

The application of endoscopic technique in high cervical anterior approach to the craniovertebral junction

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Abstract

Background

Surgery on the craniovertebral junction (CVJ) presents particular challenges owing to the close proximity of critical neurovascular structures and the brainstem. It is difficult for classic approaches to obtain the extra exposure of neurovascular structures of the CVJ in practice. The surgical approach to the craniovertebral junction (CVJ) offers specific challenges. We explored the feasibility of an endoscope-assisted high anterior cervical approach to the CVJ.

Methods

We quantitatively assessed the surgical corridor to, and extent of exposure of, the CVJ in six cadaveric specimens, using 0° and 30° endoscopes.

Results

The endoscope provided sufficient exposure of neurovascular structures and the brainstem in the CVJ. Resection of the anterior arch of C1 was avoided in minimal anterior clivectomy. After removing the odontoid, greater exposure of the CVJ was obtained.

Conclusion

An endoscope-assisted high anterior cervical approach to the CVJ preserves cervical spine stability while minimizing the risk of neurovascular injury within the surgical corridor.

Background

Surgery on the craniovertebral junction (CVJ) presents particular challenges owing to the close proximity of critical neurovascular structures and the brainstem. Many ventral and dorsal approaches to the CVJ for accessing a variety of pathologies have been reported and may be classified into anterior, posterior, and lateral approaches. Classic approaches, such as the midline suboccipital and the transcondylar approaches, are preferred for posterior and laterally located lesions at the cervicomedullary junction [1]. Ventral lesions, especially extradural pathologies, may be more readily accessed through anterior corridors, including transoral and transnasal approaches [2–7]. In the setting of oral or nasal cavity lesions, or when the majority of the lesion extends laterally or caudally into the cervical spine, it is difficult to apply transoral and transnasal approaches; rather, the high anterior cervical approach is advocated. Some reports have shown that the high anterior cervical approach provides adequate decompression of the cervicomedullary junction [8]. Some studies indicated that anterior cervical fixation or fusion can be performed via this approach [9]. At the same time, the oropharyngeal mucosa could be preserved with

fewer pharyngeal complications. However, the working distance is very long under the microscope via this approach, which utilizes the posterior pharyngeal space. Due to maxilla and muscle soft tissue constraints, it is difficult to retract and gain access to the posterior pharyngeal wall soft tissue. It is a tubular surgical field with a very long working distance under the microscope. Additionally, there is only a tiny bony window through the clivus within minimal anterior clivectomy [8]. It is difficult to obtain the extra exposure of neurovascular structures of the CVJ in practice. Recently, endoscopes have gained increasing popularity and acceptance as part of the neurosurgical armamentarium. We explored the feasibility of the endoscope-assisted high anterior cervical approach to the CVJ for extended exposure.

Methods

All anatomical dissections were performed at the Skull Base Laboratory and Minimally Invasive Neurosurgery Laboratory. Six embalmed human cadaveric heads were studied and measured. The cadaver heads were obtained from body donations. The cadavers were from the anatomical laboratory of shanxi medical university. Donors agree that cadavers should be used for medical research. Following the Chinese regulation, the donors had to sign a statement about this specific study and they did express their consent to anonymously give part of their body to science for ethically approved experiments. All experiments were performed in accordance with the relevant guidelines and local regulations. The study was approved by the Ethics Committee of the Hospital. We have obtained the permissions to utilise these samples from shanxi medical university. Microscopic anatomical dissections were performed under 3X to 40X optical magnification using an operating microscope (Global Instruments, Trenton, MO, USA). Endonasal anatomical dissections were carried out using 0° and 30° rod-lens, 4 mm diameter, 18 cm length, Hopkins II endoscopes (Karl Storz Endoscopy, Tuttlingen, Germany). The scopes were attached to a high-definition camera and projected onto a monitor. All data was digitally recorded and stored into a workstation (Gefen System, Petaluma, CA, USA).

Results

Surgical Procedure

The high anterior cervical retropharyngeal approach to the upper cervical spine has been previously described in detail [10-12]. Russo et al. used this approach to the clivus and foramen magnum [8]. The procedure is performed with the patient positioned supine. The head is extended 20° to 30° and rotated 30° to 45° away from the side of the approach. The mandible is displaced superiorly. An incision is made approximately 3-4 cm inferiorly and parallel to the mandible to avoid injury to the marginal mandibular branch of the facial nerve (Figure 1A). The platysma is divided and retracted superiorly. The submandibular gland is exposed and elevated upward (Figure 1B). The posterior belly of the digastric muscle is brought into view under the submandibular glands. The anterior belly of the digastric muscle is retracted medially, and the facial artery and vein laterally. The posterior belly and tendons of the digastric muscle are elevated superiorly. When the posterior belly is divided deep, the hypoglossal nerve is revealed, which passes inferiorly to the muscle (Figures 1C, 1D). The hypoglossal nerve is carefully dissected and

retracted rostrally. The external carotid artery and the facial artery branch is retracted laterally and superiorly and the lingual artery is retracted inferiorly (Figures 1B and 1C). The pharyngeal muscles are retracted medially and thus the retropharyngeal space is opened. The pharyngeal muscles are further separated deeply and the anterior tubercle of C1 and anterior surface of the cervical vertebrae are exposed (Figure 1E). Next, the prevertebral fascia and the anterior longitudinal ligament in the midline are resected, exposing the entire arch of C1 and the body of C2. The anterior atlantooccipital membrane, as well as the longus capitis muscles are detached from the anterior rim of the foramen magnum and midlateral portion of the clivus (Figure 1F). The upper boundary is the vomer and pterygoid process medial plate. The bilateral boundary is the petroclival fissure.

Anatomical measurements

We performed distance measurements of the anatomical structures of the free clivus. In another specimen, the mean distance from the anterior rim of the foramen magnum to the vomer was 27.1 mm (range 26-28.9 mm). The width of the clivus at the pterygoid process medial plate level was 21.6 mm (range 21.0-22.3 mm). The width of the clivus at the pharyngeal tubercle level was 27.8 mm (range 26.9-28.4 mm). The width of the clivus at the hypoglossal canal outside the hole midpoint level was 28.7 mm (range 27.6-29.1 mm). The width of the clivus at inferior margin of the hypoglossal canal outside the hole was 29.6 mm (range 28.7-31.1 mm; Figure 2A).

We also performed distance measurements of the previous step on the heads, which had good exposure of the clivus. The anterior rim of the foramen magnum adheres to the longus capitis muscle, rectus capitis anterior muscle, pharyngobasilar fascia, and mucosa. It is difficult to dissect from the anterior margin of the foramen magnum, especially the fascia on the supracondylar groove; it is difficult to dissect from the cortical bone surface of the groove, which is an important landmark on the clivus for localizing the hypoglossal canal. It is located deep, at the same level. In this stage, the mean distance from the pharyngeal tubercle to the vomer was 19.1 mm (range 18.7-20.9 mm). The width of the clivus at the pterygoid process medial plate level was 20.1 mm (range 19.3-20.9 mm). The width of the clivus at the pharyngeal tubercle level was 25.9 mm (range 24.9-26.4 mm; Figure 2B). There was not an obvious difference compared with the measurements of the free clivus. This indicated that it was sufficient for the mucosa of the clivus to be separated bilaterally from the petroclival fissure.

For the CVJ, the hypoglossal canal and nerve are very important structures. The hypoglossal canal is directed posteriorly and medially at a 45° angle with the sagittal plane; its extracranial outside hole is located immediately above the junction of the anterior and middle third of the occipital condyle and medial to the jugular foramen. In the interior view of the clivus, the hypoglossal canal is located at the back of the free anterior rim of the foramen magnum; the medial border of intracranial hole and the petroclival fissure have the same vertical line (Figure 2C). In the outside view of the clivus, the hypoglossal canal is located at the front of the free anterior rim of the foramen magnum. The midpoint of the hypoglossal canal outside the hole acts as the lateral limiting points. We dotted a black line as the

lateral limit of the medial condylectomy (petroclival fissure to the midpoint of the hypoglossal canal outside the hole to hypoglossal canal inside the hole (Figure 2D).

Exposure of the CVJ

The clivus and the high cervical area are exposed. First, clivus resection is performed. A high-speed drill or rongeur is used. Drilling is performed in the midline of the inferior portion of the clivus. The upper boundary is the sphenoidal sinus, which is limited laterally by the medial border of the petroclival fissure. The lower boundary is the anterior rim of the foramen magnum. In this resection, the atlantooccipital anterior membrane, anterior longitudinal ligament, and apical ligament of the dens of C1 are reserved. There is a 20 x 30 mm bony window through the clivus, as Russo previously reported [8]. After opening the dura mater, we could observe the ventral aspect of the brainstem and the related vascular and neural structures (Figure 3A). The proximal segment of the basilar artery (BA) and bilateral vertebral artery (VA) can first be observed. In the upper view, the abducens nerve could be observed from its origin. The pontomedullary sulcus is exposed in the middle of the view. In the midline, the anterior spinal artery is observed. Posterior inferior cerebellar artery (PICA) and cranial nerve (CN) XII are bilaterally partly observed.

When performing the endoscope-assisted high anterior cervical approach and expanding the bone window, the anterior rim of the foramen magnum, atlantooccipital anterior membrane, and anterior longitudinal ligament are resected. After drilling the medial third of the lateral mass of C1 and the anteromedial third of the occipital condyle, we observe the CVJ vascular and neural structures using 0° and 30° rod-lens endoscopes. The BA, VA, abducens nerve, and pontomedullary sulcus can be observed. Exposure of the inferior field is increased. The hypoglossal canal, CN XII, and P.I.C.A. are still bilaterally partially observed using 0° endoscopes, with a greater observation range (Figure 3B). However, it is observed completely using 30° endoscopes (Figures 3C-F). It is noted that the occipital condyle anatomic levels in turn are cortical bone, soft cancellous bone, hard cortical bone, and hypoglossal canal. It is important to protecting the hypoglossal nerve when drilling deeper layer of hard cortical bone of occipital condyle which surrounds the hypoglossal nerve.

When drilling out the dens down to the level of the body of C2, and continuing to expand inferior field exposure. After opening the dura, then we exposed the cervicomedullary junction. It is worth noting the CVJ area is sufficiently exposed after drilling out the dens (Figure 4A). In addition to the aforementioned structure, others such as the BA, VA, abducens nerve, pontomedullary sulcus, hypoglossal canal, CN XII, and PICA are exposed. More CVJ region vascular and neural structures is observed using 0° endoscopes. Upper cervical spinal cord is also exposed. The vertebral artery intradural segments are observed completely, especially from their dural entrance points to the supramedial rising segment. More importantly, the spinal nerve C1 could be bilaterally observed completely using 0° endoscopes. Using 30° endoscopes results in greater exposure for the CVJ region (Figures 4B-E).

Exposure degree and resection range of the CVJ

The relationship of exposure degree and resection range of the CVJ are summarized in Figure 5. The Figure 5A, 5B, 5C is the endoscopic view of the resection of the clivus in the endoscope-assisted high anterior cervical approach. The Figure 5D, 5E, 5F is the endoscopic view of resection of the clivus and atlas. There is not an obvious increase in exposure degree of the CVJ. The Figure 5G, 5H, 5I is the endoscopic view of the resection of the clivus, atlas, and odontoid. There are not obvious increases in the exposure degree of the CVJ when the atlas is drilled out based on the resected clivus, in the anterior cervical approach (Figures 5C, 5F). After removing the odontoid, greater exposure of the CVJ area is obtained (Figures 5C, 5F, 5I). It is imperative to resect the dens in order to sufficiently expose the CVJ in the anterior cervical approach, especially for large lesions involving the high cervical spinal region.

Discussion

Use of the high anterior cervical approach has been reported by some studies. Vender et al. performed anterior cervical fixation or fusion via this approach [9]. Park et al. studied the high anterior cervical approach for the upper cervical spine [13]. Singh et al. reviewed the high anterior cervical retropharyngeal approach in Ventral Surgical Approaches to Craniovertebral Junction Chordomas [14]. Russo et al. performed a microsurgical anatomy study of the high anterior cervical approach to the clivus and foramen magnum [8]. But the working distance is very long under the microscope via this approach, even if a deep retractor and a self-retaining retractor are used to elevate the pharyngeal mucosa upward, and maintain lateral displacement of the longus capitis, rectus capitis anterior, and longus colli. In fact, by maxilla and muscle soft tissue constraints, it is difficult to retract the posterior pharyngeal wall soft tissue. The ventral surface of the foramen magnum, clivus, petroclival region, and CVJ are exposed in a tubular surgical field under the microscope (Fig. 6). In addition, there is only a 20 x 30 mm bony window through the clivus within minimal anterior clivectomy [8]. It is quite difficult to obtain extra exposure of neurovascular structures of the CVJ, in practice. These factors limit the application of this approach in clinical practice. There is a fish eye effect under endoscopy, which can obtain a multi-angle and close distance observation of the operative region (Fig. 6,7). It can overcome the limitation of the tubular surgical field under the microscope. In addition, endoscope technology as part of the neurosurgical armamentarium has recently gained increasing popularity and acceptance. The endoscope-assisted high anterior cervical approach will be further developed.

When a deep retractor and a self-retaining retractor were used to expose the CVJ, visualization of the inferior portion of the clivus and the anterior rim of the foramen magnum was obstructed by the anterior arch of C1 under the microscope during the high anterior cervical approach [8]. At this stage, resection of the anterior arch of C1 between the lateral masses becomes a normal drilling or resection step in the high anterior cervical approach, even in minimal anterior clivectomy [8]. In order to obtain greater exposure via the operation corridor under the microscope, the deep retractor is repeatedly forced towards the bilateral and upward sides. The blood vessels and nerves of the neck are very easy to damage. Utilizing the multi-angle and close distance observation of the endoscope, we could clearly observe the inferior portion of the clivus and the anterior rim of the foramen magnum (Fig. 4), as well as avoid resection of the anterior arch of C1. It maintains stability of the cervical spine as far as possible.

Regarding the lateral limit of resection, there are different descriptions. Wang et al. designed the vertical line (from the foramen lacerum to the occipital condyle) in medial condylectomy as the lateral limit of the medial condylectomy [15]. Russo et al. [8] described the lateral limit of bone resection, the petroclival fissure, the anteromedial third of the occipital condyle, and anterior half of the jugular tubercle. These landmarks exist in the free occipital bone. In the actual operation, these landmarks are covered or embedded with other tissue and they are difficult to judge during the operation itself. We also have the same lateral limit of resection but we think that intraoperative assessment should be simple.

The petroclival fissure and the medial border of the intracranial hole are the superolateral and inferior lateral limits of resection, respectively. In the inside view of the clivus, the medial border of the intracranial hole and the petroclival fissure have the same vertical lines (Fig. 2C). The midpoint of the hypoglossal canal outside the hole acts as the limiting lateral point (Fig. 2D). The supracondylar groove and hypoglossal canal are at the same craniocaudal level and the hypoglossal canal is deep. The supracondylar groove is on the surface of the supracondylar groove. The supracondylar groove is a surface landmark on the clivus for localizing the hypoglossal canal. Thus, the lateral point of the supracondylar groove could act as the lateral limit during the operation (Figs. 2C, 2D). Thus, using the petroclival fissure, vertical line, and the lateral point of the supracondylar groove, we can easily draw the outline of the boundaries for resection (black dot line) during the operation. All of these landmarks are on the outside surface of the occipital bone.

The high anterior cervical approach is used more in the upper cervical spine, such as for chordomas of the upper cervical spine [16], fusion at the cervical spine [9], cervical pyogenic C1-2 abscess [17], and cervical spondylosis [18]. There is a degree between the spine long axis and the operation corridor in the high anterior cervical approach. It is sometimes an acute angle, less than 45° . As shown in Fig. 6, it is relatively easy to operate in upper cervical spine lesions. When the lesion is located in the lower clivus and foramen magnum, the degree between the spine long axis and the operation corridor becomes more and more minor. On the other hand, it is difficult to resect the anterior atlantooccipital membrane, occipital condyle, atlantooccipital joint, and apical and alar ligaments. Furthermore, only the upper structures in the bone windows could be observed as the acute angle between the operation corridor and operation bone window. When the atlas is drilled out (Figs. 5D, 5E), no significant increase is obtained in the acute angle between the operation corridor and operation bone window. So there is no obvious increase in exposure degree of the CVJ than with clivectomy in the anterior cervical approach (Figs. 5C, 5F). After removing the odontoid, greater exposure of the CVJ area is obtained (Figs. 5C, 5F, 5I). It is imperative to resect the dens in order to sufficiently expose the CVJ in the anterior cervical approach, especially for large lesions involving the high cervical spinal.

Conclusions

The endoscope-assisted high anterior cervical approach to the CVJ has greater feasibility. It maintains the stability of the cervical spine as far as possible, and minimizes the chances of damage to blood

vessels and nerves around the operation corridor. We can obtain maximum exposure with the least amount of resection with the endoscope-assisted high anterior cervical approach.

Abbreviations

CVJ

Craniovertebral junction

BA

Basilar artery

VA

Vertebral artery

PICA

Posterior inferior cerebellar artery

CN

Cranial nerve

Declarations

Ethics approval and consent to participate: The research was approved by the Ethics Committee for Shanxi Provincial People's Hospital, Shanxi Medical University. Following the regulation, the donors had to sign a statement about this specific study and they did express their consent to anonymously give part of their body to science for ethically approved experiments. All experiments were performed in accordance with the relevant guidelines and local regulations.

Consent for publication: Not applicable. The manuscript contains no individual person's data in any form (including any individual details, images or videos).

Availability of data and materials: All data are available from the corresponding author upon reasonable request.

Competing interests: All authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

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Authors' contributions: Conception and design: CH. Acquisition of data: KX and PL. Analysis and interpretation of data: CH. Drafting the article: all authors. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: CH. Statistical analysis: HJ and SZ. Administrative / technical / material support: GZ, SC, JZ, ML, YZ and HL. Study supervision: CH.

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Figures

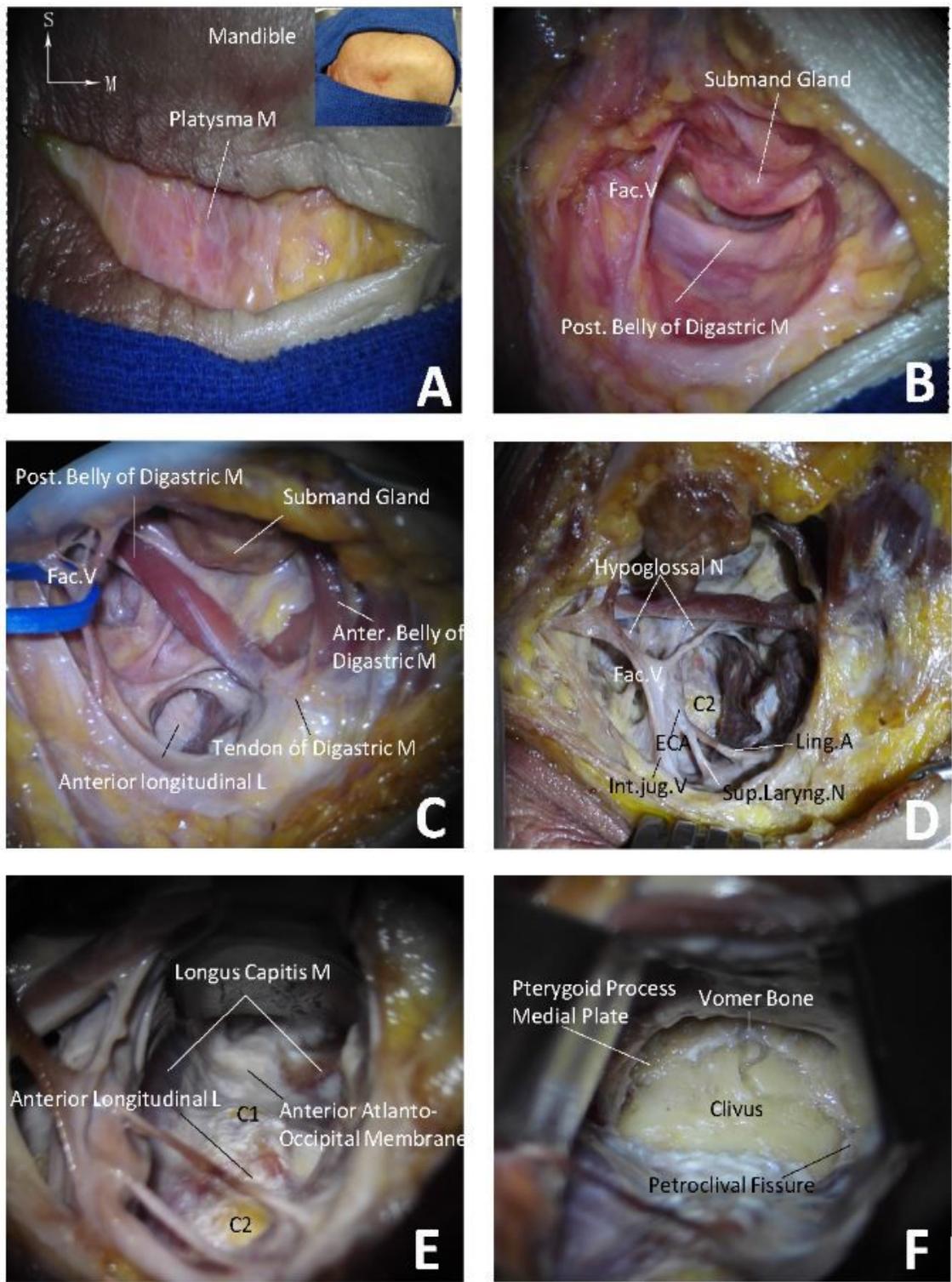


Figure 1

The surgical procedure of endoscope-assisted high anterior cervical approach. A, A straight skin incision is made about 2 cm below and parallel to the inferior border of the mandible. B. The platysma muscle is elevated. The submandibular gland and posterior belly of the digastric muscle are exposed. C. The submandibular gland and posterior belly of the digastric muscle are released and retracted and the entrance of the retropharyngeal space is exposed. D. The hypoglossal nerve passes and the lingual artery

is divided; and the retropharyngeal space is opened. E. The pharyngeal muscles are retracted medially and further separated deeply. The anterior surface of the cervical vertebrae and anterior atlantooccipital membrane are exposed. F. The lower clivus is exposed, including the vomer, pterygoid process medial plate, petroclival, and the anterior rim of the foramen magnum. The arrows indicate the direction in the space, S represents the superior part of the cadaveric heads, M represents the medial part of the cadaveric heads.

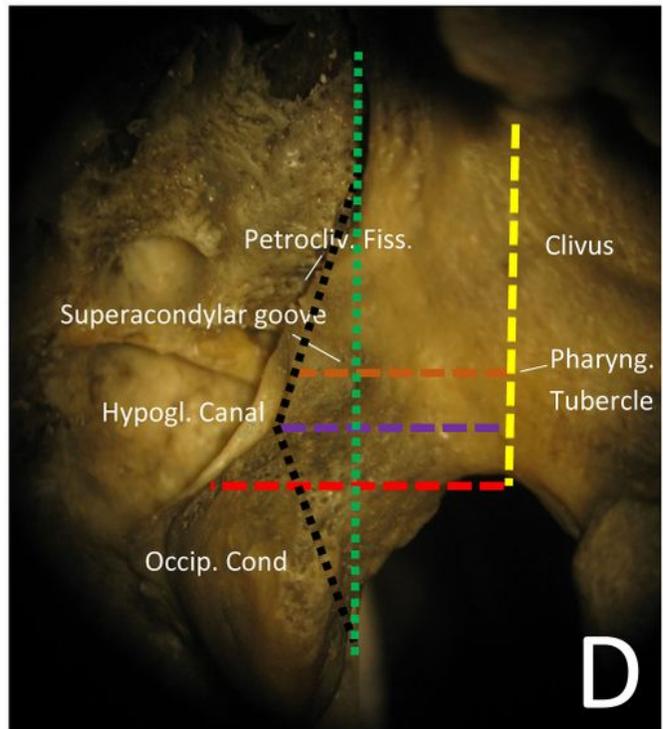
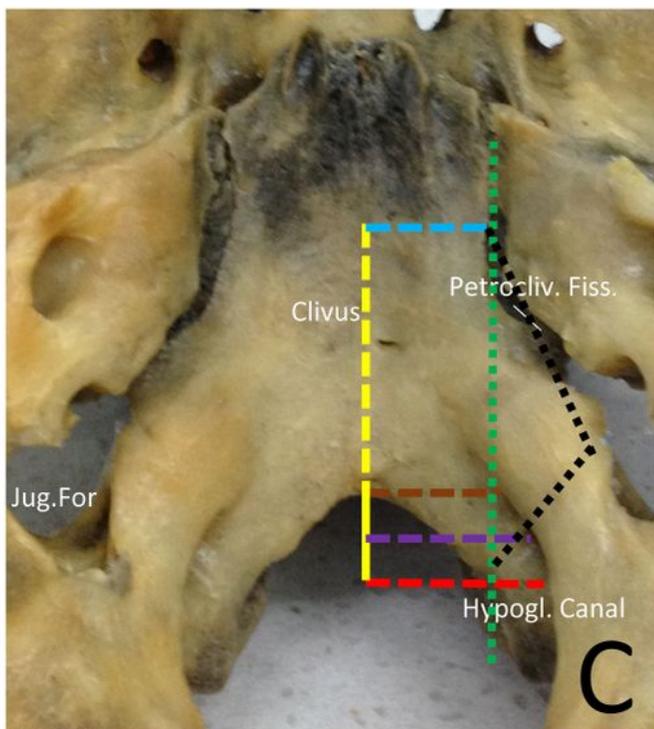
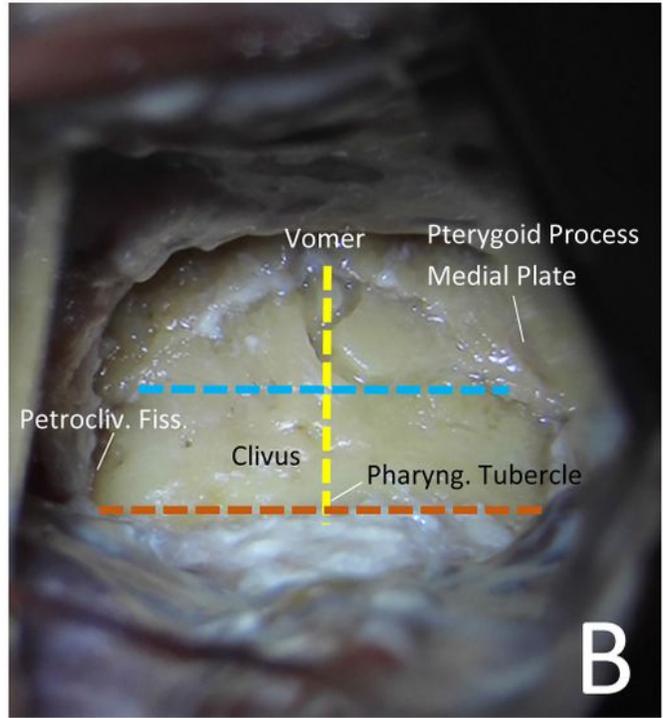
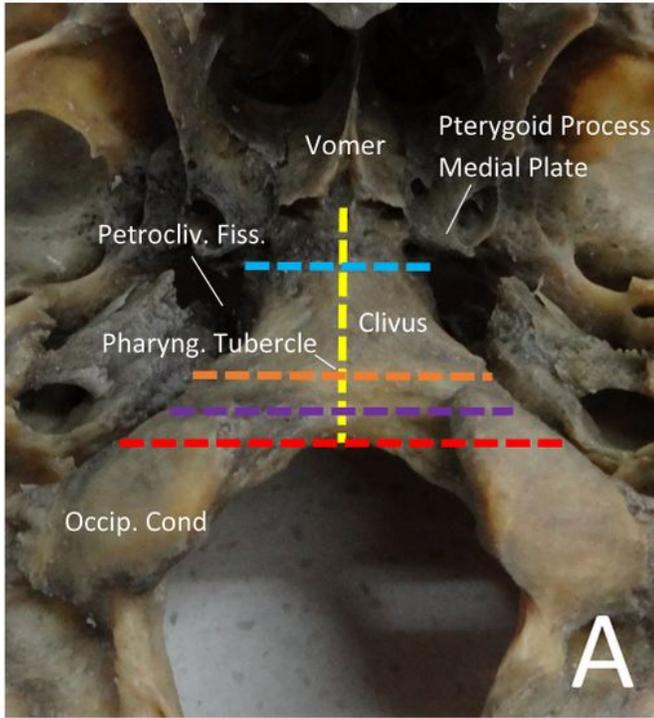


Figure 2

Surgical anatomy and measurements of the lower clivus and ventral foramen magnum. **A.** The ventral side of the clivus. Occipital foramen-vomer (yellow line). The width of the clivus at the pharyngeal tubercle level (brown line). The width of clivus at the pterygoid process medial plate level (blue line). The width of clivus at the hypoglossal canal outside the hole midpoint (purple line). The width of the clivus at the inferior margin of the hypoglossal canal outside the hole (red line). **B.** Initial exposure of the clivus. **C.** The interior side of the clivus. The green line is the line from the petroclival fissure to the hypoglossal canal inside the hole. The lateral limit of the medial condylectomy is the hypoglossal canal inside the hole. **D.** The hypoglossal canal outside the hole. It is directed backward and medially at a 45° angle with the sagittal plane. The pharyngeal tubercle is at the same level with the superior margin of hypoglossal canal outside the hole. The lateral limit of the medial condylectomy is defined by the dotted black line (petroclival fissure to superior margin hypoglossal canal outside the hole to the hypoglossal canal inside the hole).

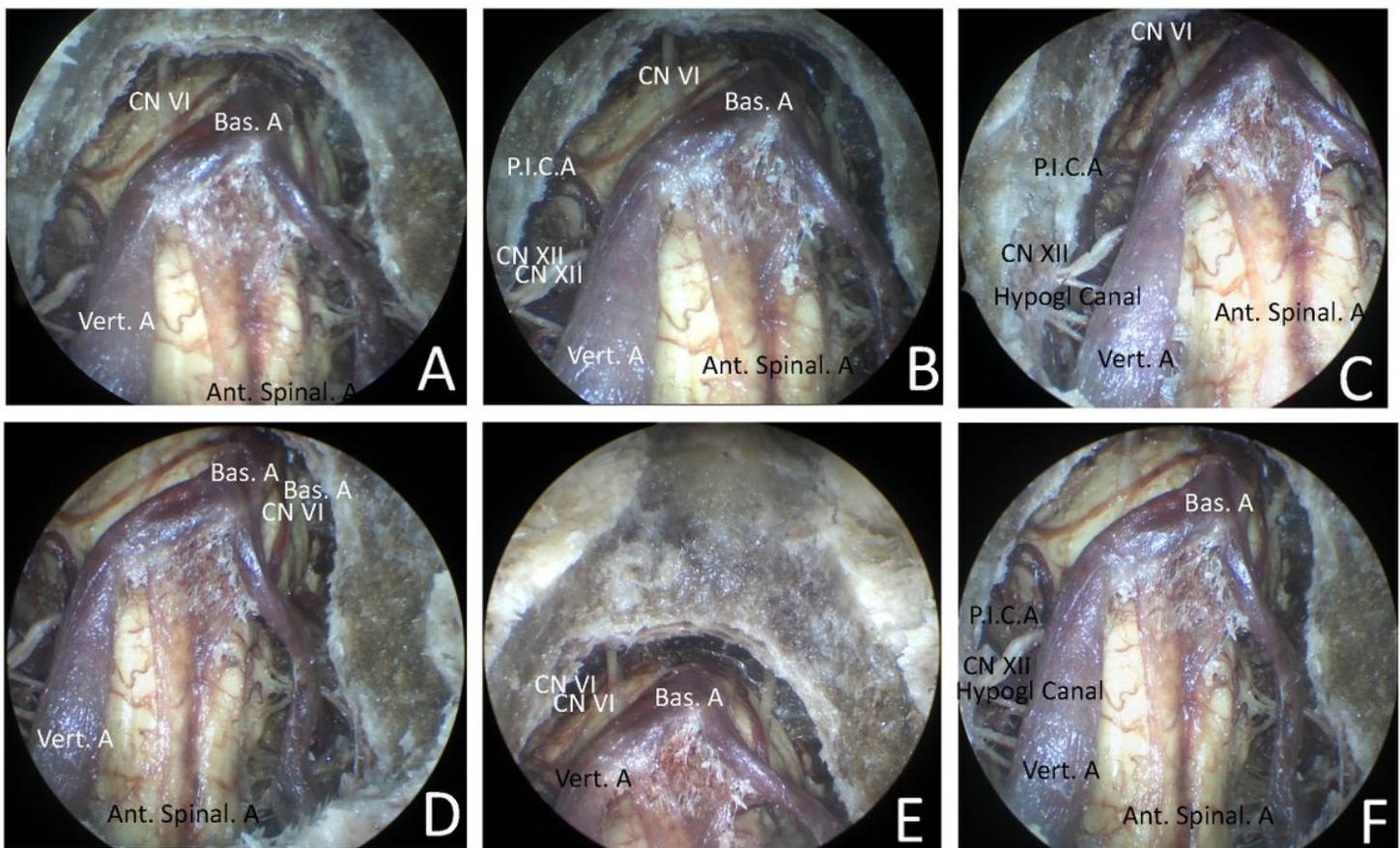


Figure 3

A, The view of the resection of the clivus (0°). **B-F.** The view of the resection of the clivus and the atlas. **B.** The view of resection of the clivus and the atlas (0°). **C.** The view of the resection of the clivus and the atlas (30°, right) **D.** The view of the resection of the clivus and the atlas (30°, left) **E.** The view of the

resection of the clivus and the atlas (30°, cranial) **F**. The view of the resection of the clivus and the atlas (30°, caudal).

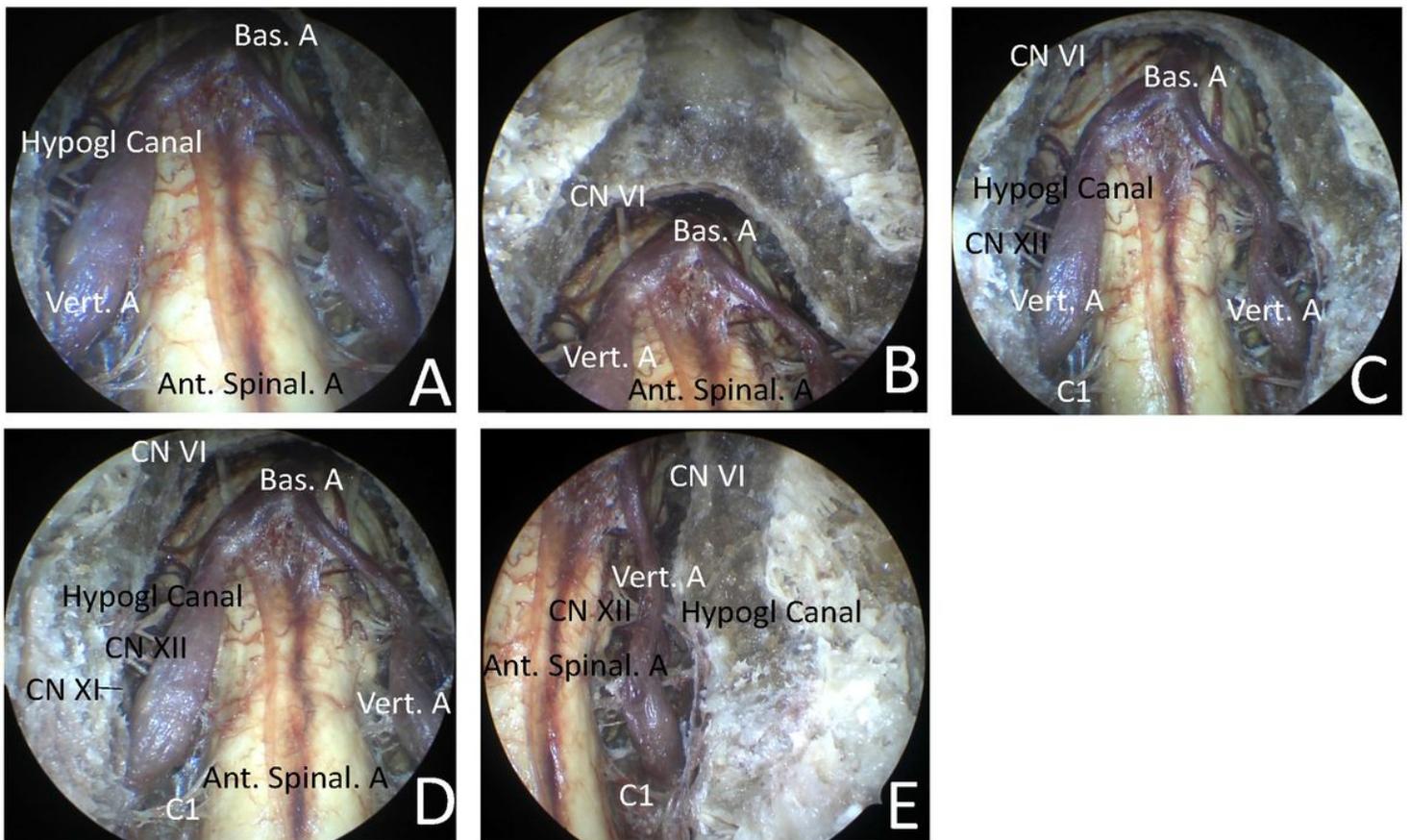


Figure 4

The view of the resection of the clivus, atlas, and dens. **A**. The view of the 0° endoscope. **B**. The view of the 30° endoscope (cranial). **C**. The view of the 30° endoscope (caudal). **D**. The view of the 30° endoscope (right). **E**. The view of the 30° endoscope (left).

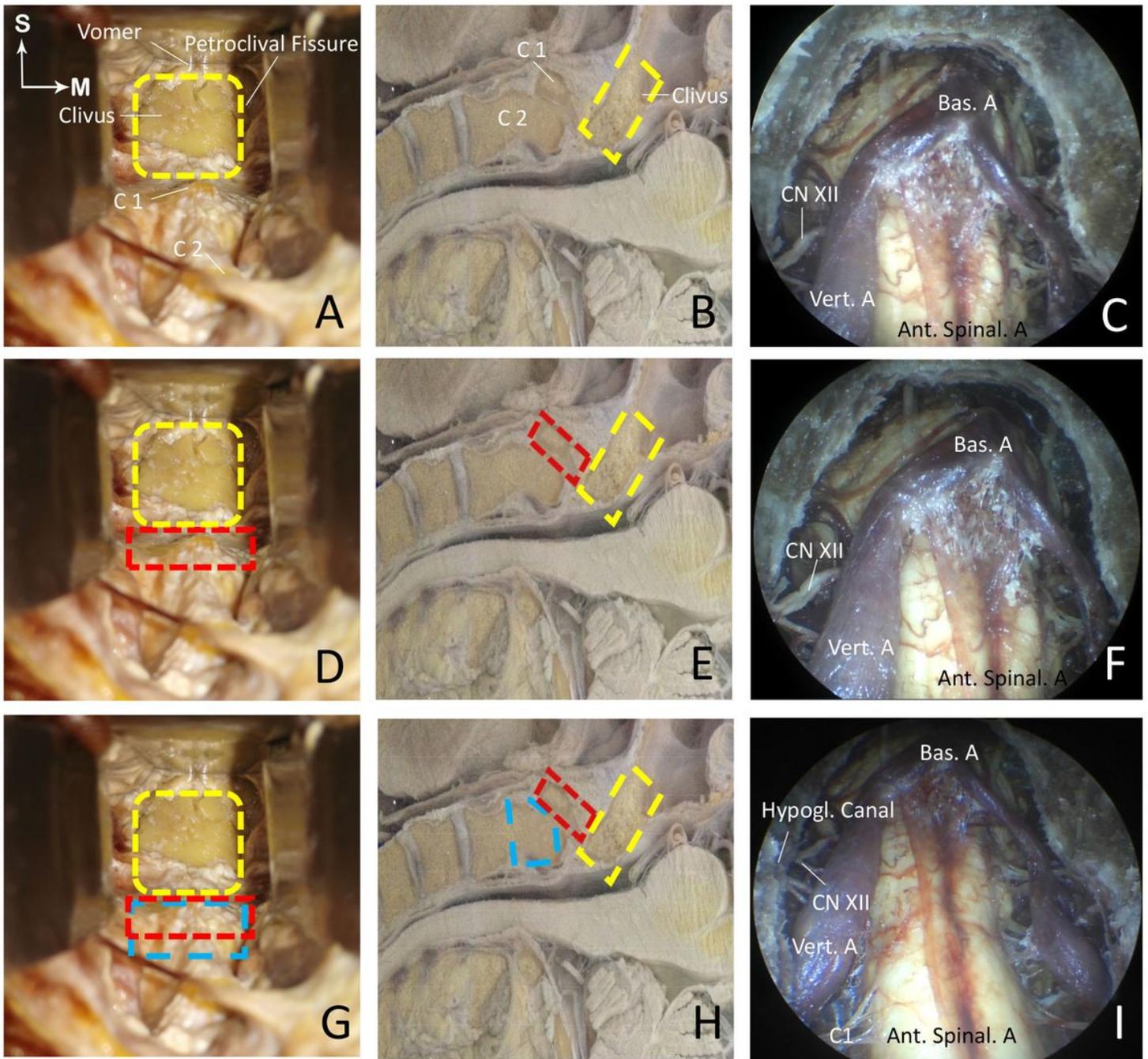


Figure 5

The relation of exposure degree and resection range of CVJ. **A.D.G.** The different resection range of CVJ. **B.E.H.** From the sagittal display, different degrees of resection of CVJ in another specimen. **C.F.I.** Exposure degree under the endoscope. **A-C.** The view of the resection of the clivus. The orange portion represents the resected clivus. **D-F.** The view of the resection of the clivus and the atlas. The green portion represents the resected atlas. **G-I.** The view of the resection of the clivus, atlas, and odontoid. The yellow portion represents the resected odontoid. It is important to resect the odontoid in order to sufficiently expose the CVJ in the anterior cervical approach to the CVJ. There is not an obvious increase in the exposure degree of the CVJ when the atlas is drilled out based on the resected clivus in the anterior cervical approach.

After removing the odontoid. A greater exposure of the CVJ area is obtained. It is imperative to resect the dens in order to sufficiently expose the CVJ in the anterior cervical approach. The arrows indicate the direction in the space, S represents the superior part of the cadaveric heads, M represents the medial part of the cadaveric heads.

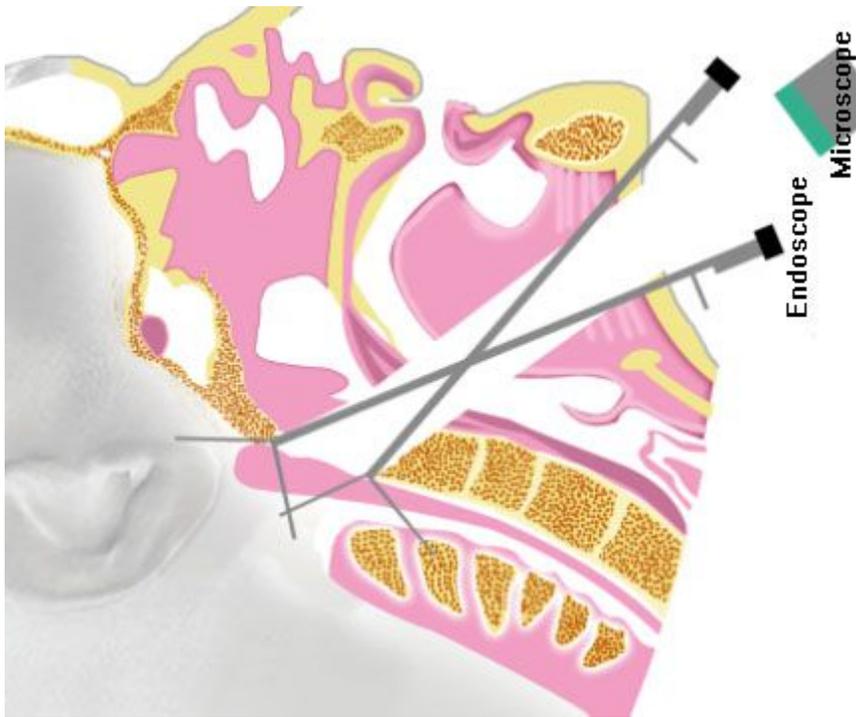


Figure 6

The comparison of the high anterior cervical approach to the craniovertebral junction under the endoscope and microscope.

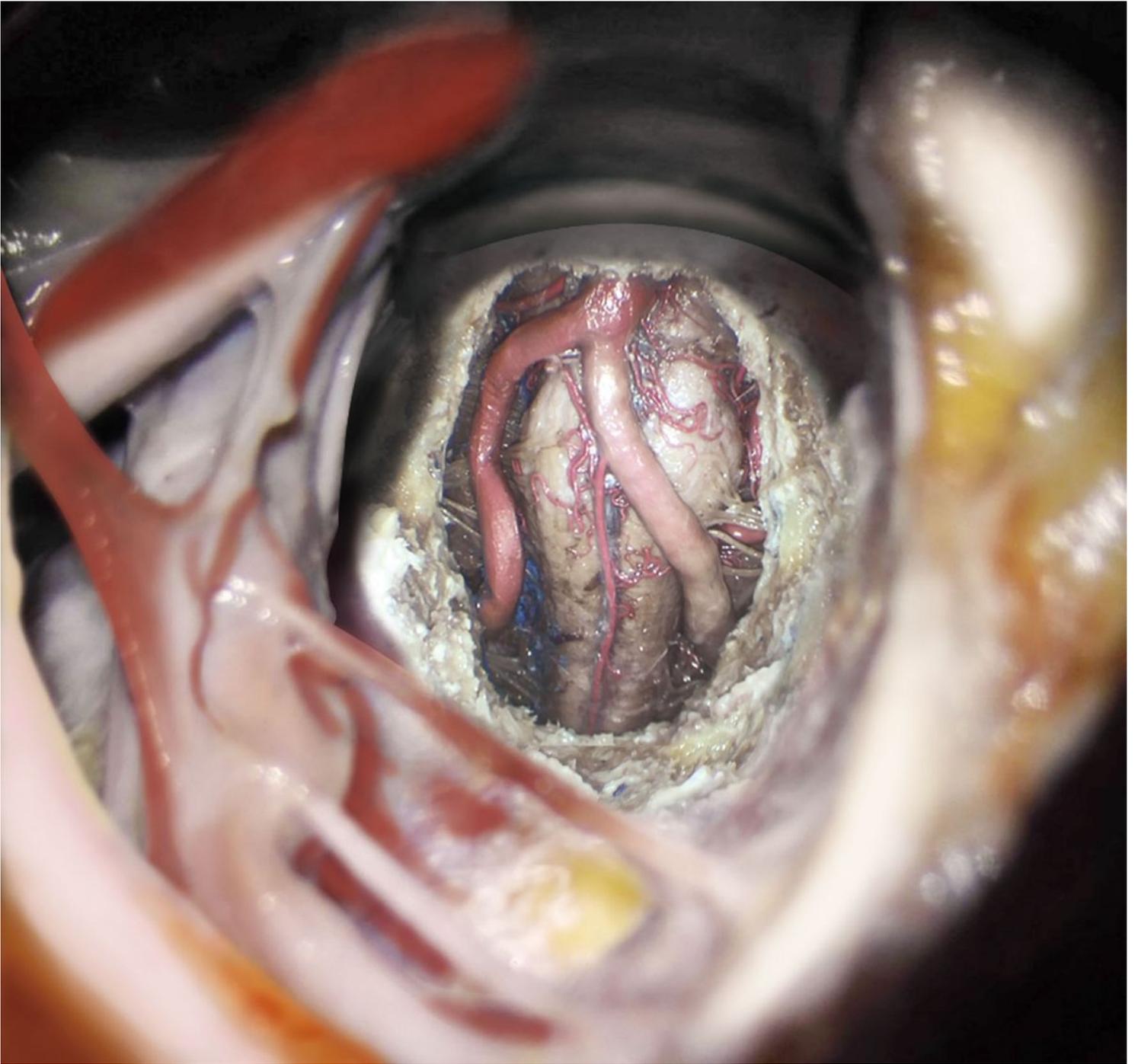


Figure 7

Artist's illustration of the exposure of the high anterior cervical approach to the craniovertebral junction.