Craniocervical Approach: Transcervical

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Overview

The ventral craniovertebral junction (CVJ) is difficult to safely access surgically due to its deep, anatomically complex location that can be affected by diverse pathologies, including basilar invagination, congenital skull base malformations, lower clival chordomas and chondrosarcomas, metastatic diseases, rheumatoid pannus, and the intradural pathologies of meningiomas and vascular malformations [1]. The most direct and widely used approach to reach the ventral CVJ has been the ventral transoral route, introduced by Fang and Ong in 1962 [2]. The approach has been successful in its ability to directly reach the region, offering the widest view of the anatomy and the options to combine it with transfacial and/or high cervical retropharyngeal approaches to improve the narrow and deep working channel [3–11].

Currently, the standard direct approach is a transoral-transpharyngeal approach with the option to add a transmandibular route [10, 12–16] or Le Fort osteotomy [3, 17–19] for increased visualization of lesions as well as the surgical bed. However, this approach comes with significant morbidities, including postoperative bacterial meningitis, especially in the setting of intraoperative dural tears, the need for tracheostomy, dysphasia, changes in phonation, airway impairment, pharyngeal wound dehiscence, and suboptimal esthetic outcomes [20]. In addition, the operative microscope, while allowing for direct illumination of the operative field, is not well suited to this type of approach, which requires a wide range of movement and visualization beyond a narrow cone of direct light [21]. Fortunately, the endoscope has been a major advancement for this type of surgery, as it offers direct illumination and a wider panoramic view of the field [22–24]. Because its illumination is at the end of a long rod, it allows light to penetrate deeper and closer to the surgical target. In addition, it offers a field of view of approximately 80° [21, 24], providing the surgeon with a panoramic perspective. In effect, the eyes of the surgeon are brought directly into the surgical field. Its shape can be used to gently retract structures, preventing retraction-associated morbidities [1, 20]. In addition, both the endoscope and its related technology are widely available in hospitals and operating rooms.

In 2002, Frempong-Boadu and Fessler used the endoscope for an endoscopically assisted transoral approach [2], followed in 2005 by Kassam at the University of Pittsburgh with the first fully transnasal endoscopic resection of the

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odontoid [23]. Finally, it was Wolinsky et al. who completed the first endoscopic transcervical odontoidectomy for basilar invagination [21]. It is our hope that this chapter may provide neurosurgeons with an additional method of an approach to the CVJ when indicated to increase safety and improve patient outcomes.

Indications, Contraindications, and Advantages

The principal indication for a transcervical approach to the cervical spine is basilar invagination of C2, with no need for clival resection [3, 22]. The use of the endoscope limits the degree of morbidities associated with retraction [20] and has been effective in all three approaches to the CVJ [1–4, 10, 22, 24–30]. The transcervical approach also offers the benefit of familiarity—the anatomy of the exposure is familiar to neurosurgeons, which, given the narrowness of the approaches to the CVJ, leads to a significant surgical advantage. This approach also adds a new trajectory (Fig. 4.1), allowing for the resection of more caudal vertebral bodies below the odontoid and for the decompression of deeper basilar invagination [3]. This allows surgeons to treat a wider range of pathologies than with just the transoral or transnasal approach [3, 31].

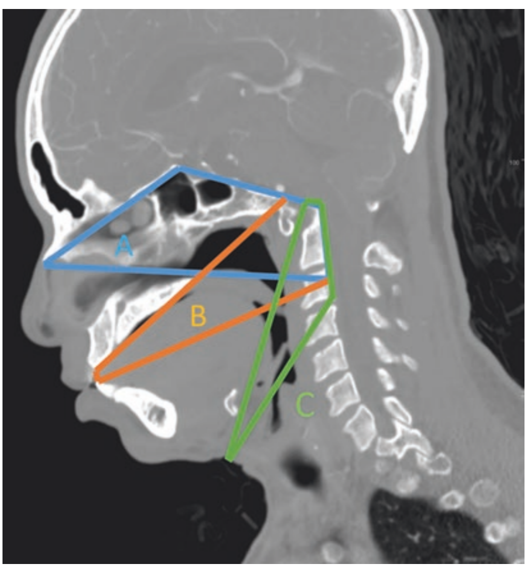

Fig. 4.1 Comparing the (A) transnasal and (B) transoral approaches to the CVJ with the (C) endoscopic transcervical approach

Another advantage of this approach is the preservation of a sterile surgical field to reduce the risk of postoperative complications [1, 3, 10, 20–22, 25]. The transoral and transnasal approaches violate the oropharyngeal and nasopharyngeal mucosa, respectively. This increases the chances of infection or wound dehiscence of the posterior pharyngeal wall secondary to the invasion of bacterial flora native to these regions [3, 6, 20, 30, 31]. The transoral approach also may require palate splitting and tongue retraction, which may require postoperative intubation for extended periods [2, 5, 6, 8, 14, 15, 20, 21, 31–36]. The transnasal approach, as mentioned, also requires crossing a cavity with bacteria, increasing the chance of postoperative meningitis in the setting of a cerebrospinal fluid (CSF) leak [20–22, 30, 31, 34, 37]. In addition, the anatomy encountered in the transoral and transnasal approaches may be less familiar to neurosurgeons and places the vidian nerves and Eustachian tubes at risk [20, 38]. The transcervical approach involves anatomy more familiar to neurosurgeons and does not violate the unsterile mucosal membranes, thereby decreasing the chance of postoperative meningitis in the case of an inadvertent or intentional breach of dura mater and subsequent CSF contamination [1, 3, 10, 20–22, 25].

In addition, patients treated with endoscopic-assisted transcervical approach were found able to ingest food orally after removal of the endotracheal tube, with a decreased need for tracheostomy and tube feeding [10, 22]. This approach also decreases the risk of postoperative phonation difficulty potentially present in the transoral approach because the soft palate is neither split nor retracted [3, 10, 20–22]. There is also no need to split the mandible or maxilla, thereby minimizing the risk of complications such as difficulty in mastication or suboptimal aesthetic outcomes [1–3, 10–12, 14, 20, 21, 25]. Although the risk of injury to the recurrent laryngeal nerve exists, it is not increased when compared with an anterior cervical approach [10].

Not all patients, however, are candidates for this approach. This trajectory may not be achieved in patients who are obese, barrel-chested, or severely kyphotic [1, 3, 10, 21]. Based on its trajectory, this approach should not be used to access the clivus and related pathologies, as accessing the lower clivus for resection requires undue retraction and is restricted by constraints of the chest on the angle of attack [3].

Clinical Materials and Methods

Surgical Preparation and Positioning

The surgical positioning for a transcervical anterior Craniocervical approach is similar to that of the anterior cervical discectomy and fusion (ACDF) but with nasotracheal intubation using a soft armored endotracheal tube rather than orotracheal intubation [1, 3, 10, 22]. The patient is positioned supine on a flat Jackson table with a shoulder roll placed behind the neck for gentle neck extension. The level of neck extension the patient can tolerate should be determined preoperatively [1]. Somatosensory evoked responses and motor evoked responses are monitored throughout the procedure. The head is fixed to the table via a halo ring attached to a Mayfield halo adaptor (Fig. 4.2a).

Two table-mounted arms are attached to the table contralateral to the surgeon: one to fix the retractor to the table and the other to hold the endoscope. They are both attached to the table caudal to the cervical spine such that they do not interfere with lateral fluoroscopy. The endoscopy monitor is contralateral to the surgeon, with the frameless stereotactic display just rostral to

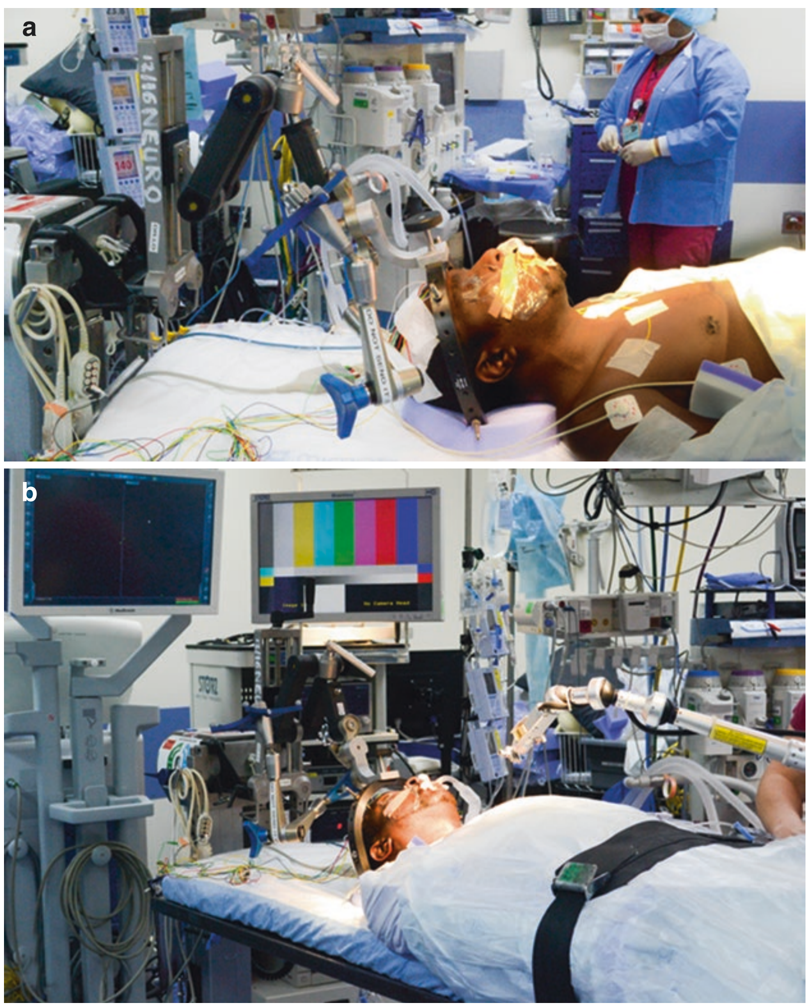

Fig. 4.2 (**a**) The head is fixed to the table using a halo ring attached to a Mayfield halo adaptor. (**b**) Final setup

Fig. 4.3 Registration for neuronavigation using O-arm

the monitor and the fluoroscopy monitor caudal to the endoscopy monitor. Reference array for the frameless stereotactic navigation system is fixed to the patient via the halo ring (Fig. 4.2b). The patient is registered intraoperatively using the Medtronic O-arm intraoperative CT (Medtronic, Minneapolis, MN, USA) and Medtronic StealthStation S7 System for navigation (Medtronic, Minneapolis, MN, USA) (Fig. 4.3) [10, 22, 26]. The neck is then prepped and draped in a sterile fashion as for an ACDF [1, 3, 10, 22]. The side of approach is determined by the handedness of the surgeon: the approach is made from the right side of the patient for a right-handed surgeon and left for a left-handed surgeon [1]. Image guidance use is flexible: because the head is fixed in place, imaging guidance selection may be based on surgeons' preference [1, 3, 10, 22].

Surgical Techniques

The standard Smith-Robinson approach to the cervical spine is used for incision and initial exposure. A transverse incision is made near the C4–C5 level starting immediately off the midline and extending approximately 4 cm laterally. Bovie cautery (Bovie Medical Corporation, Purchase, New York, USA) is used to incise underlying cutaneous and platysma muscles. To access the cervical spine, dissection is done medial to the sternocleidomastoid muscle and carotid sheath and lateral to the strap muscles. Blunt dissection aimed superiorly between plane tissues is performed with the esophagus and trachea swept medially and sternocleidomastoid muscles swept laterally, allowing access to the anterior tubercle of C1. Retraction of the esophagus may be maintained using a handheld Cloward retractor. Kitner dissectors are used to sweep open loose areolar tissue anterior to the spine, exposing the spine rostrally to the level of the C1 tubercle. A beveled, tubular retractor (Fig. 4.4a, b) is positioned flat against the spine with its most rostral tip at the anterior tubercle of C1. The position of the retractor is then confirmed using the navigation system. A soft armored endotracheal tube is utilized to allow the retractor to push the trachea to the contralateral side with minimal resistance from the tube; the armor simultaneously prevents distortion or occlusion of the endotracheal tube.

The longus colli muscles are dissected through the retractor and moved laterally off the spine to expose the ventral aspect of C2.[1] A Misonix

[1] *Vertebral Arteries*. Following the dissection of the longus colli muscles through the retractor, the ventral aspect of C2 will become exposed. The vertebral arteries lie ventral to C2, especially just rostral to the C2–C3 disc space [38]. Great care should be taken to avoid injury to the vertebral arteries during this portion of the procedure.

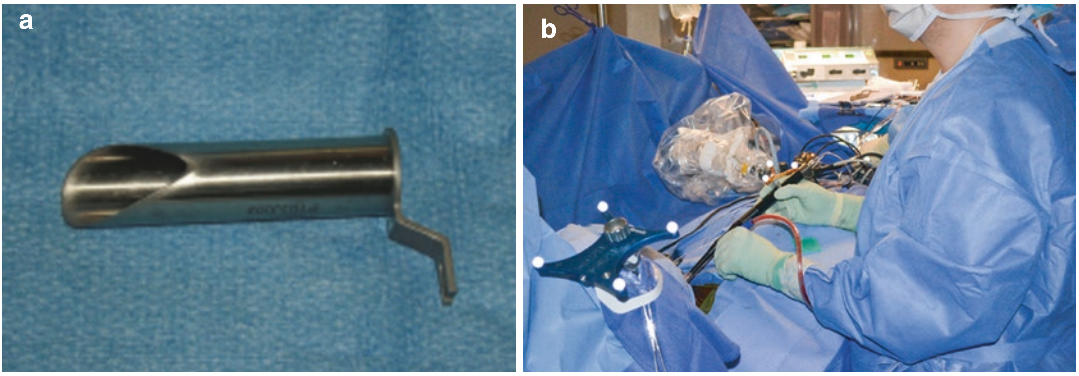

Fig. 4.4 (**a**, **b**) Beveled, tubular retractor and Medtronic Sofamor Danek METRx tubular retractor system. The retractor is modified such that the base of the tubular retractor is cut at a customizable angle, which allows the retractor to be directly attached to the spine in a stable fashion, providing an optimal view and trajectory for inserting the transodontoid screw through the base of C2 and the odontoid, while minimizing tissue retraction and offering 360° protection of the soft tissue surrounding the surgical area. In addition, if it is fixed to the table, it removes the need for an assistant to perform the retraction

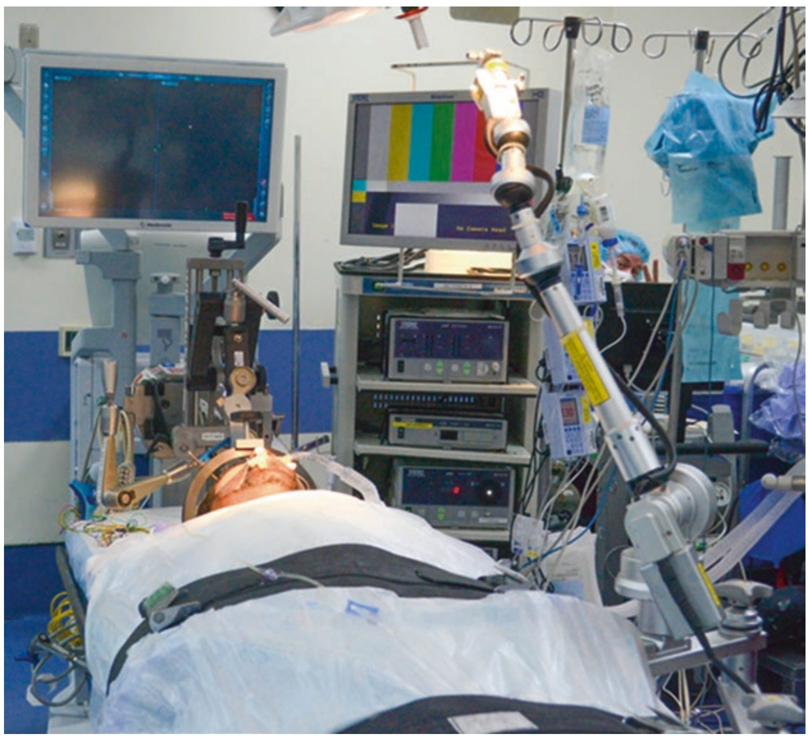

Fig. 4.5 Neuro-endoscope. An endoscope may be used free-hand or put into a holding system to let the surgeon use both hands during the procedure. A 30° 4-mm endoscope is described here, but 0, 30°-upviewing and 30-downviewing endoscopes are also available; the greater angle endoscopes may provide adequate visualization without corresponding ability to perform manual dissection [3]

BoneScalpel M.I.S. (Misonix, Farmingdale, New York, USA) is then calibrated and used in conjunction with the neuronavigation system, with the BoneScalpel recalibrating for each different drill bit and drill attachment. A 30° 4-mm neuro-endoscope is attached to the endoscope arm, where it will stay for the remainder of the operation to provide visualization down the retractor (Fig. 4.5). In order to capture a view of C2 from above, the neuro-endoscope is positioned within the retractor such that it lies flat against the retractor superior surface.

Resection begins between the posterior aspect of the anterior ring of C-1 and the odontoid. Drilling then proceeds rostrally until the tip of the odontoid is encountered. Progression of resection is continuously monitored via direct visualization through the endoscope as well as via the stereotactic neuronavigation. Once the tip of the odontoid is visualized, resection should proceed in a "top-down" fashion throughout the length of the odontoid until all bony structures are removed. A 3-mm diamond burr is then used to completely resect the remaining bone. Once the osseous resection is complete, the resection of the ligaments (transverse, alar, and apical) and any pannus, if present, should be performed, exposing the underlying dura.[2] Since the dens is completely mobile, it can be disconnected at its base and delivered in an en bloc fashion using a combination of pituitary rongeurs, curettes, and microdissectors.

Once the resection of the odontoid and the apical and transverse ligaments is complete, the cervical spine is unstable [10, 32, 33, 39, 40]. Great care is required for further transport or repositioning in the setting of a combined anterior-posterior approach. For the majority of patients, instability exists from the occiput through C2, although, in certain instances, especially those in which C1 has been assimilated into the occiput, the instability is between C1 and C2. For those patients with localized C1–C2 instability, an anterior arthrodesis is achieved using the same approach with bilateral anterior lateral mass/pedicle/transarticular screw instrumentation and fusion across the C1–C2 joints [10, 22, 41]. However, if it is not feasible due to anatomical considerations or if the instability is present more extensively, a second-stage occiput-cervical fusion is required. For further safety, a 1/8-inch Hemovac drain may be tunneled deep into the osteotomy to prevent a post-operative hematoma compressing the ventral brainstem.

The next steps depend on the nature of the procedure. The C1 ring can be left intact if only the odontoid was to be removed. However, in order to gain access to the lower clivus, the C1 ring must be removed, requiring the retractor to be angled more anteriorly to gain access to the lower clivus. Realistically, however, the angle of attack, depth of surgical field, and position of the retractor relative to the chest make this portion of the dissection difficult or impossible to achieve [3, 10, 21, 22, 34].

[2]*Apical and transverse ligaments*. These ligaments should not be resected during the odontoid resection, as they provide a protective barrier between the osseous resection and the dura mater.

Surgical Anatomy

Access Granted by Procedure and Surgical Corridors

The entry point is the midline of the skin at the C4–C5 cervical disc level [1, 3, 10, 22]. The approach theoretically permits access to the anterior tubercle of C1 superiorly and the lower cervical spine inferiorly [3]. Within the surgical field, the most superior access is the point in the middle at 1 cm above basion, and the most inferior access is the inferoposterior aspect of the body of C2, based on access using surgical trajectory through the retractor. However, this approach can technically access the cervical spine from C5 to the basion [3]. As noted by Syre and Lee, there is theoretically no lower limit because a wide cervical incision can expose the entire cervical spines through to the cervicothoracic junction (Figs. 4.6, 4.7, and 4.8) [1].

Cadaveric and image-based studies have compared the surgical corridors of the transcervical, transoral, and transnasal approaches. The actual distances to the surgical targets, however, were found to be 94 mm for the extended endonasal approach, 102 mm for the transoral approach, and 100 mm for the transcervical approach [3–11, 25]. The transcervical approach has the narrowest angle of attack, at 15°, compared to 30° for the transoral approach and 28° for the extended endonasal approach [3–11, 25]. Finally, the transoral approach offers the widest working area at 1402 mm^2, followed by the extended transnasal approach at 1305 mm^2, and the transcervical approach at 743 mm^2 [3–11, 25]. These findings are summarized in Table 4.1.

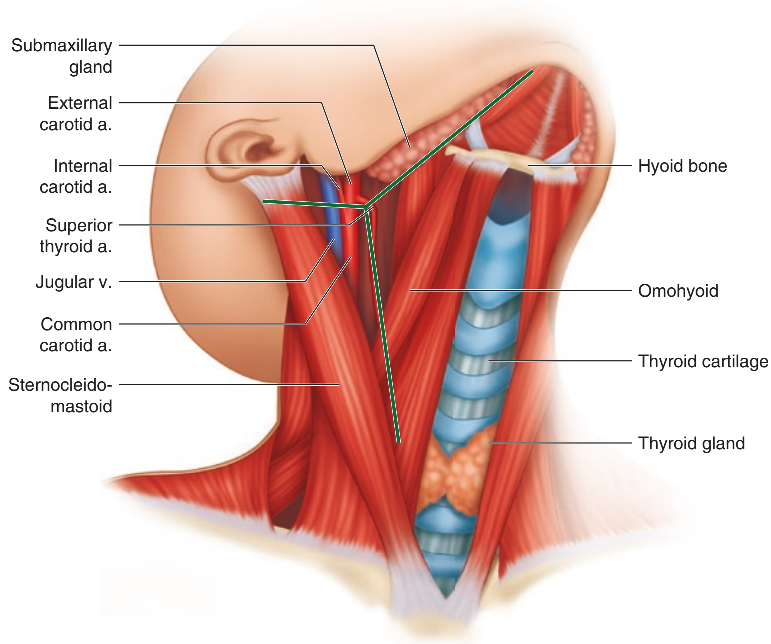

Fig. 4.6 Lateral rotation and head hyperextension for transcervical exposure. (Reproduced with permission from Stevenson et al. [49])

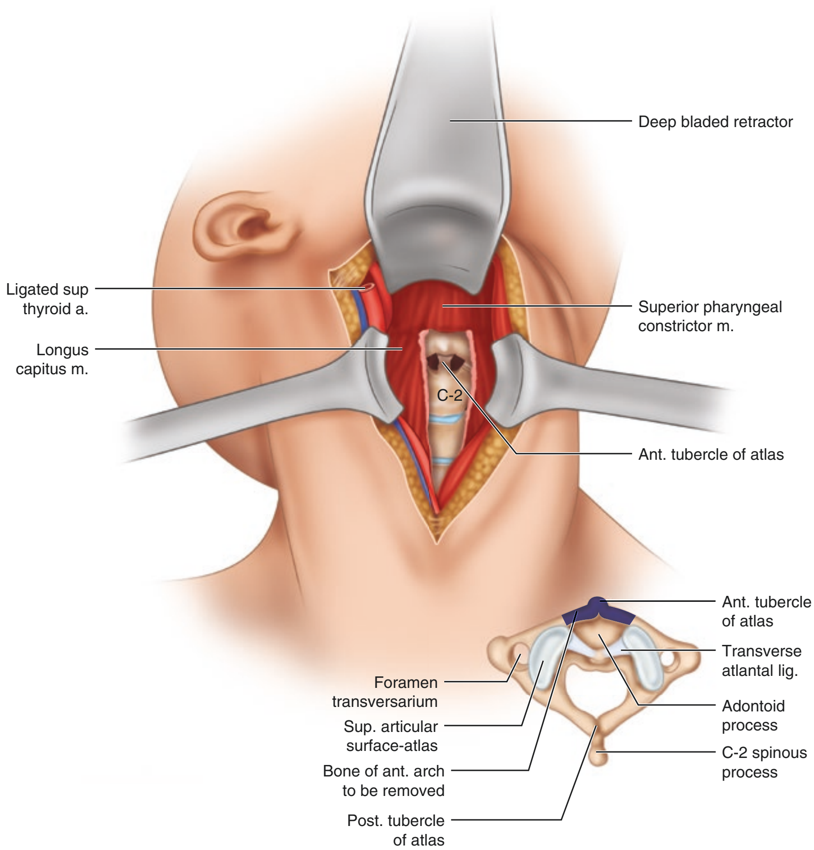

Fig. 4.7 Retraction and exposure of upper cervical spine. (Reproduced with permission from Stevenson et al. [49])

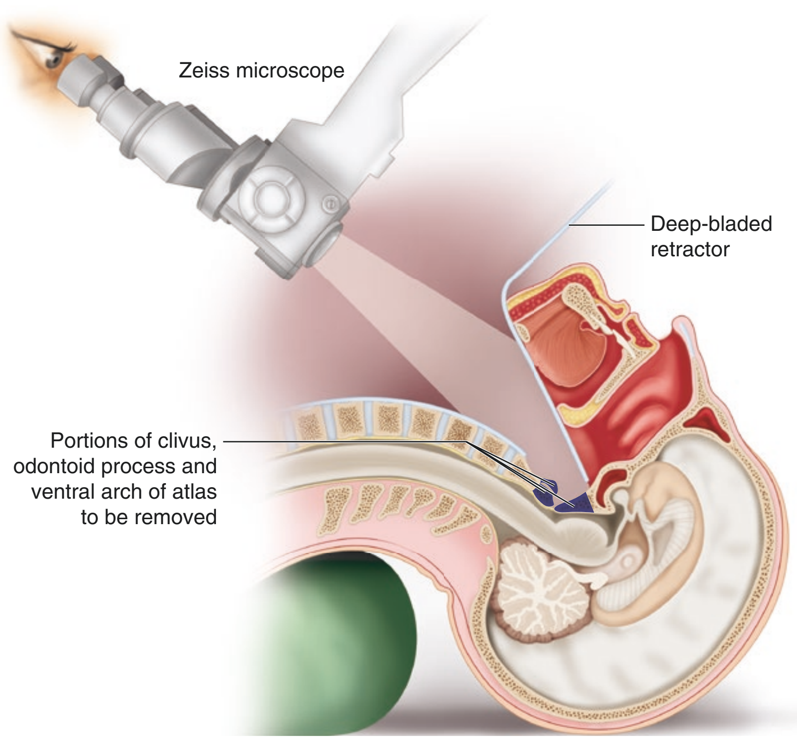

Fig. 4.8 Deep-blade retraction for visualization of the clival area with the transcervical approach. (Reproduced with permission from Stevenson et al. [49])

Table 4.1 Comparison of the features of the transcervical, transoral, and transnasal approaches to the CVJ

	Transcervical approach	Transoral approach	Transnasal approach
Distance to surgical target (mm)	100	102	94
Angle of attack (°)	15	30	28
Working area (mm^2)	743	1406	1305

Understanding the Anatomy of the Craniocervical Junction

One of the key advantages of this approach is its surgical anatomy: it mirrors that of the anterior approach to the lower cervical spine, and thus, the majority of spine surgeons are familiar with it. However, a thorough understanding of the anatomy of the CVJ adds an additional level of safety to the procedure. There are several considerations based on the anatomy of the CVJ, which will be discussed as follows:

Arteries

As mentioned in footnote 1, special attention should be paid to the vertebral arteries during this approach. The ventral aspect of C2 will become visible following the dissection of the longus colli muscles [1, 10, 42]. The vertebral arteries lie ventral to C2, especially just rostral to the C2–C3 disc space [1, 10, 38, 42]. The vertebral arteries that lie caudal to C3 lie in the transverse foramen of the cervical spine [1, 10, 22, 38, 42]. Eventually, these arteries enter the transverse process of C2, at which point the anatomy can be variable. The vertebral artery in this region may swing ventral to C2 prior to coursing laterally [10, 42]. This, in conjunction with possible craniocervical bone abnormalities of the region, may put the vertebral arteries at risk. Risk can be minimized with careful preoperative analysis using a 3D CT reconstruction in conjunction with MR imaging [10].

C1 and C2

The C1–C2 junction is intrinsically very mobile and has the potential to move even while the head is immobilized using the halo ring [10, 38]. This creates a unique challenge for both registration and accurate navigation of the three-dimensional relationship between intraoperative CT scan images and the actual surgical anatomy [3, 10, 21, 34, 38]. The patient's head should be secured to the table using the halo ring and Mayfield adaptor prior to image acquisition in order for us to minimize movement and thereby registration inaccuracy [10].

Ligaments

There are many anatomical layers between the osseous odontoid and the dura mater as well as between the dura mater and the brainstem. These include multiple ligaments providing protection to the brainstem and spinal cord; these ligaments create a boundary through which one should not drill [10, 22, 38, 43]. Immediately posterior to the dens, the transverse ligament inserts into the tubercles on the medial aspects of the lateral masses of C1 and surrounds the odontoid [10, 38]. The apical ligament lies rostrally, inserting into the tip of the dens and base of the clivus. The apical ligament is often associated with pathological conditions of the region, usually resulting in laxity (rather than destruction) of the ligaments [10]. During the approach, the apical and transverse ligaments should be resected only after completion of the odontoid resection to provide a protective barrier for the dura mater [10, 22, 43]. Finally, posterior to the apical and transverse ligaments are the vertical and horizontal ligaments and tectorial membrane; these exist as the final barrier before encountering the dura mater [10, 38]. In the case of an advanced disease, the ligaments stabilizing the dens can be thin or almost nonexistent [1, 10, 38].

Other Anatomical Structures

One of the caveats of this approach is the narrow workspace provided. Retraction, while integral to the procedure, can create potential risks [1, 3, 10, 20–22, 29]. The tubular retractor can help minimize overly aggressive retraction [10]. This may be especially useful in preventing traction injury to the digastric muscles and hypogastric nerves due to their proximity to the point of retraction [1, 38]. This, used in conjunction with a 30° endoscope placed at the superior portion of the tubular retraction, can look down on the anatomy, thus providing a familiar perspective of the head-on view of the ventral cervical spine [1, 10]. Notably, the tubular retractor does limit visualization of the surgical field through a narrow rigid corridor. Should more visualization be required, both the tubular retractor and endoscope must be repositioned [1, 3, 10, 22]. This removes the ability to visualize anatomic relationships of neighboring structures, obligating a fundamental knowledge of anatomy essential for successful surgery. As stated earlier, it is also advisable to use intraoperative frameless stereotactic navigation adjunctively to allow an appreciation of surface anatomy not seen through the endoscope and to provide feedback on the location of neural structures as they relate to the bone being resected [1, 10].

Complications

Dasenbrock et al. [22] described the outcomes of 15 patients who underwent endoscopic image-guided transcervical odontoidectomies. Of the 15 patients, 6 presented with postoperative complications, including upper airway swelling ($n = 2$), urinary tract infection ($n = 2$), dysphasia ($n = 2$), an asymptomatic pseudomeningocele ($n = 1$), and gastrostomy tube placement ($n = 1$). One patient required intubation for more than 48 h postoperatively. However, no patients presented with late neurological deterioration, bacterial meningitis, venous thromboembolic event, or need for tracheostomy. Meanwhile, McGirt et al. described the outcomes of four patients who also underwent surgery using an endoscopic transcervical approach and reported that one patient experienced subluxation in the halo vest [21, 43]. In a retrospective analysis of three patients, Wolinksy et al. found that one patient had the complication of an intraoperative CSF leak [10, 21]. Due to the limited number of clinical studies reported in the literature, further multicenter, prospective studies are warranted to better understand the benefits of this novel approach.

Discussion

When approaching the anterior cervical spine to reach the CVJ, there is no standardized approach; the transoral, transnasal, and transcervical approaches all have their own advantages and disadvantages. The transoral approach has several advantages: when combined with other approaches (e.g., Le Fort osteotomy or transmandibular-circumglossal approach), it provides a wide working area and allows for top-down drilling [2–19]. However, one of the greatest disadvantages is a contaminated surgical field, making CSF leak management significantly more difficult [21, 35, 36, 44–46]. Furthermore, it requires tongue retraction and palate splitting, which can cause several severe complications and the need for extensive postoperative intubation as elaborated earlier [2, 5, 6, 8, 14, 15, 20, 21, 31–36]. Finally, the anatomy is also less familiar to neurosurgeons in general and may require the expertise of an otolaryngologist.

The transnasal approach was developed in response to these disadvantages and also has its own set of advantages and disadvantages. It allows for top-down drilling, causes fewer retraction complications, and provides a wide working area [23, 30, 31, 37, 45, 47, 48]. However, it requires crossing a cavity with natural bacterial flora, increasing the risk of postoperative meningitis in the event of a CSF leak [20–22, 30, 31, 34, 37]. Both the transoral and transnasal approaches also place the vidian nerves and Eustachian tubes at risk, should exposure be made too wide [20, 38].

While these approaches remain ideal for treating tumors or rheumatoid disease involving the clivus through C2, the transcervical approach presents a new and potentially advantageous approach in the case of basilar invagination of C2 without clival resection [3, 22]. It proceeds through a sterile surgical field, presents familiar anatomy to spine surgeons, causes fewer retraction complications, and may decrease postoperative complications [1, 3, 10, 20–22, 25].

However, there are several drawbacks related to this technique, which includes its narrow working angles (15° compared to 30° in the transoral approach and 28° in the extended endonasal approach), long working distances (approximately 100 mm), and pharyngeal retraction, all while requiring the maintenance of a midline dissection trajectory [3–11, 21, 22, 25, 34]. It may also increase the likelihood of durotomy due to the need to pull the odontoid tip [22, 43]. However, the consequences of a CSF leak may be potentially neutralized by the sterile surgical field provided by the approach. The bony resection of the odontoid is more difficult than in the other approaches which allow the odontoid process to remain attached at the base to C2 earlier in the surgical dissection [3].

The endoscope provides surgeons with a technically feasible way to treat a wider array of pathology in the region with more flexibility and less morbidities [1, 20–24]. However, like the microscope, the endoscope only provides a two-dimensional image. This can be overcome by moving the scope and using manual palpation to provide secondary depth perception clues [1, 3, 10, 21, 22, 25, 29, 34]. Resolution of the endoscope is only as good as its attached camera and screen (in comparison to the microscope, which uses direct visualization by the human retina, with resolving power greater than the best high-definition video) [1, 3, 10, 21, 22, 24, 25, 29, 34]. Rapid improvements in video technology and the current phasing-in of three-dimensional endoscopes will hopefully solve this problem in the future.

Multiple approaches provide spine surgeons the opportunity to personalize their surgical approach in order to optimize the effectiveness of surgery and maximize patient safety. The appropriate surgical exposure varies and is based on the surgical pathology, operative objective, medical history, and the surgeon's experience. We hope to have provided insight into a new approach that may allow for easier, more sterile access to the ventral CVJ when pathology and its localization support it.

Conclusion

The endoscopic transcervical approach to the ventral CVJ can be a useful tool to safely decompress the brainstem and spinal cord while adding the extra safety feature of sterility of surgical field. It also offers the benefit of decreased recovery time by minimizing postoperative periods where patients are intubated and/or under nasogastric tubes for feeding. This procedure is contraindicated for those patients who present with pathologies predominantly at the clivus, or who are obese, barrel-chested, or kyphotic. However, in those for whom the approach is indicated, the anterior transcervical approach to the CVJ offers a useful tool in the arsenal that so far had only consisted of the transoral-transpharyngeal approach and the transnasal approach, by providing a more specific trajectory for treating pathologies of the CVJ and upper cervical spine.

References

1. Syre PLJ. Endoscopic approaches to the craniovertebral junction. In: Surgical anatomy and techniques to the spine E-book. Philadelphia: Elsevier Health Sciences; 2013. p. 60–8.
2. Frempong-Boadu AK, Faunce WA, Fessler RG. Endoscopically assisted transoral-transpharyngeal approach to the craniovertebral junction. Neurosurgery. 2002;51:S60–6.
3. Baird CJ, Conway JE, Sciubba DM, Prevedello DM, Quinones-Hinojosa A, Kassam AB. Radiographic and anatomic basis of endoscopic anterior craniocervical decompression: a comparison of endonasal, transoral, and transcervical approaches. Neurosurgery. 2009;65:158–63.; discussion 163-154. https://doi.org/10.1227/01.neu.0000345641.97181.ed.
4. Cavallo LM, Messina A, Cappabianca P, Esposito F, de Divitiis E, Gardner P, Tschabitscher M. Endoscopic endonasal surgery of the midline skull base: anatomical study and clinical considerations. Neurosurg Focus. 2005;19:E2.
5. Crockard HA. The transoral approach to the base of the brain and upper cervical cord. Ann R Coll Surg Engl. 1985;67:321–5.
6. Crockard HA. Transoral surgery: some lessons learned. Br J Neurosurg. 1995;9:283–93.
7. Hadley MN, Spetzler RF, Sonntag VK. The transoral approach to the superior cervical spine. A review of 53 cases of extradural cervicomedullary compression. J Neurosurg. 1989;71:16–23. https://doi.org/10.3171/jns.1989.71.1.0016.
8. Mummaneni PV, Haid RW. Transoral odontoidectomy. Neurosurgery. 2005;56:1045–50. discussion 1045-1050
9. Spetzler RF, Hadley MN, Sonntag VK. The transoral approach to the anterior superior cervical spine. A review of 29 cases. Acta Neurochir Suppl. 1988;43:69–74.
10. Wolinsky JP, Sciubba DM, Suk I, Gokaslan ZL. Endoscopic image-guided odontoidectomy for decompression of basilar invagination via a standard anterior cervical approach. Technical note. J Neurosurg Spine. 2007;6:184–91. https://doi.org/10.3171/spi.2007.6.2.184.
11. Youssef AS, Guiot B, Black K, Sloan AE. Modifications of the transoral approach to the craniovertebral junction: anatomic study and clinical correlations. Neurosurgery. 2008;62:145–54.; discussion 154-145. https://doi.org/10.1227/01.neu.0000317386.99055.3f.
12. Arbit E, Patterson RH Jr. Combined transoral and median labiomandibular glossotomy approach to the upper cervical spine. Neurosurgery. 1981;8:672–4.
13. Bertrand J, Luc B, Philippe M, Philippe P. Anterior mandibular osteotomy for tumor extirpation: a critical evaluation. Head Neck. 2000;22:323–7.
14. Delgado TE, Garrido E, Harwick RD. Labiomandibular, transoral approach to chordomas in the clivus and upper cervical spine. Neurosurgery. 1981;8:675–9.
15. Kanamori Y, Miyamoto K, Hosoe H, Fujitsuka H, Tatematsu N, Shimizu K. Transoral approach using the mandibular osteotomy for atlantoaxial vertical subluxation in juvenile rheumatoid arthritis associated with mandibular micrognathia. J Spinal Disord Tech. 2003;16:221–4.
16. Menezes AH, VanGilder JC, Clark CR, el-Khoury G. Odontoid upward migration in rheumatoid arthritis. An analysis of 45 patients with "cranial settling". J Neurosurg. 1985;63:500–9. https://doi.org/10.3171/jns.1985.63.4.0500.
17. Anand VK, Harkey HL, Al-Mefty O. Open-Door Maxillotomy Approach for Lesions of the Clivus. Skull Base Surg. 1991;1:217–25.
18. Balasingam V, Anderson GJ, Gross ND, Cheng CM, Noguchi A, Dogan A, et al. Anatomical analysis of transoral surgical approaches to the clivus. J Neurosurg. 2006;105:301–8. https://doi.org/10.3171/jns.2006.105.2.301.
19. James D, Crockard HA. Surgical access to the base of skull and upper cervical spine by extended maxillotomy. Neurosurgery. 1991;29:411–6.
20. Shriver MF, Kshettry VR, Sindwani R, Woodard T, Benzel EC, Recinos PF. Transoral and transnasal odontoidectomy complications: A systematic review and meta-analysis. Clin Neurol Neurosurg. 2016;148:121–9. https://doi.org/10.1016/j.clineuro.2016.07.019.
21. Visocchi M, Di Martino A, Maugeri R, Gonzalez Valcarcel I, Grasso V, Paludetti G. Videoassisted anterior surgical approaches to the craniocervical junction: rationale and clinical results. Eur Spine J. 2015;24:2713–23. https://doi.org/10.1007/s00586-015-3873-6.
22. Dasenbrock HH, Clarke MJ, Bydon A, Sciubba DM, Witham TF, Gokaslan ZL, Wolinsky JP. Endoscopic image-guided transcervical odontoidectomy: outcomes of 15 patients with basilar invagination. Neurosurgery. 2012;70:351–9.; discussion 359-360. https://doi.org/10.1227/NEU.0b013e318230e59a.

23. Kassam AB, Snyderman C, Gardner P, Carrau R, Spiro R. The expanded endonasal approach: a fully endoscopic transnasal approach and resection of the odontoid process: technical case report. Neurosurgery. 2005;57:E213; discussion E213.
24. Pillai P, Baig MN, Karas CS, Ammirati M. 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; 64:437–42; discussion 442–34. https://doi.org/10.1227/01.neu.0000334050.45750.c9.
25. Hsu W, Kosztowski TA, Zaidi HA, Gokaslan ZL, Wolinsky JP. Image-guided, endoscopic, transcervical resection of cervical chordoma. J Neurosurg Spine. 2010;12:431–5. https://doi.org/10.3171/2009.10.spine09393.
26. Ma H, Lv G, Wang B, Kuang L, Wang X. Endoscopic transcervical anterior release and posterior fixation in the treatment of irreducible vertical atlantoaxial dislocation. Eur Spine J. 2014;23:1749–54. https://doi.org/10.1007/s00586-014-3352-5.
27. Singh H, Rote S, Jada A, Bander ED, Almodovar-Mercado GJ, Essayed WI, et al. Endoscopic endonasal odontoid resection with real-time intraoperative image-guided computed tomography: report of 4 cases. J Neurosurg. 2017;128:1–6. https://doi.org/10.3171/2017.1.jns162601.
28. Yadav YR, Madhariya SN, Parihar VS, Namdev H, Bhatele PR. Endoscopic transoral excision of odontoid process in irreducible atlantoaxial dislocation: our experience of 34 patients. J Neurol Surg A Cent Eur Neurosurg. 2013;74:162–7. https://doi.org/10.1055/s-0032-1327441.
29. Yadav YR, Ratre S, Parhihar V, Dubey A, Dubey NM. Endoscopic technique for single-stage anterior decompression and anterior fusion by transcervical approach in atlantoaxial dislocation. Neurol India. 2017;65:341–7. https://doi.org/10.4103/neuroindia.NI_1276_16.
30. Yu Y, Hu F, Zhang X, Sun C. Endoscopic transnasal odontoidectomy. Sports Med Arthroscop Rev. 2016;24:2–6. https://doi.org/10.1097/jsa.0000000000000081.
31. Choi D, Crockard HA. Evolution of transoral surgery three decades of change in patients, pathologies, and indications. Neurosurgery. 2013;73:296–304. https://doi.org/10.1227/01.neu.0000430324.24623.10.
32. Di Lorenzo N. Craniocervical junction malformation treated by transoral approach. A survey of 25 cases with emphasis on postoperative instability and outcome. Acta Neurochir. 1992;118:112–6.
33. Goel A. Progressive basilar invagination after transoral odontoidectomy: treatment by atlantoaxial facet distraction and craniovertebral realignment. Spine. 2005;30:E551–5.
34. Lin ZK, Chi YL, Wang XY, Yu Q, Fang BD, Wu LJ. The influence of cervical spine position on the three anterior endoscopic approaches to the craniovertebral junction: an imaging study. Spine J. 2014;14:80–6. https://doi.org/10.1016/j.spinee.2013.06.079.
35. Menezes AH. Surgical approaches: postoperative care and complications "transoral-transpalatopharyngeal approach to the craniocervical junction". Childs Nerv Syst. 2008;24:1187–93. https://doi.org/10.1007/s00381-008-0599-3.
36. Perrini P, Benedetto N, Guidi E, Di Lorenzo N. Transoral approach and its superior extensions to the craniovertebral junction malformations: surgical strategies and results. Neurosurgery. 2009;64:331–42.; discussion 342. https://doi.org/10.1227/01.neu.0000334430.25626.dc.
37. Lee A, Sommer D, Reddy K, Murty N, Gunnarsson T. (2010) Endoscopic transnasal approach to the craniocervical junction. Skull Base. 2010;20:199–205. https://doi.org/10.1055/s-0029-1246220.
38. Türe U, Kaya AH. Surgical anatomy of the craniocervical junction. In: Pathology and surgery around the vertebral artery. Paris: Springer Paris; 2011. p. 317–28.
39. Menezes AH, VanGilder JC. Transoral-transpharyngeal approach to the anterior craniocervical junction. Ten-year experience with 72 patients. J Neurosurg. 1988;69:895–903. https://doi.org/10.3171/jns.1988.69.6.0895.
40. Sakou T, Morizono Y, Morimoto N. Transoral atlantoaxial anterior decompression and fusion. Clin Orthop Relat Res. 1984;187:134–8.
41. Hwang SW, Heilman CB, Riesenburger RI, Kryzanski J. C1–C2 arthrodesis after transoral odontoidectomy and suboccipital craniectomy for ventral brain stem compression in Chiari I patients. Eur Spine J. 2008;17:1211–7. https://doi.org/10.1007/s00586-008-0706-x.
42. Vanek P, Bradac O, de Lacy P, Konopkova R, Lacman J, Benes V. Vertebral artery and osseous anomalies characteristic at the craniocervical junction diagnosed by CT and 3D CT angiography in normal Czech population: analysis of 511 consecutive patients. Neurosurg Rev. 2017;40:369–76. https://doi.org/10.1007/s10143-016-0784-x.
43. McGirt MJ, Attenello FJ, Sciubba DM, Gokaslan ZL, Wolinsky JP. Endoscopic transcervical odontoidectomy for pediatric basilar invagination and cranial settling. Report of 4 cases. J Neurosurg Pediatr. 2008;1:337–42. https://doi.org/10.3171/ped/2008/1/4/337.
44. Dhaliwal PP, Hurlbert RJ, Sutherland GS. Intraoperative magnetic resonance imaging and neuronavigation for transoral approaches to upper cervical pathology. World Neurosurg. 2012;78:164–9. https://doi.org/10.1016/j.wneu.2011.09.020.
45. El-Sayed IH, Wu JC, Ames CP, Balamurali G, Mummaneni PV. Combined transnasal and transoral endoscopic approaches to the craniovertebral junction. J Craniovertebr Junction Spine. 2010;1:44–8. https://doi.org/10.4103/0974-8237.65481.
46. Salunke P, Sharma M, Sodhi HB, Mukherjee KK, Khandelwal NK. Congenital atlantoaxial dislocation:

a dynamic process and role of facets in irreducibility. J Neurosurg Spine. 2011;15:678–85. https://doi.org/10.3171/2011.7.spine1152.

47. Gladi M, Iacoangeli M, Specchia N, Re M, Dobran M, Alvaro L, Moriconi E, Scerrati M. Endoscopic transnasal odontoid resection to decompress the bulbo-medullary junction: a reliable anterior minimally invasive technique without posterior fusion. Eur Spine J. 2012;21(Suppl 1):S55–60. https://doi.org/10.1007/s00586-012-2220-4.

48. Hickman ZL, McDowell MM, Barton SM, Sussman ES, Grunstein E, Anderson RCE. Transnasal endoscopic approach to the pediatric craniovertebral junction and rostral cervical spine: case series and literature review. Neurosurg Focus. 2013;35:E14. https://doi.org/10.3171/2013.5.focus13147.

49. Stevenson GC, Stoney RJ, Perkins RK, Adams JE. A transcervical transclival approach to the ventral surface of the brain stem for removal of a clivus chordoma. JNS Spine. 1996;24:544–51.