap (Fig. 52-4). Postoperative imaging confirmed complete removal of the previously visualized mass (Fig. 52-5).

CASE 52-2 Basilar Impression

A 67-year-old female with a remote history of an upper aerodigestive tract squamous cell carcinoma treated with primary radiotherapy presented with progressive upper extremity weakness, muscular wasting, fatigue, and cervical pain. Given these progressive symptoms, she was extremely deconditioned and wheelchair bound. Examination at the time of presentation revealed upper extremity weakness and muscle wasting, with sequelae of her prior radiation therapy including 1-cm trismus and xerostomia. Radiographic studies were obtained revealing basilar impression with severe narrowing of the spinal canal (Fig. 52-7). An endoscopic transnasal odontoidectomy was planned given that it was the most direct surgical approach combined with the fact that the patient's trismus made her a poor candidate for a transoral approach.

After appropriately positioning the patient with the use of stereotactic image guidance and neurophysiology monitoring as previously described, the nasal cavities were prepared with pledgets soaked with a topical vasoconstrictor. The inferior and middle turbinates were then lateralized bilaterally, allowing easy visualization of the nasopharynx. To facilitate a two-surgeon, four-handed approach, an inferior posterior septectomy was performed preserving the posterior septal artery pedicle. This expanded the surgical working space and allowed clear visualization of the nasopharynx.

After obtaining the initial exposure, the nasopharyngeal mucosa and underlying paraspinal muscles were incised in the midline and lateralized, allowing visualization of the inferior clivus, atlanto-occipital membrane, and anterior arch of C1. A high-speed drill with a 4-mm coarse diamond bur was then used to drill the inferior clivus. Given the anatomic changes secondary to basilar impression, the dens was located just posterior to the inferior clivus that had been removed. The anterior arch of C1 was then progressively drilled to allow access to the dens (Fig. 52-8). Once the anterior arch of C1 was removed, visualized preodontoid fibrosis was removed, allowing view of the dens. The dens was then progressively cored with maintenance of the outer cortex of the cap. The cap was then thinned and removed, resulting is excellent decompression as confirmed by pulsations of the thecal sac (Fig. 52-9). No cerebrospinal fluid (CSF) leak was encountered during this dissection, and the wound was then left to heal by secondary intention. Given that the anterior decompression resulted in expected instability, a posterior fusion was sequentially performed in the same operative setting. Postoperative imaging confirmed excellent decompression (Fig. 52-10).

ENDOSCOPIC TRANSNASAL ODONTOIDECTOMY APPROACH

The primary advantage of the endoscopic transnasal approach to the dens over the transoral approach is the preservation of the soft palate and retropharyngeal soft tissues, which allows patients to be fed on the first postoperative day.[11,21,22] In the transoral approach, prolonged retraction of the soft palate can lead to loss of retropharyngeal soft tissue volume, impaired muscle movements, or even palatal scarring, all of which can result in velopalatine insufficiency. Preoperative evaluation includes radiographic evaluation with MRI and CT. On sagittal imaging, a line drawn from the anterior inferior nasal bone through the posterior aspect of the hard palate—the nasopalatine line—can predict the caudal limit of exposure of the upper cervical spine (Fig. 52-6).[23]

RECONSTRUCTION

The most significant limitation of endonasal endoscopic approaches is the risk of postoperative CSF leak. Since the advent of the vascularized nasoseptal flap, the incidence of postoperative CSF leak has decreased dramatically.[24,25] Of particular importance in endoscopic endonasal approaches to the craniocervical junction is that a nasoseptal flap is made large enough to reach the caudal limit of the defect. The caudal cut of the nasoseptal flap can be extended inferiorly to the nasal floor or even inferolaterally to include the mucosa of the inferior turbinate.[26]

Multiple reconstruction techniques exist. Generally, the dural defect is first covered with an inlay dural substitute or autologous free graft (e.g., fascia lata). The vascularized flap is placed over the graft with care to make sure the flap is in

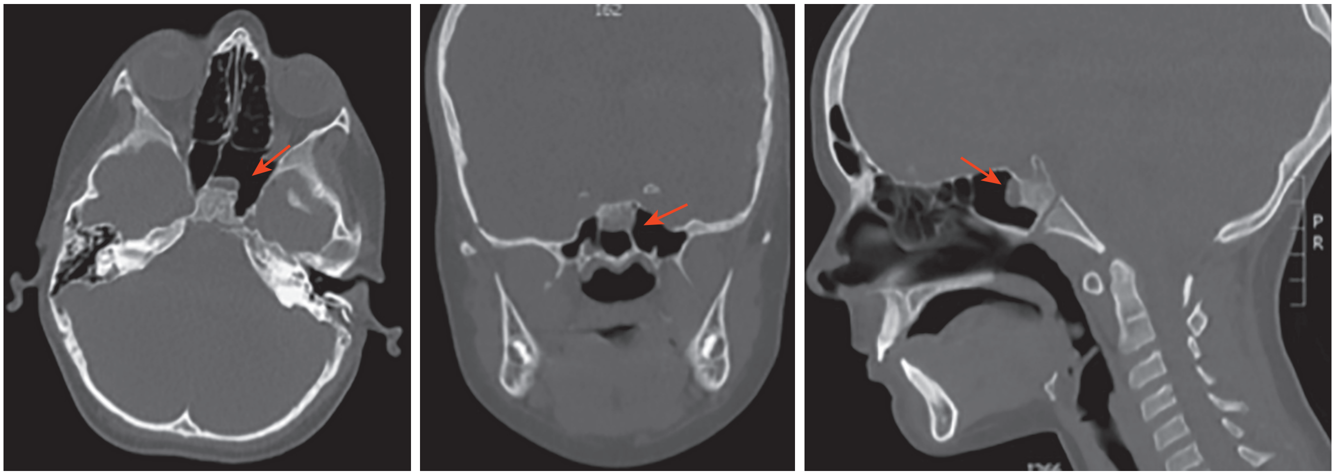

Figure 52-1. Preoperative computed tomography (CT) scan revealing a heterogenous mass involving the inferior sella, clival recess, and clivus.

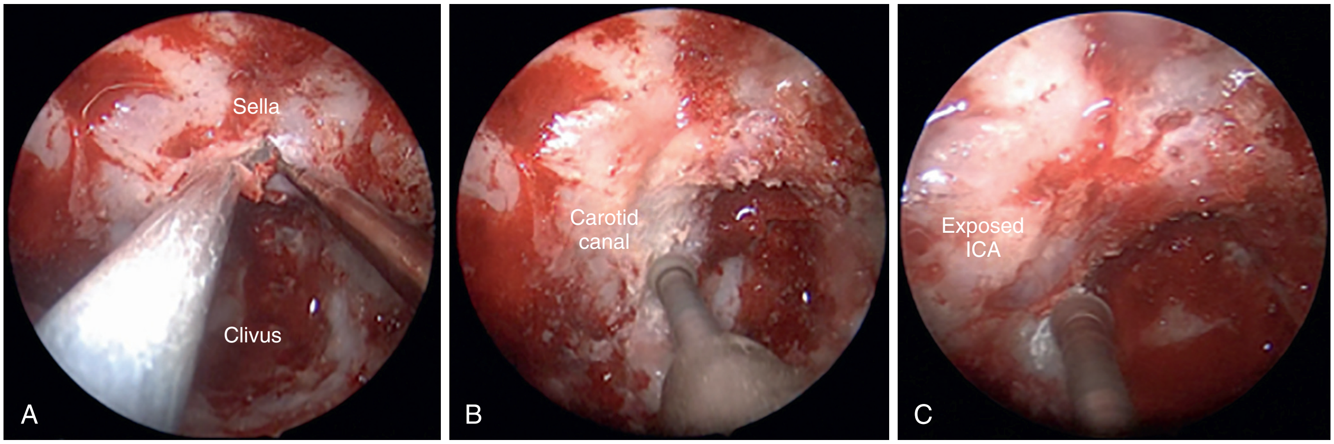

Figure 52-2. A, After progressive thinning of the inferior sella and clivus the underlying dura is exposed. **B,** The medial aspect of the carotid canal beginning at the posterolateral aspect of foramen lacerum to the paraclival segment is progressively thinned and exposed. **C,** Completion of right internal carotid artery (ICA) exposure.

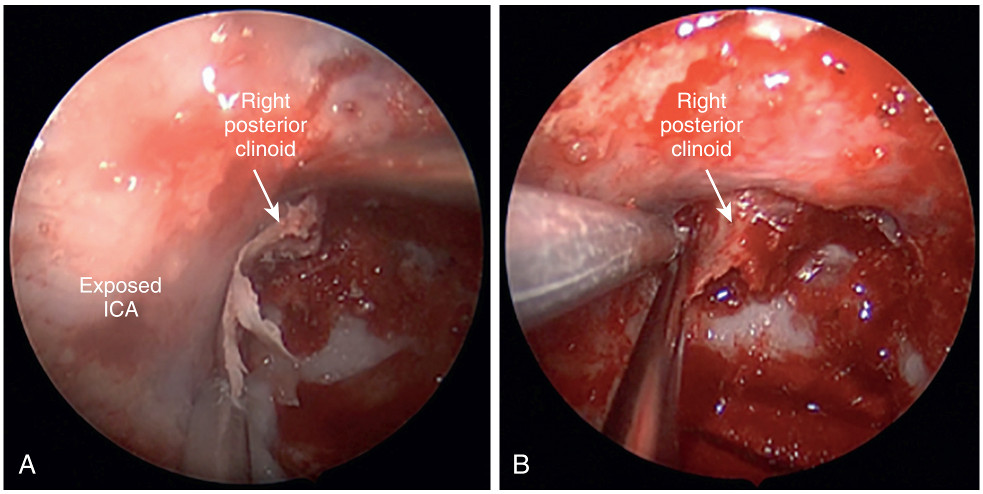

Figure 52-3. A, Dissection around the paraclival internal carotid artery (ICA) to the dorsum sella and exposure of the right posterior clinoid. **B,** Presence of an osseous posterior clinoid ring (not seen) does not allow delivery of the posterior clinoid.

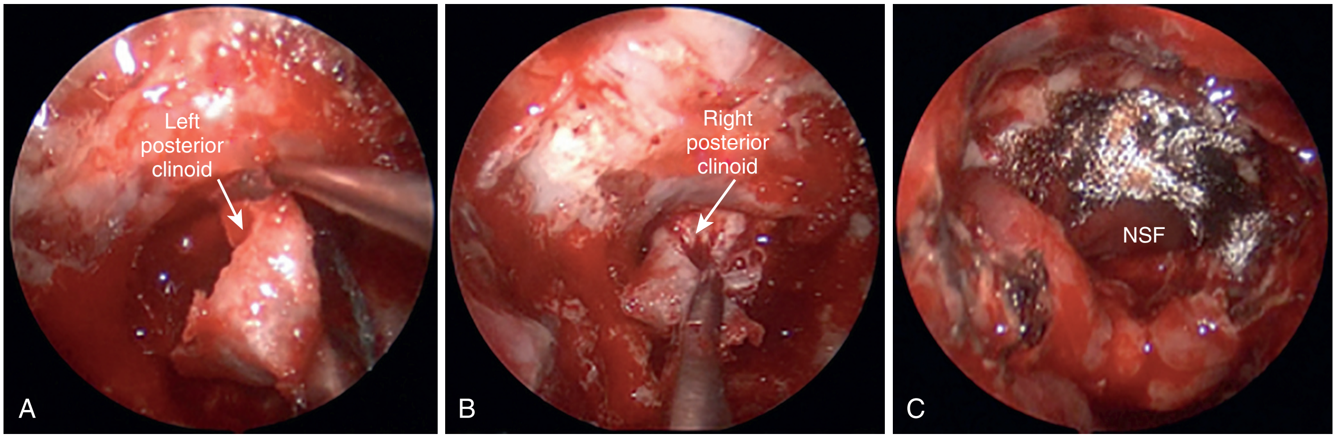

Figure 52-4. **A** and **B,** After progressive thinning of the dorsum sellae with the high-speed drill, the left posterior clinoid is delivered, followed by the right posterior clinoid. **C,** The previously harvested nasoseptal flap (NSF) is then mobilized from the right maxillary sinus and used to reconstruct the resultant skull base defect.

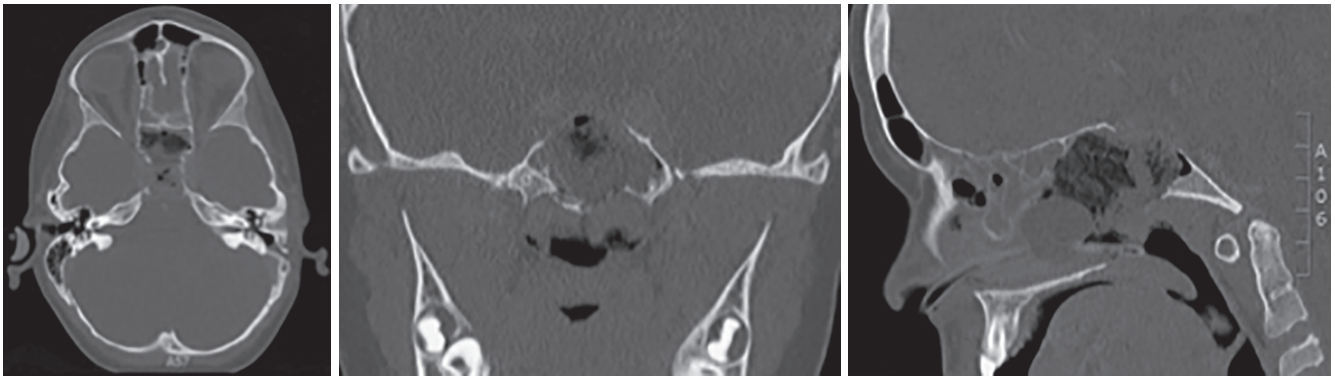

Figure 52-5. Postoperative computed tomography (CT) scan demonstrating complete resection with associated dissection of the sella and clivus.

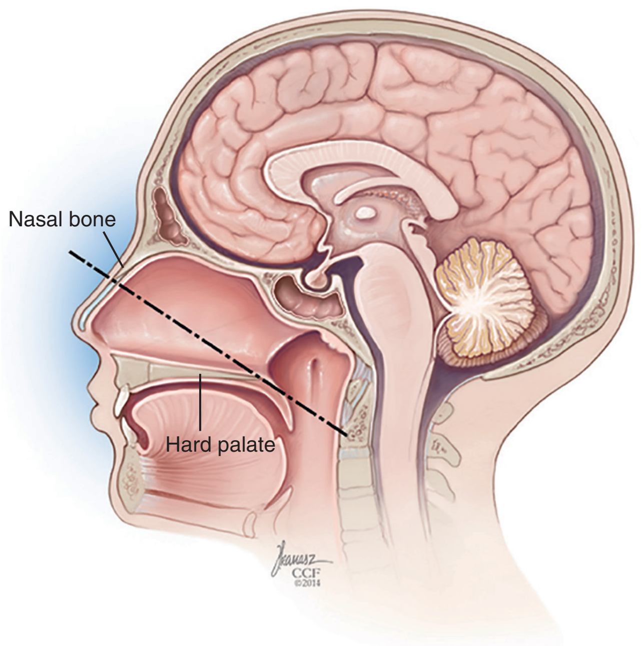

Figure 52-6. The nasopalatine line, drawn from the inferior nasal bone to the posterior aspect of the hard palate and extended to the cervical spine, predicts the caudal extent of exposure. *(With permission from Cleveland Clinic Foundation.)*

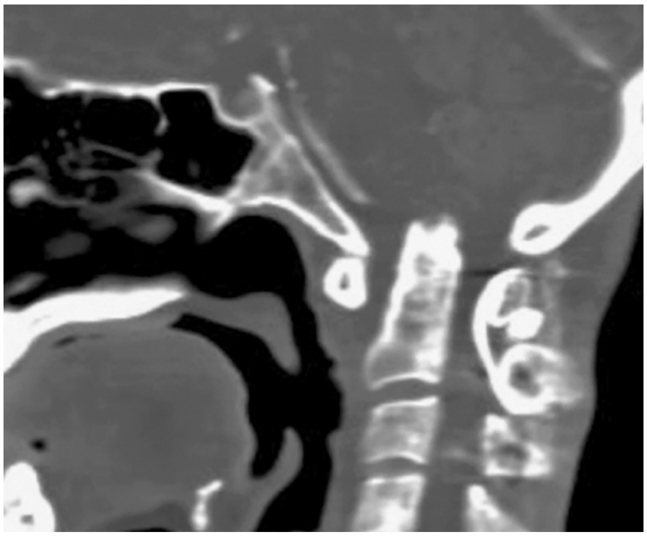

Figure 52-7. Preoperative imaging revealing significant basilar impression and increased atlantodens interval with resultant severe narrowing of the spinal canal.

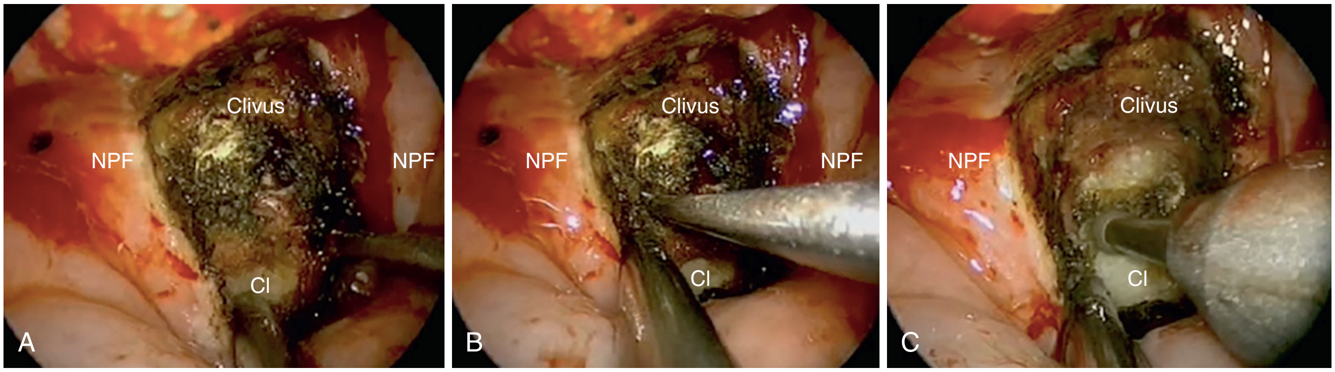

Figure 52-8. A, Visualization of the inferior clivus and anterior arch of C1 with lateralization of the nasopharyngeal mucosa and paraspinal musculature, or nasopharyngeal flap (NPF). **B,** Further view of the inferior clivus and anterior arch of C1 with instruments placed on the atlanto-occipital membrane. **C,** Initial drilling of the inferior clivus and anterior arch of C1.

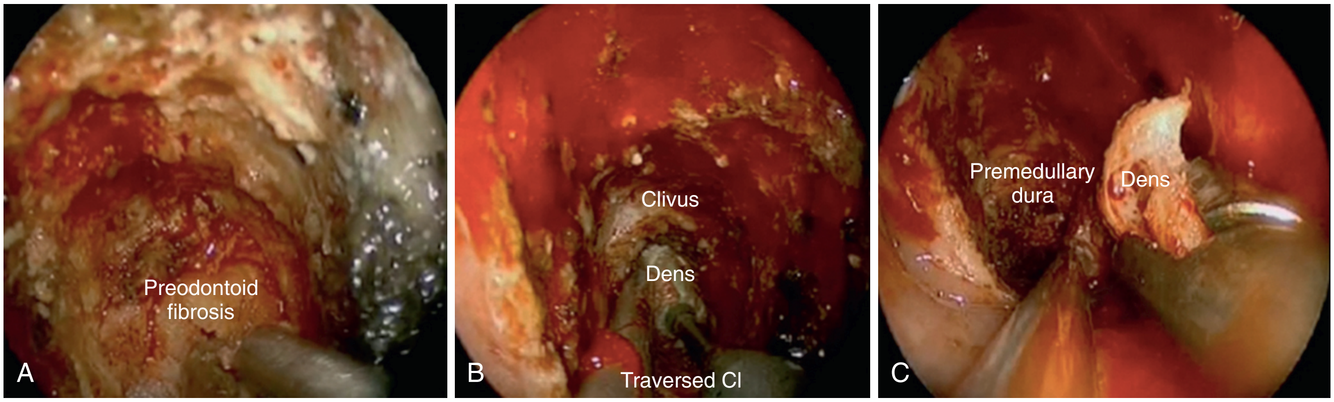

Figure 52-9. A, Visualization of preodontoid fibrosis following transgression of the anterior arch of C1. **B,** Progressive coring of the dens with maintenance of the dens cap. **C,** Removal of the thinned dens cap and visualization of the decompressed premedullary dura.

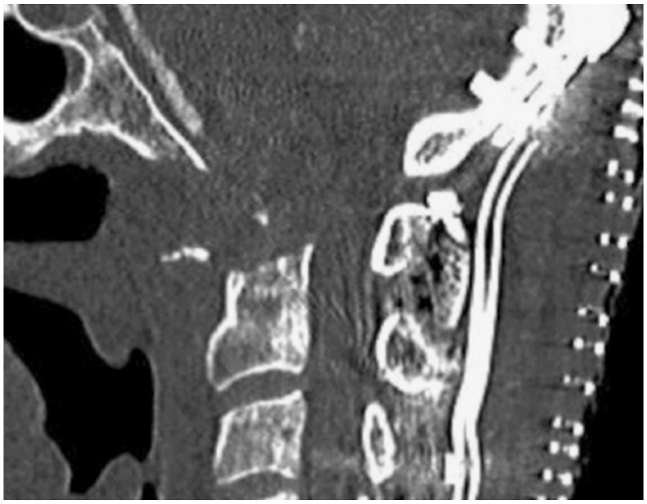

Figure 52-10. Postoperative imaging demonstrating odontoidectomy and complete decompression.

contact with surrounding bony margins. Adherence of the graft to the bone is augmented with either oxidized cellulose (Surgicel, Ethicon, Somerville, NJ) or dural sealant. A large clival bony defect may be filled with autologous fat graft. Finally, the nasal cavity is filled with absorbable or nonabsorbable packings. When a CSF leak is not encountered, the wound can be left to heal by secondary attention.

POSTOPERATIVE CARE

Patients are kept on bed rest for 24 hours postoperatively with the head of bed elevated to 30 degrees, after which patients are actively mobilized. Nasal packings are left in place for 5 to 7 days and removed at the follow-up visit. Patients are advised to avoid sneezing, blowing the nose, bending over, and bearing down for 4 weeks after surgery. A nasal saline spray is applied four to five times per day, and an antibiotic ointment is placed in the nose twice daily to reduce crusting.

DISCUSSION

One of the misconceptions of transnasal approaches to intradural pathology is the perception that there might a higher infection rate given the contamination within the nasal cavity. However, large series have demonstrated rates of postoperative infection similar to transcranial routes.[27] With the transoral approach, intubation is frequently required for 3 to 4 days postoperatively until oral swelling subsides and feeding via a nasogastric tube is utilized for 5 days.[28] With the transnasal approach, early extubation and feeding may decrease the risk of postoperative complications. One large study of more than 500 transoral operations demonstrated a postoperative complication rate of 29.2% in cases without soft palate splitting and 34.6% in cases with soft palate splitting.[29]

Another potential concern with transnasal approaches is the ability to obtain hemostasis. Techniques, hemostatic agents, and specialized instrumentation designed for endoscopic, endonasal procedures including the use of diamond burs, injectable hemostatic agents, warm irrigation, and pistol grip bipolar devices have all made hemostasis feasible.[30-32]

Alternative anterior approaches to the craniocervical junction are worth mentioning. First, although the transoral approach will be discussed in detail in another chapter, the use of an endoscope during the transoral approach can improve visualization and angled endoscopes can help improve the surgical working area. The subjective benefit has been demonstrated in prior clinical reports.[33,34] One cadaveric study demonstrated quantitatively that the area over the posterior pharyngeal wall was significantly higher with the endoscope compared to the microscope without any compromise of surgical freedom. In addition, the area of clivus exposed without splitting the soft palate was significantly higher with the endoscope compared to the microscope.[35] Second, the endoscopic transcervical approach has been used successfully for odontoidectomy in small case series.[36-38]

CONCLUSION

The endoscopic transnasal approach provides a direct surgical route to anteriorly located lesions at the craniocervical junction. Lesions extending lateral to the lower cranial nerves cannot be fully treated via an endonasal approach. Clinical series demonstrate low rates of postoperative infection after transnasal approaches despite nasal contamination. The endoscopic transnasal odontoidectomy allows preservation of the soft palate and patients can be more rapidly extubated and started on an oral diet in comparison with the transoral approach. The vascularized nasoseptal flap has dramatically reduced the incidence of postoperative cerebrospinal fluid leak, which historically was one of the primary limitations of the endonasal approach. A collaborative effort between neurosurgery and otolaryngology employing a two-surgeon, four-hand approach is necessary to optimize patient outcomes.

KEY REFERENCES

de Almeida JR, Zanation AM, Snyderman CH, et al. Defining the nasopalatine line: the limit for endonasal surgery of the spine. *Laryngoscope*. 2009;119:239-244.

Choi D, Crockard HA. Evolution of transoral surgery: three decades of change in patients, pathologies, and indications. *Neurosurgery*. 2013;73:296-303, discussion 303-304.

Hadad G, Bassagasteguy L, Carrau RL, et al. A novel reconstructive technique after endoscopic expanded endonasal approaches: vascular pedicle nasoseptal flap. *Laryngoscope*. 2006;116:1882-1886.

Kassam AB, Prevedello DM, Carrau RL, et al. Endoscopic endonasal skull base surgery: analysis of complications in the authors' initial 800 patients. *J Neurosurg*. 2011;114:1544-1568.

Kassam A, Snyderman CH, Mintz A, et al. Expanded endonasal approach: the rostrocaudal axis. Part II. Posterior clinoids to the foramen magnum. *Neurosurg Focus*. 2005;19:E4.

Perez-Orribo L, Little AS, Lefevre RD, et al. Biomechanical evaluation of the craniovertebral junction after anterior unilateral condylectomy: implications for endoscopic endonasal approaches to the cranial base. *Neurosurgery*. 2013;72:1021-1029, discussion 1029-1030.

The complete list of references is available online at ExpertConsult.com.

REFERENCES

1. Love JG, Thelen EP, Dodge HW Jr. Tumors of the foramen magnum. *J Int Coll Surg*. 1954;22:1-17.
2. Stein BM, Leeds NE, Taveras JM, et al. Meningiomas of the foramen magnum. *J Neurosurg*. 1963;20:740-751.
3. Arnautovic KI, Al-Mefty O, Husain M. Ventral foramen magnum meningiomas. *J Neurosurg*. 2009;92(suppl 1):71-80.
4. Babu RP, Sekhar LN, Wright DC. Extreme lateral transcondylar approach: technical improvements and lessons learned. *J Neurosurg*. 1994;81:49-59.
5. Crockard HA, Sen CN. The transoral approach for the management of intradural lesions at the craniovertebral junction: review of 7 cases. *Neurosurgery*. 1997;28:88-97, discussion 97-98.
6. George B, Lot G. Anterolateral and posterolateral approaches to the foramen magnum: technical description and experience from 97 cases. *Skull Base Surg*. 1995;5:9-19.
7. Miller E, Crockard HA. Transoral transclival removal of anteriorly placed meningiomas at the foramen magnum. *Neurosurgery*. 1987;20:966-968.
8. Rhoton AL Jr. The far-lateral approach and its transcondylar, supracondylar, and paracondylar extensions. *Neurosurgery*. 2000; 47(suppl 3):S195-S209.
9. Abdullah KG, Schlenk RS, Krishnaney A, et al. Direct lateral approach to pathology at the craniocervical junction: a technical note. *Neurosurgery*. 2012;70(suppl 2 Operative):202-208.
10. Kassam A, Snyderman CH, Mintz A, et al. Expanded endonasal approach: the rostrocaudal axis. Part II. Posterior clinoids to the foramen magnum. *Neurosurg Focus*. 2005;19:E4.
11. Kassam AB, Snyderman C, Gardner P, et al. The expanded endonasal approach: a fully endoscopic transnasal approach and resection of the odontoid process: technical case report. *Neurosurgery*. 2005;57(suppl 1):E213, discussion E213.
12. Morera VA, Fernandez-Miranda JC, Prevedello DM, et al. "Far-medial" expanded endonasal approach to the inferior third of the clivus: the transcondylar and transjugular tubercle approaches. *Neurosurgery*. 2010;66(suppl 6 Operative):211-219, discussion 219-220.
13. Blitz AM, Macedo LL, Chonka ZD, et al. High-resolution CISS MR imaging with and without contrast for evaluation of the upper cranial nerves: segmental anatomy and selected pathologic conditions of the cisternal through extraforaminal segments. *Neuroimaging Clin N Am*. 2014;24:17-34.
14. Atlas G, Lee M. The neural integrity monitor electromyogram tracheal tube: anesthetic considerations. *J Anaesthesiol Clin Pharmacol*. 2013;29:403-404.
15. Paulsen F, Tillmann B, Christofides C, et al. Curving and looping of the internal carotid artery in relation to the pharynx: frequency, embryology and clinical implications. *J Anat*. 2000;197(Pt 3):373-381.
16. Pfeiffer J, Ridder GJ. A clinical classification system for aberrant internal carotid arteries. *Laryngoscope*. 2008;118:1931-1936.
17. Panjabi M, Dvorak J, Crisco J 3rd, et al. Flexion, extension, and lateral bending of the upper cervical spine in response to alar ligament transections. *J Spinal Disord*. 1991;4:157-167.
18. Panjabi M, Dvorak J, Crisco JJ 3rd, et al. Effects of alar ligament transection on upper cervical spine rotation. *J Orthop Res*. 1991;9:584-593.
19. Little AS, Perez-Orribo L, Rodriguez-Martinez NG, et al. Biomechanical evaluation of the craniovertebral junction after inferior-third clivectomy and intradural exposure of the foramen magnum: implications for endoscopic endonasal approaches to the cranial base. *J Neurosurg Spine*. 2013;18:327-332.
20. Perez-Orribo L, Little AS, Lefevre RD, et al. Biomechanical evaluation of the craniovertebral junction after anterior unilateral condylectomy: implications for endoscopic endonasal approaches to the cranial base. *Neurosurgery*. 2013;72:1021-1029, discussion 1029-1030.
21. Mazzatenta D, Zoli M, Mascari C, et al. Endoscopic endonasal odontoidectomy: clinical series. *Spine*. 2014;39:846-853.
22. Ponce-Gomez JA, Ortega-Porcayo LA, Soriano-Baron HE, et al. Evolution from microscopic transoral to endoscopic endonasal odontoidectomy. *Neurosurg Focus*. 2014;37:E15.
23. de Almeida JR, Zanation AM, Snyderman CH, et al. Defining the nasopalatine line: the limit for endonasal surgery of the spine. *Laryngoscope*. 2009;119:239-244.
24. Hadad G, Bassagasteguy L, Carrau RL, et al. A novel reconstructive technique after endoscopic expanded endonasal approaches: vascular pedicle nasoseptal flap. *Laryngoscope*. 2006;116: 1882-1886.
25. Kassam AB, Thomas A, Carrau RL, et al. Endoscopic reconstruction of the cranial base using a pedicled nasoseptal flap. *Neurosurgery*. 2008;63(1 suppl 1):ONS44-ONS52, discussion ONS52-ONS53.
26. Peris-Celda M, Pinheiro-Neto CD, Funaki T, et al. The extended nasoseptal flap for skull base reconstruction of the clival region: an anatomical and radiological study. *J Neurol Surg B Skull Base*. 2013;74:369-385.
27. Kassam AB, Prevedello DM, Carrau RL, et al. Endoscopic endonasal skull base surgery: analysis of complications in the authors' initial 800 patients. *J Neurolog Surg*. 2011;114:1544-1568.
28. Menezes AH. Surgical approaches: postoperative care and complications "transoral-transpalatopharyngeal approach to the craniocervical junction." *Childs Nerv Syst*. 2008;24: 1187-1193.
29. Choi D, Crockard HA. Evolution of transoral surgery: three decades of change in patients, pathologies, and indications. *Neurosurgery*. 2013;73:296-303, discussion 303-294.
30. Kassam A, Snyderman CH, Carrau RL, et al. Endoneurosurgical hemostasis techniques: lessons learned from 400 cases. *Neurosurg Focus*. 2005;19:E7.
31. Schlegel-Wagner C, Siekmann U, Linder T. Non-invasive treatment of intractable posterior epistaxis with hot-water irrigation. *Rhinology*. 2006;44:90-93.
32. Stangerup SE, Dommerby H, Siim C, et al. New modification of hot-water irrigation in the treatment of posterior epistaxis. *Arch Otolaryngol*. 1999;125:686-690.
33. El-Sayed IH, Wu JC, Ames CP, et al. Combined transnasal and transoral endoscopic approaches to the craniovertebral junction. *J Craniovertebr Junction Spine*. 2010;1:44-48.
34. Visocchi M, Doglietto F, Della Pepa GM, et al. Endoscope-assisted microsurgical transoral approach to the anterior craniovertebral junction compressive pathologies. *Eur Spine J*. 2011;20: 1518-1525.
35. Pillai P, Baig MN, Karas CS, et al. Endoscopic image-guided transoral approach to the craniovertebral junction: an anatomic study comparing surgical exposure and surgical freedom obtained with the endoscope and the operating microscope. *Neurosurgery*. 2009;64(5 suppl 2):437-442, discussion 442-444.
36. Dasenbrock HH, Clarke MJ, Bydon A, et al. Endoscopic image-guided transcervical odontoidectomy: outcomes of 15 patients with basilar invagination. *Neurosurgery*. 2012;70:351-359, discussion 359-360.
37. McGirt MJ, Attenello FJ, Sciubba DM, et al. Endoscopic transcervical odontoidectomy for pediatric basilar invagination and cranial settling: report of 4 cases. *J Neurosurg*. 2008;1:337-342.
38. Wolinsky JP, Sciubba DM, Suk I, et al. Endoscopic image-guided odontoidectomy for decompression of basilar invagination via a standard anterior cervical approach: technical note. *J Neurosurg Spine*. 2007;6:184-191.