Endonasal Endoscopic and Transoral Approaches to the Craniovertebral Junction and the Clival Region: A Comparative Anatomical Study

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■ OBJECTIVE: Anterior craniovertebral junction (CVJ) surgery has continued to be one of the most debated neurosurgical topics. The transoral approach (TOA) has been considered the choice for this region. However, it has some limitations and a not negligible degree of surgery-related morbidity. With the advent of endoscopy, the endoscopic endonasal approach (EEA) was developed, which minimized morbidity and improved exposure. To the best of our knowledge, despite the extensive reported data, a comparative anatomical study has not been performed and no definitive consensus has been reached on the indications for both approaches.

■ METHODS: We compared the TOA and EEA to the CVJ using the previously described operability score (OS), calculated at 4 different targets: the C1 tubercle (C1), the lowest exposed point of the odontoid process (C2), the basion (BS) and the middle clivus (MC). The higher the OS for the selected targets, the more favorable the approach.

■ RESULTS: The TOA had higher OSs at the MC, C1, and C2 targets, and the EEA showed greater OSs at MC and C1. The TOA and EEA had similar OSs at the BS. These results have shown that the OS is more favorable at C1-C2 using the TOA and the OSs at the MC and BS were similar.

■ CONCLUSIONS: The OS is an effective method to compare surgical approaches. The present study demonstrated the maximal exposure capability of the 2 approaches. The TOA seemed to be superior for lower targets and the EEA for upper targets. Because of the strong variability in the CVJ anatomy and pathological features, we suggest considering the OS as a further tool to better define the best surgical approach.

INTRODUCTION

Surgery of the anterior part of the craniovertebral junction (CVJ) has been one of the most debated topics in skull base surgery.[1-5] The transoral approach (TOA) has been considered the approach of choice for the treatment of lesions located in the middle to lower part of the clival bone and anterior aspect of the CVJ. However, the TOA carries the risk of potential morbidity owing to the critical neurovascular structures involved during the approach.[2,6-12] Moreover, the CVJ has great anatomical variability, mostly related to its bone development and the characteristics of the specific disease.[2,6,7,13-18] In addition, the impossibility of treating lesions located more laterally or cranially using a minimally invasive approach has been one of the main limitations of the TOA.[1-4,8,19]

To overcome this issue, the endoscopic endonasal approach (EEA) to the CVJ was developed.[14,20-25] However, even this approach could present with some limitations, such as the capability of reaching lesions located in the inferior part of the clival

Key words
- Clivus
- Craniovertebral junction
- Endoscopic endonasal approach
- Operability score
- Transoral approach

Abbreviations and Acronyms
BS: Basion
C1: C1 tubercle
C2: Lower exposed part of odontoid process
CVJ: Craniovertebral junction
EEA: Endoscopic endonasal approach
ET: Eustachian tube
MAC: Maneuverability arc
MC: Most inferior point of sphenoid sinus as reference for middle clivus
NPL: Nasopalatine line
OS: Operability score

SAA: Surgical angle of attack
TOA: Transoral approach

bone and the challenge in harvesting mucosal flaps for post-operative reconstruction.[14,20-25] Because of these findings, the selection of the best approach for clival and CVJ lesions should be individualized and tailored to the specific features.[2,8,14,24-27] The operability score (OS), as recently demonstrated, is a useful tool for comparative analysis and selecting the best approach to reach a target region according to anthropometric parameters.[28-30]

The purpose of the present cadaveric study was to compare the TOA and EEA for clival and CVJ lesions in terms of the operability at selected points.

METHODS

Ten cadaver specimens fixed with glutaraldehyde and injected with colored latex were used for the anatomical dissections. The heads were placed in the surgical position, fixed in a Mayfield head holder (Codman Neuro Inc., Raynham, Massachusetts, USA). Dissection was performed under a microscope (Zeiss OPM 1 FC [Carl Zeiss, Oberkochen, Germany]) using dedicated micro-surgical instruments. A high-speed drill was used to perform the bone drilling (Midas Rex [Medtronic, Fort Worth, Texas, USA]). In addition, a rigid endoscope, 4 mm in diameter and 18 cm in length was used, with 0°, 30°, and 45° scope lenses (Karl Storz Inc., Culver City, California, USA). Measurements were performed using a graded scale.

For each specimen and each approach, we measured the depth of the surgical field, defined as the length of the surgical corridor at the end of the procedure at the selected target points. We also measured the surgical angle of attack (SAA), which represents the angle of the incidence of the corridor in selected points. Finally, we measured the maneuverability arc (MAC) and the degree of freedom in manipulating the surgical instruments.

Four different reference points (Figure 1) exposed through the 2 approaches were selected. These were the C1 tubercle (C1), the lower exposed part of the odontoid process (C2), the basion (BS), and the most inferior point of the sphenoid sinus as a reference for the middle clivus (MC). To assess the OS for the SAA and the MAC, we selected the same cutoff values from our previous reports on the OS (60° and 45°, respectively). We selected 90 mm as the cutoff value for the depth of the surgical field.[28,30] A score of 1 was assigned if the depth of the surgical field was <90 mm, the SAA was >60°, and the MAC was >45°. A score of 0 was assigned if the depth of the surgical field was >90 mm, the SAA was <45°, and the MAC was <45°.

The recorded data were statistically analyzed using Prism software, version 5.0a (GraphPad Software Inc., La Jolla, California, USA). The P values were computed using the t test. The OS is able to quantify the surgical freedom around a target. Thus, when comparing 2 different approaches, the higher the score, the better that surgical strategy could be for the selected target.

SURGICAL TECHNIQUES

Transoral Approach

The head was placed in a neutral position and slightly extended to directly visualize the CVJ. The mouth was opened using a Crockard transoral retractor (Codman Neuro Inc.). The tongue was moved downward using a Crockard tongue blade to the retractor
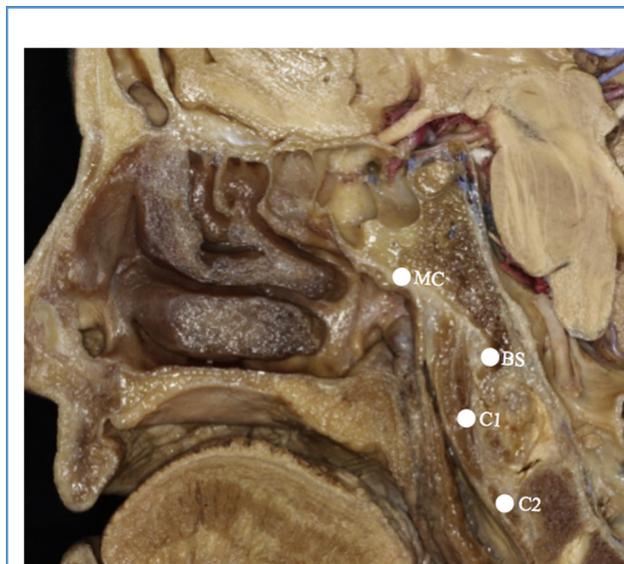
Figure 1. Sagittal section of the specimen showing the anatomical targets. BS, basion; C1, C1 tubercle; C2, lowest exposed point of the odontoid process; MC, middle clivus.

(Codman Neuro Inc.). Likewise, the proximal portion of the soft palate was moved upward using a palatal blade.

To expose the lower portion of the clivus, the distal part of the soft palate was split and moved laterally. Once the midline had been identified by palpating the C1 tubercle, a midline longitudinal incision of the posterior wall of the pharynx was performed. The longus colli and longus capitis muscles were then detached, and the anterior longitudinal ligament and anterior arch of the atlas were exposed. Next, the dissection was continued more cranially. The mucosa of the nasopharynx was incised at the midline until the inferior aspect of the sphenoid sinus was exposed and then it was moved laterally to visualize the mid-to lower clivus.

Endoscopic Endonasal Approach

The head was placed in a neutral position and slightly extended. The procedure was initiated in the right nares with the introduction of the endoscope into a nasal vestibule through a lower trajectory. The nasal septum medially and the inferior turbinate and middle turbinate laterally were the first structures visualized. The inferior margin of the middle turbinate led to the choana, which represents a landmark for the EEA.

Resection of the tail of the inferior turbinate was performed if the Eustachian tube (ET) was not properly visualized. The Rosenmüller fossa and ET represented the lateral limit of the dissection; thus, an accurate view of these structures is mandatory. The floor of the sphenoid sinus forms the roof of the nasopharynx where the pharyngobasilar fascia is attached. To expose the CVJ, the mucosa of rhinopharynx was incised along its lateral limits at the edge of the ostia of the ET and along the inferior wall of the sphenoid sinus superiorly. The mucosal layer and superior constrictor muscle at the posterior wall of the nasopharynx were

removed to expose the prevertebral muscles: the longus capitis and the rectus capitis anterior.

Behind these muscles, the anterior atlanto-occipital membrane was opened to expose the anterior ring of C1, body of C2, atlanto-occipital joint, and foramen magnum. The anterior arch of the atlas can be removed using a combination of a high-speed drill, ultrasound aspiration, and standard Kerrison rongeurs. The safety zone for our drill was between both condyles.

RESULTS

The anthropometric measurements recorded during surgical dissections and the OSs are summarized and presented in Tables 1 and 2. The average depth of the surgical field at C1 was 94.1 mm (range, 88−102) for the EEA and 82.2 mm (range, 75−88) for the TOA. The average depth of the surgical field at C2 was 104.3 mm (range, 98−112) for the EEA and 89.4 mm (range, 79−96) for the TOA. The average depth of the surgical field at the BS was 99 mm (range, 87−112) for the EEA and 94.7 mm (range, 87−101) for the TOA. The average depth of the surgical field at the MC was 82.5 mm (range, 76−90) for EEA and 82.4 mm (range, 74−89) for the TOA.

The average SAA at C1 was 60.9° (range, 49°−72°) for the EEA and 77.7° (range, 66°−97°) for the TOA. The average SAA at the C2 was 57.7° (range, 45°−70°) for the EEA and 67.2° (range, 58°−80°) for the TOA. The average SAA at the BS was 56.4° (range, 46°−64°) for the EEA and 47° (range, 33°−60°) for the TOA. The average SAA at the MC was 117.3° (range, 104°−136°) for the EEA and 84.4° (range, 72°−99°) for the TOA.

The average MAC at C1 was 59.6° (range, 49°−68°) for the EEA and 79.1° (range, 70°−97°) for the TOA. The average MAC at C2 was 58.8° (range, 51°−68°) for the EEA and 69.7° (range, 62°−80°)

for the TOA. The average MAC at the BS was 60.6° (range, 57°−64°) for the EEA and 48.4° (range, 41°−60°) for the TOA. The average MAC at the MC was 119° (range, 109°−136°) for the EEA and 80.6° (range, 72°−92°) for the TOA.

The depth of the surgical field at C1 and C2 was significantly lower (P < 0.0001) for the TOA compared with the EEA. The depth of the surgical field was quite similar at the BS and MC for both approaches. The SAA was significantly greater at the MC for the EEA and the C1 for the TOA. However, the differences for the other targets was not statistically significant. The MAC was significantly greater for the upper targets (MC and BS) in the EEA and was better for the lower targets (C1 and C2) in the TOA.

Our critical review of these data showed that the TOA seems to be a more direct approach for all 4 targets, even if the more significant depth of the surgical field was noted only for the lower targets. As expected, a more direct surgical trajectory was related to a more favorable SAA and MAC, as shown by the MC using the EEA and the C1 using the TOA. In terms of the OS, the BS showed lower results, which reflects the difficulty in operating around this target. However, the OS at MC was similar for both approaches, although in most cases, palatal splitting was needed to reach this target using the TOA.

DISCUSSION

Surgery of the anterior part of the CVJ has represented one of the most debated topics in the development of skull base surgery.[1] The selection of the surgical approach to reach the mid-to lower clivus and the anterior aspect of CVJ has continued to be greatly debated.[2,8,23,31] The TOA has been considered the approach of choice because it represents the shortest and most direct route to reach this anatomic area compared with the lateral, posterolateral,

Table 1. Measurements

Point Stratified by Approach	Depth of Surgical Field (mm)			SAA (°)				MAC (°)			
	Mean	Range	P Value	Mean	Range	SD	P Value	Mean	Range	SD	P Value
C1			<0.0001				0.0003				<0.0001
EEA	94.1	88−102		60.9	49−72	8.19		59.6	49−68	6.68	
TOA	82.2	75−88		77.7	66−97	8.64		79.1	70−97	7.43	
C2			<0.0001								0.001
EEA	104.3	98−112		57.7	45−70	8.92	0.018	58.8	51−68	6.42	
TOA	89.4	79−96		67.2	58−80	7.34		69.7	62−80	6.81	
BS			0.157				0.134				<0.0001
EEA	99	87−112		56.4	46−64	7.26		60.6	57−64	2.45	
TOA	94.7	87−101		47	33−60	8.05		48.4	41−60	5.96	
MC			0.965				<0.0001				<0.0001
EEA	82.5	76−90		117.3	104−136	8.88		119	109−136	7.97	
TOA	82.4	74−89		84.4	72−99	10.67		80.6	72−92	6.96	

SAA, surgical angle of attack; MAC, maneuverability arc; SD, standard deviation; C1, tubercle of C1; EEA, endoscopic endonasal approach; TOA, transoral approach; C2, lowest exposed point of odontoid process; BS, basion; MC, most inferior point of sphenoid sinus.

Table 2. Operability Score*

Approach	OS			
	Depth of Surgical Field	SAA	MAC	Total
EEA				
C1	0	1	1	2
C2	0	0	1	1
BS	0	0	1	1
MC	1	1	1	3
TOA				
C1	1	1	1	3
C2	1	1	1	3
BS	0	0	1	1
MC	1	1	1	3

OS, operability score; SAA, surgical angle of attack (grade); MAC, maneuverability arc (grade); EEA, endoscopic endonasal approach; C1, tubercle of C1; C2, lowest exposed point of odontoid process; BS, basion; MC, most inferior point of sphenoid sinus.

*Score definitions: depth of surgical field <90 mm, score 0; depth of surgical field >90 mm, score 1; SAA >60°, score 1, SAA <60°, score 0; MAC >45°, score 1; MAC <45°, score 0.

and posterior approaches. The TOA has been applied in the treatment of extradural and intradural lesions of the CVJ, without the need to mobilize any neurovascular structures.[1,3,4,8-10,12,14,20,22,32-40]

Transoral Approach

The pioneering works of Crockard[1] showed that the CVJ and lower clivus can be easily approached using the TOA without the need to split the soft palate. The TOA has continued to be widely used to expose the lower third of the clivus, anterior portion of the foramen magnum, and the C1-C2 complex.[2] This region is characterized by large individual anatomical variations, such as basilar invagination and other congenital abnormalities, which can change the relative position of the clivus, C1, and odontoid.[2,3,12] Furthermore, the anatomy can be distorted by the pathological lesion itself, making the surgical exposure and identification of anatomical landmarks extremely challenging.[31]

One of the main drawbacks of the TOA has been the limitation in the lateral exposure in terms of visualization of occipital condyles, mostly owing to the bulk related to the presence of the palatine tonsils.[8] In the case of upper clival or paraclival lesions with lateral extension, modified Le Fort I maxillotomy with medial and posterior antrectomy and removal of the pterygoid plates to improve the lateral extension has been proposed.[41] Another anatomical limitation has been the rate of mouth opening. In cases of a narrow interdental space, the rostral or caudal exposure could be more challenging owing to the presence of the hard palate superiorly and the mandible and tongue inferiorly.[1-3,9,22,32,34,42-44]

By splitting the soft and hard palate, it is possible to improve the area of exposure of the middle to lower clivus and the superior aspect of the CVJ, especially on the sagittal plane. However, these maneuvers could increase the risk of approach-related morbidity.[1,2,8,12,20,31,32,43,45] Palatal extensions of the TOA will be indicated in cases of clival lesions located above the palatal line.[1,2,46] For the TOA, we calculated an OS of 3 for the C1, C2, and MC and 1 for the BS (**Table 2**).

In the anatomical study by Balasingam et al.,[6] the addition of splitting of the soft palate to the standard TOA provided an additional 50% of clival exposure. However, this increase was not related to greater surgical freedom compared with the standard procedure.[6] Balasingam et al.[6] reported that splitting of the soft palate can be avoided by lifting the palate into the nasopharynx, although this maneuver will not improve accessibility to the CVJ.

To preoperatively define the potential surgical exposure obtained by the TOA, it is essential to define the anatomical conformation of the CVJ on sagittal computed tomography scans, which could help in understanding the relationship of the clivus, odontoid, soft and hard palate, and the axis (**Figure 2A**).[13,46]

Two anatomical lines should be considered: the Wackenheim line (**Figure 3A**), which corresponds to the contour of the caudal extension of the clivus, and the McGregor line, which corresponds to the line running from the hard palate to the lowest point of the occipital curvature on the midline (**Figure 3B**).[16] The Wackenheim line and the posterior vertebral body line define an important angle, the clivus−canal angle, which can range from 180° in extension to 150° in flexion in physiological conditions (**Figures 2A** and **3A**).[13,17,18]
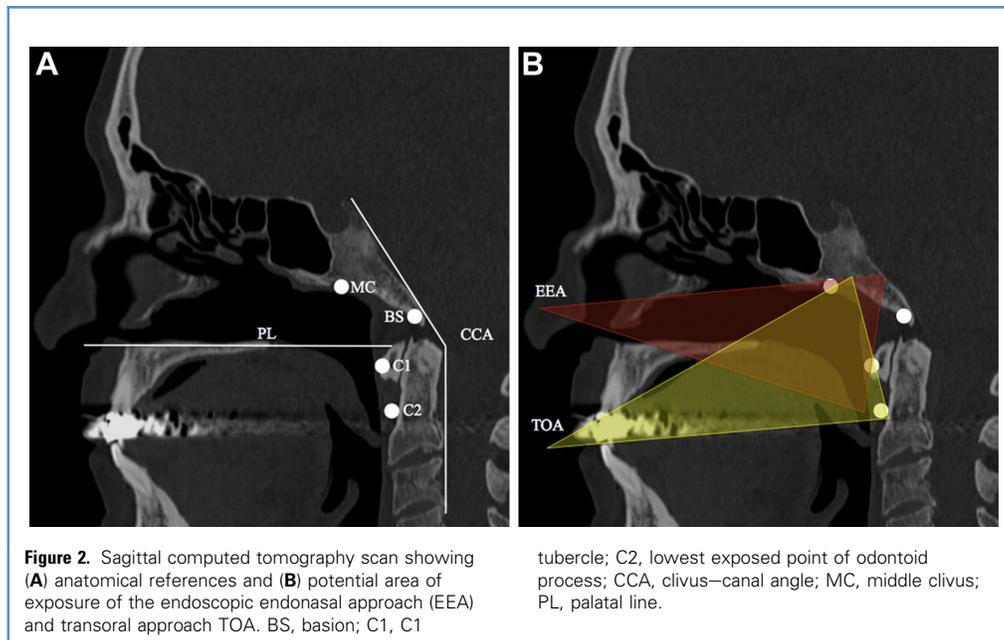
Endoscopic Endonasal Approach

With the introduction of endoscopic techniques, some investigators have developed endonasal endoscopic routes to access the CVJ to minimize surgery-related morbidity.[2,20,22,31,32,47] The EEA has the advantage of the extraoral corridor, which minimizes palatal manipulation. However, the surgical corridor will usually be longer than the length for the oral corridor, limiting the surgical freedom of the approach.[14,20,22,31,32] The endoscopic technique provides a laterally angled view, which might be favorable for visualization of the lateral aspect of the surgical field.[22,25,31,32]

Cranial base reconstruction and dural repair still represent critical points of the EEA, despite the introduction of the nasoseptal flaps.[14,25,31,32,46,48,49] Another disadvantage of the EEA is the limitation in caudal extension owing to the presence of the soft and hard palate.[25-27,50,51] This aspect dramatically influences the potentiality of EEA, because in cases of an extremely caudal location of the C1-C2 junction, transnasal odontoidectomy might be not feasible owing to the bulk created by the hard palate.[52]

de Almeida et al.[26] proposed using the nasopalatine line (NPL) to preoperatively assess the caudal limit of the EEA. The NPL represents the line running from the inferior point of the nasal bone (rhinion) to the posterior edge of the hard palate (posterior nasal spine) on the midsagittal plane (**Figure 3C**).[26]

Recently, the nasoaxial line has been proposed to better predict the lower limit of the EEA based on a cadaveric series.[25,27,50] It represents the crossing line starting from the midpoint of the distance between the anterior nasal spine of the maxillary bone

Figure 2. Sagittal computed tomography scan showing (**A**) anatomical references and (**B**) potential area of exposure of the endoscopic endonasal approach (EEA) and transoral approach TOA. BS, basion; C1, C1 tubercle; C2, lowest exposed point of odontoid process; CCA, clivus—canal angle; MC, middle clivus; PL, palatal line.

and the rhinion (the posterior nasal spine of the palatine bone) and extending inferioposteriorly to the C2 vertebra (**Figure 3D**).[50] Preoperatively, the nasoaxial line seemed to better predict for the potential of caudal extension of the EEA compared with the NPL, because the NPL underestimated >1 cm of the actual surgical inferior limit of the EEA.[50] Despite the possibility to preoperatively define the possible caudal extension, as demonstrated in our study, the operability of the region below C1 region remained demanding using the EEA.[20,27,31,46,50]

The application of endoscopy can significantly increase the anatomical exposure. However, it has not always been associated with increased satisfactory surgical operability, especially in terms of the angle of attack, even when using angled endoscope optics.[14,28,30,53] In our study, the OS calculated for the EEA was 1 for the C2 and BS targets, 2 for C1, and 3 for MC (**Table 2**).

Comparison of TOA and EEA

During dissection, we detected some anatomic variants, which influenced our capability to expose selected target areas with both approaches, even in the same specimen. The most relevant variants included the distance between the C1-C2 complex and the palatal axis, such as in the case of platybasia, which jeopardized surgical access to the BS and CVJ with both microscopic and endoscopic approaches.[26] Furthermore, the type and development of the sphenoid sinus influenced the anatomy of the clivus and the surgical accessibility to clival targets.[7]
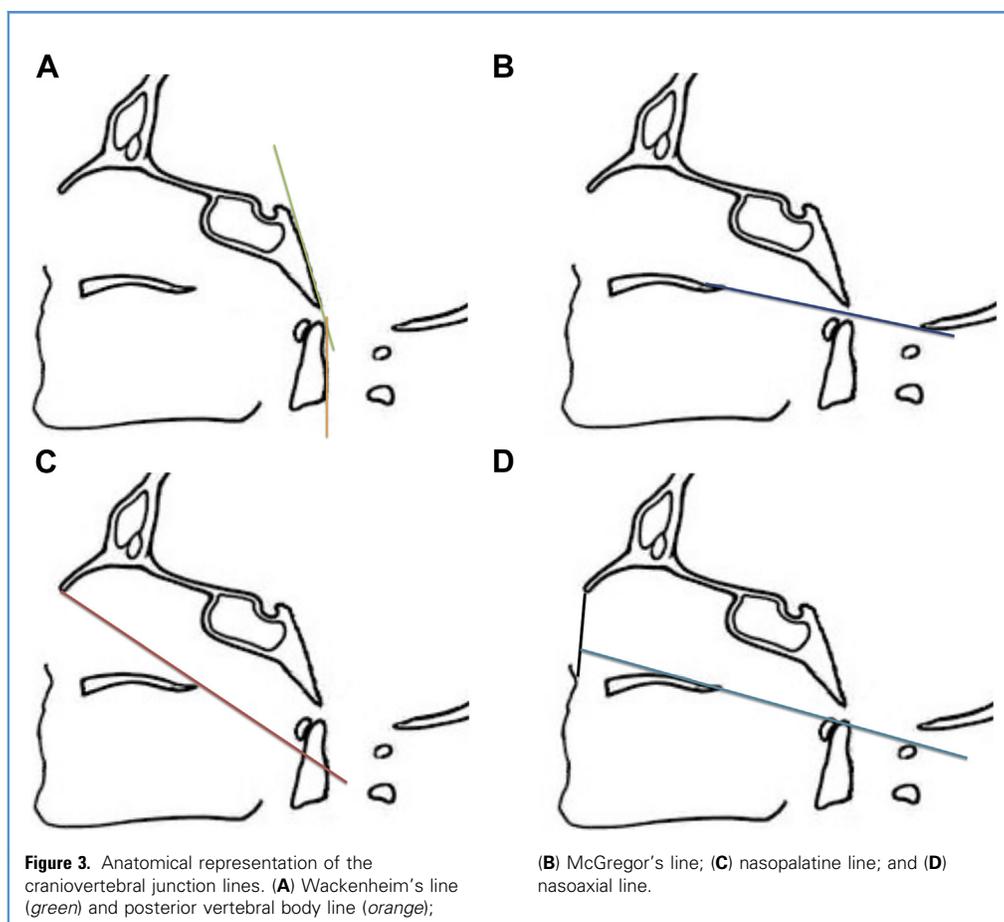
Ultimately, although often not sufficiently recognized, sagittal extension of both the soft and the hard palate is crucial in determining the potential caudal extension of surgical exposure using the EEA or the cranial extension when using the TOA. In addition, palate splitting will not always provide significant improvement in surgical accessibility.[6,16,20,26,46,50,53,54]

In our cadaveric study, EEA resulted in a greater depth of the surgical field to C1 ($P < 0.0001$), C2 ($P < 0.001$), and BS

($P = 0.157$). In contrast, the depth of the surgical field at the MC was greater with the TOA ($P = 0.965$). This finding reflects the more direct route of the TOA compared with the EEA for these targets. Similarly, we found higher values for the SAA and MAC at C1 and C2 with the TOA ($P = 0.0003$ and $P = 0.018$, respectively, for SAA; and $P < 0.0001$ and $P = 0.001$, respectively, for MAC). In contrast, these values were greater at the BS and MC with the EEA ($P = 0.134$ and $P < 0.0001$, respectively, for the SAA; and $P < 0.0001$ and $P < 0.0001$, respectively, for the MAC). Despite the similar depth of the surgical field at the BS for the 2 approaches, the TOA showed a lower SAA and MAC because they can be influenced by the presence of a prominent C1 tubercle or by the angle between the clivus and the C1-C2 complex. These variations can make it more difficult to work at the BS because of the tight angles. Although the OS for the SAA and MAC at the MC was 1 for both approaches, the EEA had greater values and the differences were statistically significant ($P < 0.0001$).

By combining the advantages of the TOA with the application of endoscopy, some investigators have suggested an endoscope-assisted TOA to include the advantages of a direct surgical route and the use of angled endoscopes to increase the surgical exposure.[2,14,25,31,32] However, this has not been related to a significant increase in operability (**Figure 2B**).[6,46]

The results of the present study have demonstrated the maximal possibility of exposure obtained using the 2 approaches. However, these approaches will not always be appropriate in actual cases, considering the potential surgery-related complications and the extreme interindividual variability in this particular anatomical region.[30] Furthermore, the cadaveric model could limit the interpretation of our results because of tissue stiffness and the more difficult retraction in the cadavers, which might have favored the EEA. Further studies are needed to definitively outline the role of the TOA and EEA for this region. The advantages and disadvantages of the TOA and EEA are summarized in **Table 3**.

Figure 3. Anatomical representation of the craniovertebral junction lines. (**A**) Wackenheim's line (*green*) and posterior vertebral body line (*orange*); (**B**) McGregor's line; (**C**) nasopalatine line; and (**D**) nasoaxial line.

Because of the anatomical variability of this region, the main features of the pathological lesions, and surgeon's personal skills and experience, we suggest considering the OS as an additional tool in the preoperative evaluation to individualize the treatment and determine the best case-specific surgical approach.

CONCLUSIONS

Extensive data have been reported regarding the potentials of the TOA and EEA, although, to date, no definitive consensus has been reached on the indications for the 2 approaches. In particular,

different tools have been described for the EEA to preoperatively define the potential limits of single surgical strategies. However, to the best of our knowledge, a comparative anatomical study between TOA and EEA has not been reported. The OS has been described as an effective method to evaluate the surgical operability of different approaches to the same target. For the EEA, we reported a higher OS at the C1 and MC and for the TOA, a higher OS at C1, C2, and MC. For anterior CVJ surgery, the OS represents another important tool to preoperatively assess the capability of reaching special target regions using different approaches.

Table 3. Summary of Transoral Approach and Endoscopic Endonasal Approach at Anterior Medial Skull Base and Craniovertebral Junction

Approach	Advantages	Disadvantages	Morbidity
TOA	Direct visualization of C1-C2 complex; wider and shorter surgical corridor	Limited lateral visualization; limited upper surgical trajectory; limited mouth opening and oral corridor; tongue and tonsil retraction	Postoperative palatal insufficiency; greater infection risk
EEA	Increased lateral and craniocaudal visualization; better anatomical sharpness	Longer surgical route; surgical defect repair; limited lower surgical visualization	Nasal complications; postoperative palatal insufficiency
TOA, transoral approach; EEA, endoscopic endonasal approach.			

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