Posterior midline approach to odontoidectomy: A novel method to treat basilar invagination

ABSTRACT

Background: Basilar invagination (BI) is a common malformation of the craniocervical region where the odontoid process protrudes into the foramen magnum. Surgery in this region is difficult because of the complex anatomy of the craniocervical junction. Serious life-threatening complications have been observed with previously described approaches. Therefore, we conceived a novel surgical approach that can be implemented by neurosurgeons with different skill levels to facilitate better outcomes.

Methods: We describe a new surgical technique for the treatment of BI that we used in two patients in whom cervical myelopathy and direct ventral compression of the cervicomedullary junction were confirmed through clinical and radiological findings. We present the technique of posterior odontoidectomy in a step-by-step, didactic, and practical manner with surgical tips and tricks.

Results: The resection was completed without intraoperative or postoperative complications in both cases. The patients experienced substantial neurological improvements, and full recovery was observed during the 9-month and 12-month follow-up visits after discharge. Compared with the transoral approach, our technique provides a larger decompression area.

Conclusions: We describe a novel method for the treatment of BI that was applied in two patients and suggest that the posterior approach might be a safe and effective method for ventral decompression of the craniocervical junction. Posterior odontoidectomy followed by craniocervical fixation helped achieve complete cervicomedullary decompression.

Keywords: Basilar invagination, occipitocervical fusion, odontoidectomy, posterior approach, transoral approach, ventral decompression

INTRODUCTION

The congenital or developmental and acquired bony anomalies of the craniovertebral junction are complex and may cause compression of the cervical spinal cord or medulla. This may then lead to myelopathy, intractable neck pain, and a substantial risk of deterioration of neurological function caused by trauma. Many congenital, developmental, and acquired pathologies in this region have been described.[1] Some of these pathologies are odontoid bone anomalies accompanied by ventral compression.[2,3]

Basilar invagination (BI) is a developmental or degenerative anomaly of the craniovertebral junction that results from a defect in the chondrocranium where the odontoid process projects into the foramen magnum and causes progressive neuraxial compression, which may become life-threatening.[4-7] In 1998, Goel *et al*.[8] categorized BI based on the absence (Type 1) or presence (Type 2) of a

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Chiari malformation. Later, another classification system was described depending on the presence (Type A) or absence (Type B) of clinical and radiological evidence of instability at the craniocervical junction.[9]

Depending on the degree of ventral compression of the brain stem and cranial nerves by the odontoid, various symptoms and signs may occur. BI is widely diagnosed radiologically using various landmarks and lines of the cranial base, such as Chamberlain's line,[10] McGregor's line,[11] McRae's line,[12] and Wackenheim's clival line,[13] that are visible on lateral cervical spine or skull radiographs. The anterior atlantodental interval (AADI) and basion–dens interval (BDI) have been described as the most reliable and commonly used measurements to determine atlantoaxial stability.[14,15]

The first line of treatment to reduce BI is to place the patients in traction. In cases where atlantoaxial distraction fails to achieve sufficient reduction to alleviate compression of the spinal cord based on magnetic resonance imaging (MRI) and computed tomography (CT) assessments, the treatment proceeds with ventral decompression followed by fusion and stabilization.

Although the transoral approach is accepted as the gold standard for anterior decompression of the craniocervical junction, this method has several disadvantages including a deep and narrow working space; difficulty in closing tears of the dura mater; direct communication with the nasopharynx, which creates a risk of serious infection; and the need for a second surgical procedure to stabilize the cervical spine.[16]

In 2013, Yadav *et al.* described a study on a series of 34 patients who underwent surgery using the endoscopic transoral approach for odontoidectomy. They reported disadvantages including difficulties in closure and early postoperative oral feeding, severe trismus, and contamination by bacterial flora.[17] Additionally, most patients in this series continued to experience swallowing difficulties for 2–3 weeks. Seker *et al.* compared the endoscopic transnasal and transoral approaches to the craniovertebral junction and summarized the common disadvantages of the transoral approach: longer working distance; possible increased risk of meningitis; tongue swelling and necrosis; splitting of the soft and hard palates, tongue, or mandible; hypernasal speech; nasal regurgitation; velopharyngeal insufficiency; and an increased risk of requiring a tracheotomy.[18]

The commonly preferred transoral approaches or extended variations for anterior odontoidectomy employed to surgically treat BI carry risks of complications, such as wound dehiscence, persistent dysphagia after the pharyngeal dehiscence, retropharyngeal infection, hypernasal voice and nasal regurgitation, cerebrospinal fluid (CSF) leakage, tongue swelling, tracheal swelling, prolonged intubation, velopharyngeal insufficiency, dysphagia, dysphonia, swallowing difficulty requiring gastrostomy, and bacterial infection.[19-21]

Although the approaches for the surgical treatment of BI vary, the common goal of these techniques is to achieve ventral decompression of the cervicomedullary junction. In current neurosurgical practice, posterior midline craniocervical surgeries are one of the most common interventions performed for various pathologies.

We present a new posterior surgical approach to perform ventral decompression and odontoidectomy that we used in two BI patients with the aim of avoiding complications of the anterior approach. This approach offers the advantages of a wide exposure, a short and sterile surgical corridor, and the ability to perform craniocervical fixation during the same surgery with no change in the patient's position. We preferred this approach because of our greater experience with the posterior surgical anatomy of the craniocervical region. Therefore, we suggest the posterior approach for odontoidectomy to neurosurgeons who are less experienced with the transoral approach.

METHODS

Informed consent including parental consent for the minor patient was obtained before the surgical procedure and for participation in the follow-up.

The preoperative and postoperative assessments included neurological examinations and determination of the modified Japanese Orthopedic Association (mJOA) scores.[22] The radiological findings and measurements before and after surgery were evaluated and reviewed by two neurosurgeons (KE and SS) to ensure correct diagnosis and appropriate management. MRI and CT scans were used to determine the preoperative measurements of Chamberlain's, McGregor's, McRae's, and Wackenheim's lines [Table 1]. Preoperative CT angiography was performed to visualize the course of the vertebral arteries. All procedures were performed by the senior author (ID).

We applied the technique to two patients:
1. A 26-year-old man presented with a 1-year history of progressive pain in the neck and both arms, weakness of his arms and legs, and numbness and tingling in the

fingers. He reported difficulty with fine motor tasks, electric shock-like pain associated with neck flexion, and deterioration in his ability to walk.

Neurological examination revealed a score of 4/5 strength in his upper and lower extremities according to the Manual Motor Strength Grading Scale[23] with bilateral positive Hoffmann[24] and Babinski[25] signs and generalized hyperreflexia. His gait was wide based and slightly unsteady.

The T2-weighted MRI and CT scans of the cervical spine demonstrated a posteriorly displaced odontoid process compressing the cervicomedullary junction with myelomalacia at that level [Figure 1]. The odontoid process extended 5.6 mm beyond the Chamberlain's line and compressed the upper cervical spine. The AADI and BDI were 5.5 mm and 1.7 mm, respectively.

A 9-year-old boy with a 2-week history of pain in the neck, transient numbness in all four extremities, and weakness

of his left arm after doing a somersault was referred to our department. On admission, his neurological examination revealed a manual motor strength score of 3/5 and a positive Hoffmann's sign in the left arm. Vertigo and convergence provoked by head extension were observed in the neurological examination.

The T2-weighted sagittal cervical MRI scan demonstrated basilar impression and platybasia with diffuse myelomalacia caused by severe compression of the cervicomedullary junction. The ligaments and membranes of the craniocervical region seemed intact. The axial CT image showed a hypoplastic posterior C1 ring. The tip of the odontoid process protruded 3.7 mm above the Chamberlain's line. The AADI and BDI were 9.1 mm and 8.9 mm, respectively [Figure 2].

Surgical technique
Patient positioning, preparation, skin incision, and exposure
After administering general anesthetic and intubating the patient in the supine position, all neuromonitoring devices, including those that record somatosensory evoked
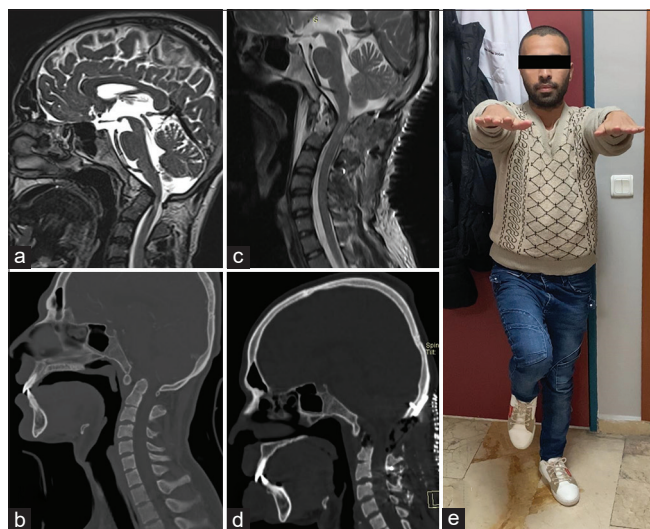
Figure 1: A 26-year-old male patient presented with a 1-year history of progressive pain in the neck, weakness of both arms and legs, and numbness and tingling in the fingers. (a and b) Sagittal T2-weighted magnetic resonance imaging and computed tomography scans demonstrate an invagination of the odontoid process through the foramen magnum with intramedullary hyperintense signals resulting from compression of the spinal cord. (c and d) Postoperative sagittal plane magnetic resonance and computed tomography images show adequate odontoidectomy and decompression of the spinal cord. (e) The patient exhibits neurological recovery at the 9-month follow-up examination
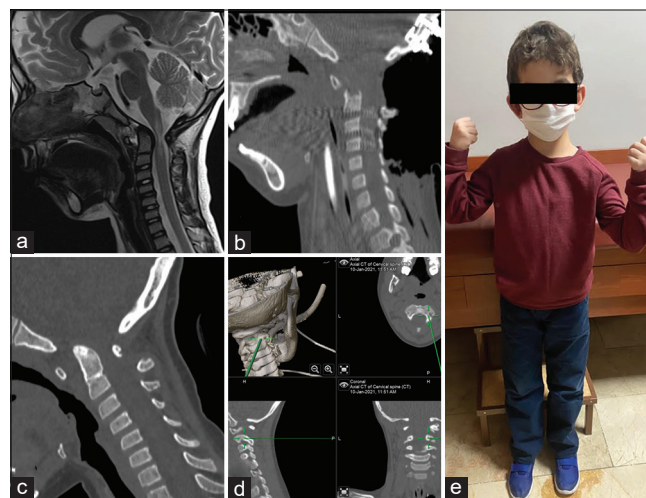
Figure 2: A 9-year-old boy presented with a 2-week history of pain in the neck, transient numbness in all four extremities, and weakness in his left arm after doing a somersault. (a) Preoperative sagittal T2-weighted magnetic resonance imaging demonstrates basilar invagination and severe compression of the brain stem. (b) Preoperative sagittal computed tomography (CT) scan showing the tip of the odontoid protruding into the foramen magnum. (c) Intraoperative CT scan demonstrating decompression of the craniocervical junction. (d) Axial, sagittal, and coronal CT navigation images indicating the basis of the odontoid process. (e) The patient shows strength recovery at the 12-month follow-up neurological examination

Table 1: Measurements and anatomical evaluation of the craniocervical junction and skull-base lines

Patient	Age (years)/sex	CL (mm)	MRL (mm)	MGL (mm)	WCL (mm)	AADI (mm)	BDI (mm)	Symptoms	Outcome	Follow-up (months)
1	26/Male	5,6	DNC	5.8	1.1	5.5	1.7	Pain in the neck and both arms, quadriparesis (4/5)	Fully recovered	9
2	9/Male	2.7	DNC	2.8	0.4	9.1	8.9	Weakness in the left arm (3/5)	Fully recovered	12

AADI - Anterior atlantodental interval, BDI - Basion-dens interval, CL - Chamberlain's line, DNC - Odontoid tip does not cross the McRae's line, MGL - McGregor's line, MRL - McRae's line, WCL - Wackenheim's clivus line

potentials, motor evoked potentials, and electromyogram, were installed. The baseline preoperative neuromonitoring values were obtained and recorded. Subsequently, the anesthesia and surgical teams coordinated the repositioning of the patient in the prone position. The preoperative neuromonitoring values were obtained again after the head was placed in a neutral position and fixed with pins in a head holder. After securing the patient's head, the antenna of the navigation system was attached to the head holder, and CT imaging was performed (Airo® mobile CT scanner; model number MobiCT-32, Mobius Imaging, Phoenix Park 2 Shirley, MA, USA) and integrated with the navigation system [Figure 3a and b]. The registration process was completed based on the CT images.

After the registration was confirmed, the surgical site was prepped and draped. A midline skin incision was made from the external occipital protuberance to the C7 vertebral prominence. The occipitocervical paravertebral muscles were dissected subperiosteally and self-retaining spreaders were installed to achieve bilateral exposure of the cervical spine laminae. After the identification of the course of the vertebral artery using intraoperative Doppler ultrasonography, the posterior arch of C1 was removed with a bone cutter (Piezo Surgystar®, DMETEC Co., Ltd., Bucheon, South Korea) under surgical microscope (Kinevo® 900, Carl Zeiss Meditec AG, Jena, Germany) guidance, and the C2 nerve roots on both

sides were exposed and protected. The pars interarticularis of C2, the inferior articular surface of the C1 lateral mass, and the atlantoaxial facet joints were sufficiently exposed bilaterally. During the C1–C2 joint exposure, we encountered bleeding from the venous plexus. We used Surgiflo® (Ethicon, Johnson and Johnson, New Brunswick, NJ, USA) on small pieces of cellulose hemostats (Surgicel®, Ethicon, Johnson and Johnson, New Brunswick, NJ, USA) and TISSEEL (Baxter Healthcare Corporation, Deerfield, IL, USA) and placed these carefully around the joint to control the bleeding.

Microscopic posterior odontoidectomy

After the C2 lamina was exposed, it was freed from the dural attachments, and the superior edge of the C2 lamina was followed in a posterior-to-anterior direction. Subperiosteal and subligamentous dissection was performed along the inner side of the C2 lamina in a medial-to-lateral and inferior-to-superior direction to avoid vertebral artery damage. The posterior longitudinal ligament was coagulated and severed. After sufficient surgical exposure was achieved, the base of the odontoid process was defined, which was confirmed with the CT-based navigation system [Figure 2d]. After the exact borders of the planned odontoidectomy were confirmed, the C2 posterior ligamentous complex was coagulated and severed to reach the odontoid process from both sides. The base of the odontoid process was identified by following the posterosuperior edge of the medial aspect of the C2 lamina
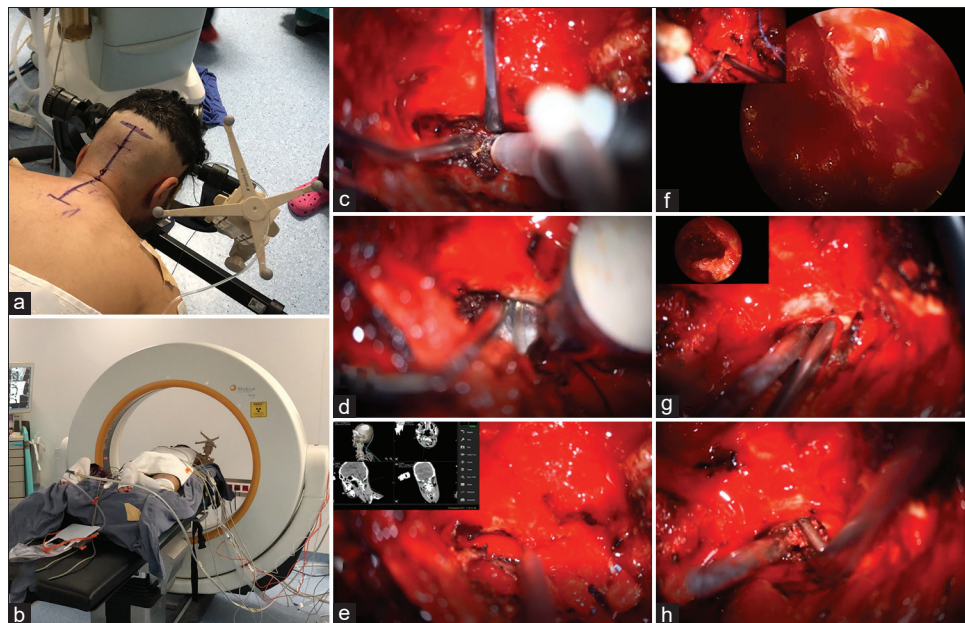
Figure 3: Illustration of a novel posterior approach to odontoidectomy in patients with basilar invagination. (a) The patient is positioned prone on the operating table, the head is fixed in a radiolucent carbon fiber clamp, midline marking is performed, and the neuronavigation system is installed, followed by the registration. (b) Computed tomography scanning is completed preoperatively to perform the image-guided procedure. Neuromonitoring modalities are also visible. (c) Bone removal of the odontoid process is initiated from the right side of the patient using the Cavitron ultrasonic surgical aspirator. (d) Odontoidectomy is continued with a bone-cutting device. (e) Location confirmation with the neuronavigation system provides safety during surgery. (f and g) Verifying the surgical trajectory with an endoscope further enhances security and confidence. (h) Completion of bone removal using punch forceps

in a posterior-to-anterior direction. The medial aspect of the pars interarticularis of C2 was identified bilaterally and followed anteriorly so that the upper cervical spinal cord was exposed circumferentially. Odontoidectomy was completed consecutively from the right and left sides with the Cavitron ultrasonic surgical aspirator (CUSA®, Integra Lifesciences Corporation, NJ, USA) and different angled tips (BS01, BS1S, and EX03) of bone cutters [Figure 3c and d]. During resection, the limits were checked periodically with the navigation system [Figure 3e]. While performing odontoidectomy on the second side, the contralateral cavity after resection provided space for an angled endoscope (Qevo®, Kinevo® 900, Carl Zeiss Meditec AG, Jena, Germany) that allows simultaneous hybrid imaging [Figure 3f and g]. After completion of endoscopy-assisted odontoidectomy, intraoperative CT imaging was performed to confirm total resection and complete ventral decompression of the craniocervical junction [Figure 3h].

Occipitocervical fixation

After odontoidectomy, occipitocervical lateral mass screw fixation was performed bilaterally with the patient in the same position, thus avoiding the need for a second surgery. We used the Magerl technique of subaxial cervical lateral mass screw fixation.[26]

RESULTS

In both patients, the technique was used without any intraoperative complications, such as dural or neurovascular injury, and the intraoperative neuromonitoring showed stable conditions.

Immediately after surgery, CT and MRI were performed in both patients to assess the achieved decompression. No additional neurological deficits were seen in the postoperative neurological examination, and neither of the patients required re-exploration. Based on the Glasgow Outcome Scale after surgery, the immediate postoperative outcomes were good in both patients.[27] They were both admitted to the intensive care unit of our department postoperatively.

The first patient was discharged from the hospital on the 3rd postoperative day without any complications, neurological deficits, or complaints during the postoperative period. At the 9-month postoperative follow-up, the patient's neurological examination was normal, and his complaints had regressed. MRI and CT scans at this follow-up revealed that the spinal canal at the level of the craniocervical junction and the foramen magnum had enlarged, and pressure on the spinal cord was relieved [Figure 1].

The second patient showed neurological improvement on the 3rd postoperative day, and he was discharged on the 5th day after an uneventful course. The neurological examination at the 12-month follow-up was normal with a 5/5 motor strength score in all four extremities. The follow-up MRI and CT scans at the time revealed a complete decompression of the cervicomedullary junction compared with that in the preoperative images [Figure 2].

The mJOA scores improved during the follow-up period compared with the preoperative and the immediate postoperative periods.

DISCUSSION

The main aims of surgical treatment for BI are (a) relieving the cervicomedullary compression, (b) restoring the stability of the craniovertebral junction, and (c) restoring normal CSF flow. Surgery of the craniovertebral junction is complex because of the difficulty in accessing the site, the critical function of the neurovascular structures in this region and their complex anatomical relationships, and various biomechanical issues.[28-30] In the face of these challenges, the surgeon needs to fully understand the problem and the method of treatment before planning and performing a surgical procedure.

Craniocervical junction anomalies are characterized by a high risk of instability and stenosis. The treatment of atlantoaxial instability with a cranially displaced odontoid process in the foramen magnum remains a challenge in neurosurgical practice. The most commonly used surgical approach is the transoral transpharyngeal approach, which is burdened with significant risks inherent to all ventral approaches, such as CSF leaks, subsequent life-threatening infection, mediastinitis, prolonged intubation or tracheostomy, need for nasogastric tube feeding, extended hospitalization, and adverse effects on phonation.

The transoral approach was first described by Kanavel[31] in 1919 to remove a bullet entrapped between the skull base and C1 and later by Scoville and Sherman[32] in 1951 for odontoid process resection in BI. In 1980, Menezes *et al*.[33] developed a treatment algorithm for craniocervical junction malformations. They distinguished between reducible and nonreducible craniocervical junction malformations and treated reducible conditions with posterior decompression and stabilization. Nonreducible pathologies were further divided into ventral and dorsal compressions. In ventrally compressed stable malformations, only transoral decompression was performed, and in ventrally compressed unstable conditions, transoral decompression

was followed by posterior occipitocervical fixation. Similarly, in dorsal compression, the authors performed dorsal decompression with or without stabilization.

In general, surgical interventions in the cranioverteberal junction entail resection or decompression and stabilization. Pathologies with a nonreducible odontoid process and atlantoaxial instability are mostly treated via an anterior transoral approach. Transoral approaches include transpharyngeal, transpalatal, transmaxillary, and transmandibular techniques.[29] Mortality rates of 2%–8% have been reported for patients undergoing transoral odontoidectomy in different studies.[34,35] The initially high surgical mortality rates observed with the anterior transoral approach have decreased over time with improving surgical techniques and technological advances.[28,30,36,37] These include retraction techniques, intraoperative imaging systems, neurophysiological monitoring, and surgical microscopes with high magnification.[28,29,36-38] However, there are several problems associated with this approach that affect the surgical results. These problems include CSF fistulae, difficult dural repair, the possibility of contamination and infection by the oropharyngeal flora, postoperative impaired mouth opening, and spinal cord injury when repositioning the patient to perform stabilization, either in the same or subsequent sessions after odontoidectomy.[3,29,36,39] Acute neurological deterioration has been reported during repositioning for posterior fusion surgery after anterior transoral decompression.[36] Furthermore, airway obstruction and respiratory problems have been reported after implementing this approach.[35,36]

Most authors recommend posterior occipitocervical fixation after ventral decompression. Goel[40] reported on three patients who underwent transoral odontoidectomy to treat BI and cervical cord compression and suffered a recurrence of their symptoms or worsening of their neurological conditions. This was attributed to congenital malalignment of the atlantoaxial joint facets and the lack of posterior occipitoaxial or atlantoaxial fixation during the procedure. More recently, Goel[41,42] also considered that there might be a dislocation of the atlantoaxial joint even without any alteration in the atlantodental interval or any dural or neural compression by the odontoid process. In their review, Tubbs *et al*.[20] summarized the major complications of transoral and transnasal odontoidectomy as CSF leakage, velopharyngeal insufficiency, wound dehiscence, pulmonary issues, meningitis, and death.

Another approach to the cranioverteberal junction is the posterolateral approach. Considering the complex anatomy

of this region and its association with the vertebral artery, this surgical approach is considered high risk.[35,43] However, mobilization of the vertebral artery has resulted in the more frequent use of this approach over time.[44] Other alternatives to approach this region include variations of the posterolateral approach, including the far lateral and extreme lateral approaches.[43,44] The far lateral approach offers surgical field visibility from the lateral to the upper cervical spine.[43,44] The extreme lateral approach provides lateral access to the anterior aspect of the cranioverteberal junction.[45,46] Although Türe *et al*.[47] reported a transatlas approach as a variant of the extreme lateral approach for odontoidectomy, they conceded that this approach only allows unilateral fixation. Variations (condylar, supracondylar, and paracondylar) of both the far lateral and extreme lateral approaches that enable greater bone resection for the required surgical field of view have also been reported.[30,43,45,46,48]

Further, Al-Mefty *et al*.[30] described a transcondylar approach to expose odontoid lesions and for nonneoplastic lesions of the cranioverteberal junction that includes the removal of the condylar surface of the atlas. This approach provides a wide field of view and allows fixation of the cranioverteberal junction in the same session, without the need for repositioning the patient or a second intervention.

Currently, there is no review, established guideline, or consensus that defines the management and surgical approach in patients with BI. We describe a new, easy-to-perform, and novel technique for odontoidectomy. We used this technique in two patients and did not encounter complications such as dural injury or CSF leakage, thus demonstrating that the odontoid process could be removed safely via the posterior approach. Furthermore, we suggest that this approach might be superior to anterior transoral approaches because of the absence of a transpharyngeal incision, lower possibility of a CSF leak, easier dural repair, and achieving the purpose in one session without the need for repositioning the patient. The posterior midline surgical approach enables bilateral access to the odontoid process and provides a wide surgical field of view for identifying critical anatomical structures. Adequate posterior decompression is possible through resection of the C1 posterior arch, and occipitocervical fixation can be performed during the same surgery without repositioning the patient, which could improve oropharyngeal wound healing and reduce the risks of contamination, infection, respiratory problems, and acute neurological deterioration.

Consequently, this surgical approach may be a valid alternative, or possibly superior to the anterior transoral and other approaches for odontoidectomy in cases of atlantoaxial

subluxation with nonreducible ventral compression. However, we must also emphasize that sound anatomical knowledge, broad experience, excellent surgical skills, and comprehensive understanding of preoperative imaging studies are indispensable qualities for any neurosurgeon to achieve good clinical outcomes.

CONCLUSIONS

We describe a novel posterior approach to odontoidectomy that may be an alternative to previously described approaches and postulate that it might be safer with regard to intraoperative complications. Additionally, we emphasize the need for stabilization in patients with BI and atlantoaxial instability. Our proposed method has to be evaluated as an initial option in terms of eliminating the potential surgical risks of anterior transoral approach and relatively short operation duration and postoperative short hospital stay.

CRediT authorship statement

Koral Erdogan: Conceptualization, methodology, and writing-original draft. Serdar Solmaz: Conceptualization, methodology, writing-reviewing, and editing. Bilal Abbasoglu: Writing-reviewing and editing. Yusuf Sukru Caglar: Supervision. Ihsan Dogan: Supervision, conceptualization, methodology, and primary surgeon.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Nil.

Conflicts of interest
There are no conflicts of interest.

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