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TECHNICAL NOTE

Safe and bloodless exposure of the third segment of the vertebral artery: a step-by-step overview based on over 50 personal cases

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Abstract
Craniovertebral junction surgery usually requires the exposure of the third segment of the vertebral artery (V3). However, the complexity of musculature, a relatively high incidence of anomalies in the course of the vertebral artery (VA), and the presence of a rich venous plexus in this region make the V3 exposure challenging with a high risk of serious complications while taking down the suboccipital muscles in a single layer. A muscle dissection in interfascial layers, however, overcomes the drawbacks inherent in a blind dissection of the V3 as each of the muscles represents substantial landmark aiding subsequent step of the procedure and thus helping identify underlying anatomical structure early and safely. Moreover, along with a bloodless VA dissection off its surrounding venous plexus, it permits a safe and comfortable V3 exposure during the surgically demanding procedures.

Keywords Suboccipital interfascial muscular dissection · Suboccipital triangle · Venous plexus · Vertebral artery

Introduction

Surgical procedures addressing intradural lesions extending from the lower third of the clivus to the upper cervical region usually require the V3 exposure initially [18, 21]. However, (a) a complex anatomy of the craniovertebral musculature [30], (b) a relatively high incidence of anomalies in the course of the V3 [1, 9, 14], (c) the presence of the superficial (SVP) and deep (DVP) venous plexus extending from the subcutaneous layer to the suboccipital triangle (SOT) [30] or surrounding the VA [30], respectively, (d) a variable relationship between the VA and anatomical landmarks, such as C1 posterior tubercle [7, 11, 15, 35], artery of Salmon [10, 33], or lower rim of the occipital bone [34], and (e) the uncertainty of manoeuvres suggested for the identification of the V3 (e.g., palpating the VA pulse or using Doppler probe [38]) make its exposure challenging. Moreover, a generally preferred suboccipital muscles dissection in a single flap [17, 19, 39] may make an early and safe identification of the V3 and its venous plexus even more obscure and tricky. Their inadvertent insult [27] may cause a severe intradural or extradural haemorrhage [2, 22, 23, 29, 37], air embolism [30], or development of arteriovenous fistulae and pseudoaneurysms [2, 22, 23, 29, 37] resulting thus in a significant morbidity and mortality [6, 16, 20, 26, 28, 32]. The following is a comprehensive description of the surgical technique that has been gradually developed over 50 supracondylar approaches by the senior author (K.T.) with the aim to decrease the risk of the complications. The surgical concept is based on the three important anatomical facts. First of all, individual muscles in the suboccipital region represent reliable landmarks that help identify each subsequent underlying anatomical structures safely. Secondly, the V3 is localised in the SOT; and finally, the VA is embedded in a rich DVP. The first step, therefore, includes a suboccipital muscles dissection in layers that leads to a clear identification of the SOT. The triangle represents a topographic guide for the second step including the opening of the SOT along with identification of the V3 dural entrance. Contrary to the muscle dissection in a single flap, an impeccable dissection in the intermuscular layers enables to identify early and safely both potential VA anomalies [13] and venous plexus coursing within the layers, and thus avoid their inadvertent injury followed by heavy bleeding or air emboli. Finally, a bloodless identification of the plane between the

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V3 and its surrounding DVP followed by a bloodless VA dissection off the venous structure represents the final step of a safe V3 exposure.

Operative technique

Patient position

The key assumption for conducting the procedure smoothly and safely is having a patient placed in a modified park bench position with the head initially secured in a three-pin head holder. A dependent arm is placed over the end of the table and a roll is placed under its axilla to prevent pressure on the brachial plexus. The table is adjusted to the reverse Trendelenburg position or flexed 10 to 20° to get the head above the heart level to facilitate venous return while keeping the axis of the head in a line with the axis of the patient's torso. The torso secured to the table with adhesive tape is rotated toward the floor 10 to 20° so that the upper shoulder falls well forward to allow a wide access to the lateral craniovertebral region. The shoulder should not be pulled away toward the foot of the bed and so heighten the risk of a stretch injury to the brachial plexus [8]. The head is rotated forward or backward as needed, while hyperflexion or lateroflexion of the neck is avoided as the compression of the internal jugular veins may enhance the blood flow through the SVP and DVP, thereby increase their lumen and the risk of heavy bleeding or air emboli.

Skin incision

The cranial end of a lazy inverted "S" skin incision commences at the level of the transverse sinus. After short horizontal course, it continues caudally and slightly curves medially 3 to 5 cm from the mastoid process based on the patient's musculature (Fig. 1a). The more muscular the patient, the more the incision is placed medially. The caudal part of the incision descends sharply towards midline at the level of the hairline, thus providing a better cosmetic result. The skin incision initiated by surgical knife and followed by monopolar coagulation should reach until the subcutaneous tissue, then the skin flaps are undermined from the most superficial muscular layer formed by the sternocleidomastoid muscle (SCM) laterally and splenius capitis muscle (SpCM) medially well behind the skin edge (Fig. 1b). The skin flaps are then retracted by fish hooks attached to the rubber bands on their both ends (one fish hook is placed in the operating field and the counterpart is fixed on surgical drapes) providing thus a dynamic form of retraction that can be well adjusted by changing the tension of the rubber bands whenever needed.

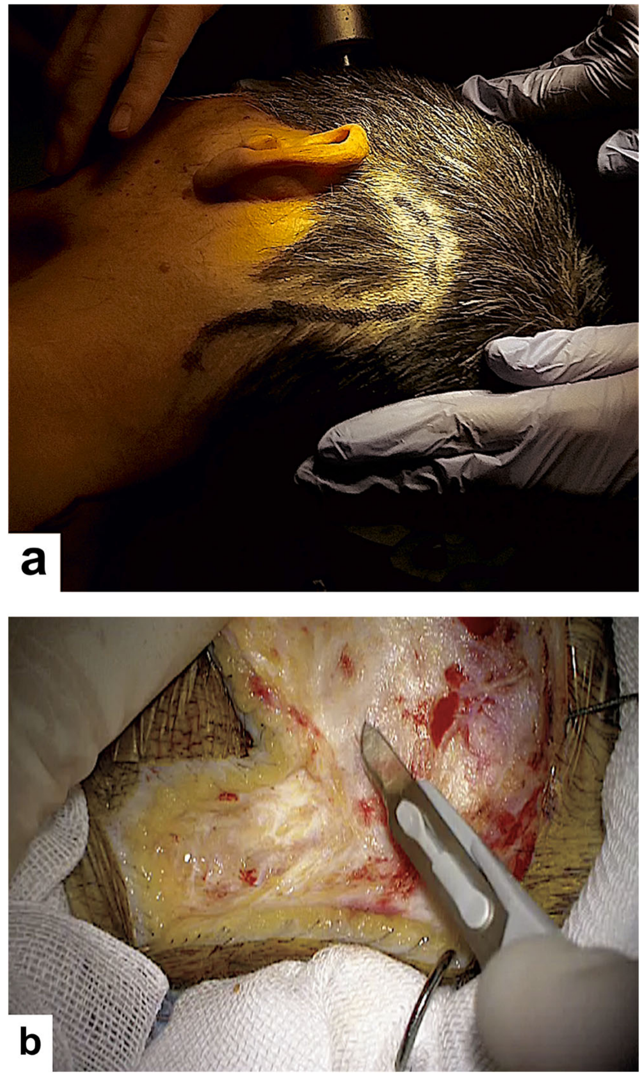

Fig. 1 A lazy inverted "S" postauricular suboccipital skin incision. **a** The incision is made 3 to 5 cm behind the mastoid process, starting at the level of the transverse sinus, extending caudally and slightly curved medially, and ending sharply medially at the level of the hairline. **b** The scalp flap is undermined and lifted from the most superficial muscular layer well behind the skin edge

Muscular dissection

Having done the skin retraction widely enough, the SCM passing obliquely downward and partially covering the SpCM is the most superficial muscle encountered (Fig. 2a). Following the identification of its thin medial border, the muscle is dissected laterally in a layer using monopolar coagulation along with partial dividing its upper attachment just below while preserving a cuff of its attachment for closure. Reflecting the SCM laterally exposes the lateral border of the SpCM (Fig. 2b). Detaching of the SpCM starts at its lateral border and continues medially while preserving a cuff of its upper attachment for closure and exposing the underlying longissimus capitis muscle (LCM) laterally (Fig. 2c, d) and

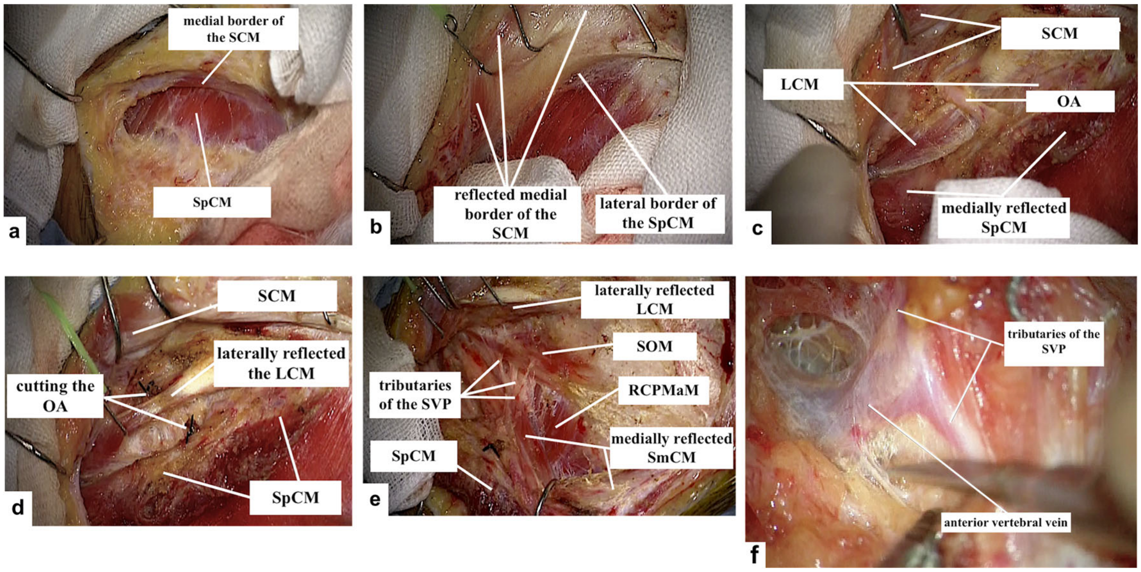

Fig. 2 A muscular dissection in the suboccipital region. **a** The sternocleidomastoid muscle laterally (SCM) and splenius capitis muscle (SpCM) medially are the first and most superficial muscles encountered. **b** The SCM has been dissected in layer and reflected laterally to expose the lateral border of the SpCM, which is attached just below the superior nuchal line. **c** The occipital artery (OA) passed superficial to the longissimus capitis muscle (LCM) and coursed medially between the semispinalis capitis (SmCM) and SpCM. **d** Reflecting the SpCM medially exposed the medial border of the LCM which was subsequently retracted laterally following the cutting of the OA. **e** The SmCM was reflected medially to expose the suboccipital triangle. The muscle can be reflected either separately or in a single layer with the SpCM if the SmCM is thin. **f** The anterior vertebral vein connects the superficial venous plexus (SVP) to deep venous plexus in the region of the fibrofatty tissue that covers the suboccipital triangle. (RCPMaM, rectus capitis posterior major muscle; SOM, superior oblique muscle)

semispinalis capitis muscle (SmCM) medially (Fig. 2e). The LCM is attached to the posterior margin of the mastoid process and extends inferiorly and medially to insert on the transverse processes of the upper thoracic vertebrae, while the SmCM arises in the area between the superior and inferior nuchal lines and pointing obliquely downward to the articular or transverse processes of C4–T7 [36]. The dissection of the LCM begins at its medial border and is directed laterally until the superior oblique muscle (SOM) and mastoid groove are exposed (Fig. 2e). Subsequently, the SmCM is dissected medially beginning at its lateral border. Its reflection exposes the rectus capitis posterior major muscle (RCPMaM). The LCM and SmCM along with the superficial muscular layer are kept in a new retracted position by fish hooks. The important step for achieving a sufficient exposure of the SOT is the dissection of the caudal part of the SpCM well behind the caudal end of skin incision. The releasing of fibrous tissue between the SpCM and LCM enables the retraction of the SpCM well medially that facilitates the exposure of the inferior oblique muscle (IOM).

Occipital artery

The occipital artery (OA) runs either above or under the LCM and subsequently courses medially between the SpCM and SmCM. One should, therefore, be aware of the vascular structure while dissecting the plane between the SpCM and LCM, especially when the preservation of the artery is required, e.g., for bypass procedure (Fig. 2c).

Venous structures

Venous structures coursing within intermuscular layers have been cited as the most common source of air emboli [5]. Therefore, their careful exposure followed by coagulation and cutting decreases the risk of the serious complication [30]. The first venous plexus encountered is the SVP located above the SpCM (Fig. 2e). Through a cleft between the SmCM and LCM, the anterior vertebral vein (AVV) connects the SVP to the DVP [30] that envelops the V3 in the SOT (Fig. 2f).

V3 exposure

The SOT is created above and laterally by the superior oblique muscle (SOM) which originates from the upper surface of the transverse process of C1 and attaches to the occipital bone, below and laterally by the IOM which extends from the spinous process and lamina of C2 to the transverse process of C1, and above and medially by the RCPMaM and rectus capitis posterior minor muscle (RCPMiM) (Fig. 2e). The RCPMaM is attached to the lateral portion of the occipital bone on the inferior nuchal line and inserts on the spinous process of C2, while the RCPMiM, which is partially covered by the RCPMaM, arises from the posterior arch of the atlas and attaches to the occipital bone in the midline [31]. The SOT is covered by the layer of fibrofatty tissue; its floor is formed by the posterior atlanto-occipital membrane and the posterior arch of the atlas, and the structures in the triangle are the V3 and the C1 nerve coursing on the lower surface of the artery and lying in a groove on the upper surface of the posterior arch of C1 [31]. Detaching and reflecting the SOM laterally (Fig. 3a) and RCPMaM medially (Fig. 3b) expose the V3 in depth of the triangle with encircling venous plexus. Occasionally, a caudal reflection of the IOM or removal of the fibrofatty tissue overlying the artery may be needed for its better exposure (Fig. 3c).

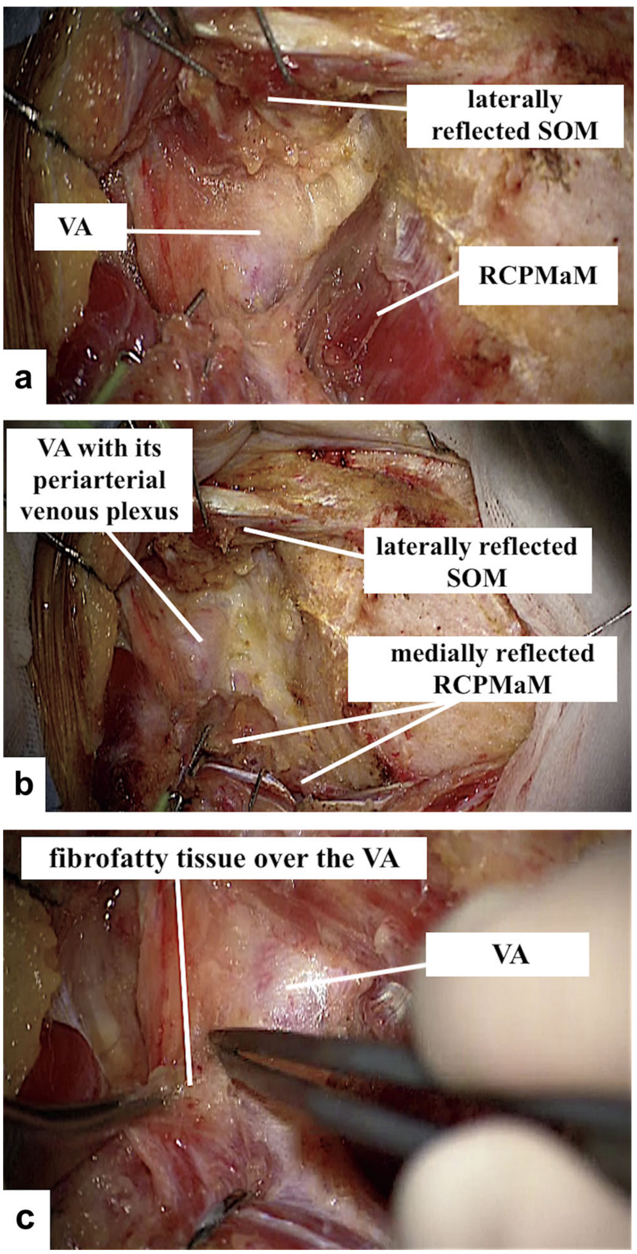

Fig. 3 An opening of the suboccipital triangle. **a** Reflecting the superior oblique muscle (SOM) exposed the lateral part of the suboccipital triangle. **b** The triangle was opened completely by reflecting the rectus capitis posterior major muscle (RCPMaM) medially. **c** The suboccipital triangle is covered by a layer of dense fibrofatty tissue which occasionally needs to be removed for better identification of the vertebral artery (VA)

Identification of the plane between the V3 and its venous plexus

The initial step in identifying the plane between the V3 and its rich venous plexus is the grasping and holding the plexus up slightly with atraumatic forceps while creating a small hole into it by bipolar forceps set at a low bipolar coagulating power (Fig. 4a). Having done the small hole, the plane between the V3 and its venous plexus is estimated and advanced (Fig. 4b). Subsequently, the V3 is exposed step by step using the bipolar coagulation for the obliteration of the part of DVP with its subsequent cutting by scissors repeatedly (Fig. 4c, d). As the V3 gives rise to muscular branches and the posterior meningeal artery [31], these vessels may need to be divided in order to mobilise or transpose the VA as needed (Fig. 4e).

Discussion

Craniovertebral surgeries usually require the V3 exposure initially [18, 21]. However, the complexity of suboccipital musculature [30], a relatively high incidence of anomalies in the course of the VA [1, 9, 14], and the presence of a rich venous plexus in this region [30] make the exposure challenging with a relatively high risk of varied complications. An inadvertent insult of the arterial or venous structures may cause a severe intradural or extradural haemorrhage [2, 22, 23, 29, 37], air embolism [30], or development of arteriovenous fistulae and pseudoaneurysms [2, 22, 23, 29, 37] resulting thus in significant morbidity and mortality [6, 16, 20, 26, 28, 32]. Many surgical techniques proposed for preventing these complications are based either on the identification of anatomical landmarks, such as inferior edge of the occipital bone [34], inferior nuchal [25] and atlanto-mastoid lines [24], or combination of inferior retrosigmoid and occipital midline dural points, C1 posterior tubercle and "J-groove" [35], or on manoeuvres, such as palpating the VA pulse [4] or using Doppler probe [38]. A drawback of these methods is the reliance on a variable relationship between the V3 and bony prominences along with performing suboccipital muscledissection in a single flap. For instance, although the mean distance from the lower rim of the occipital bone to the V3 is about 6 ± 2.5 mm, in up to 12% of cases, no space between the artery and occipital bone was found [34]. A similar variability was observed in depth of the V3 relative to the lateral and medial ends of the inferior nuchal line, ranging from 3.5 to 15.0 and 12.6 to 34.5 mm, respectively [25]. Of note, for reliability of this method, the exact determination of the points where the two ends of the line are localised is essential. However, as it is rather subjective varying from surgeon to surgeon, deviation

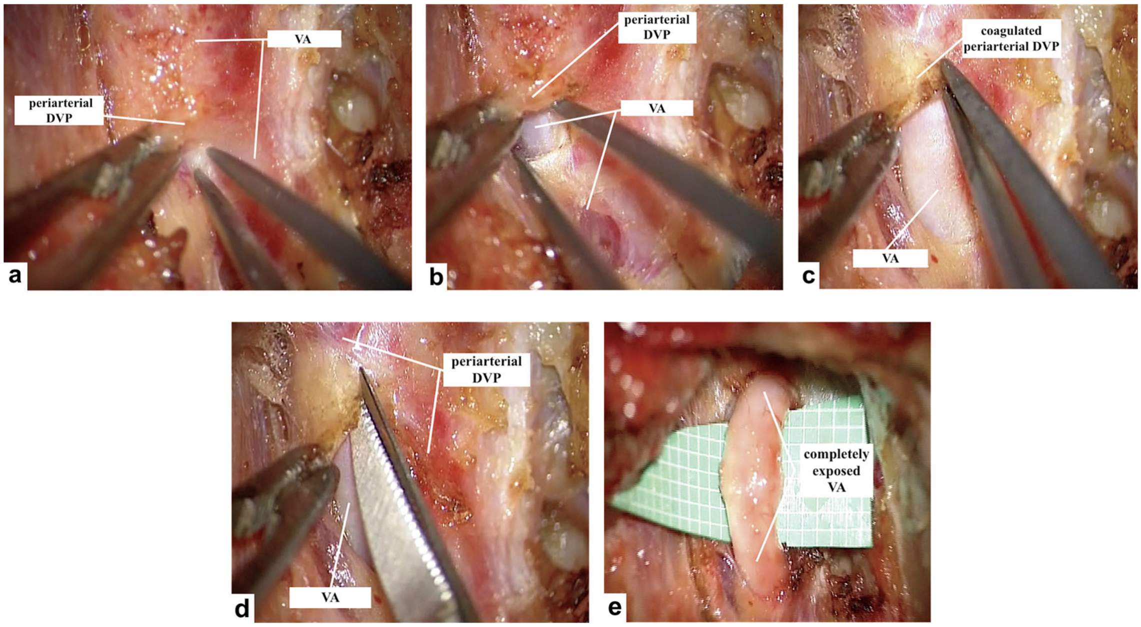

Fig. 4 An exposure of the third segment of the vertebral artery (VA). **a** Creating a small hole into the layer of the deep venous plexus (DVP) surrounding the VA while holding it up slightly with anatomical forceps. **b** The estimation of plane between the VA and DVP. **c** The coagulation of small part of the periarterial venous plexus. **d** The cutting of coagulated part of the DVP. **e** A complete exposure of the VA in the suboccipital triangle

of several millimetres might lead to the failure of this technique. Such like objections to fidelity of measurement can be also applied in the case of utilising atlanto-mastoid line [24]. Other authors [35] suggested a group of four landmarks including "J-groove" on the C1 that might help surgeon identify the V3. However, the initial need for foramen magnum opening while performing suboccipital craniotomy poses the risk of V3 injury as aforementioned [34]. Moreover, a flat shaped "J-groove" observed in up to 25% of dissections [35] may make the V3 exposure even less straightforward. Reliance on such inaccurate landmarks may therefore, in certain cases, lead to a higher risk of iatrogenic VA injury [27]. Contrary, the individually dissected muscles are reliable and stable landmarks by themselves aiding to identify underlying muscles, nerves, and vessels safely regardless of the relationship between them and surrounding bony structures. The muscles are like traffic signs on a well-marked road, no matter what is your destination (VA vs OA). One, however, must follow them and avoid field roads unless they want to lose direction or destroy a car, even though the journey with these shortcuts might seem faster. While performing surgeries in the lateral suboccipital region, a trajectory of both the skin incision and muscle dissection in a single flap usually coincides with the position of the SVP, thereby increasing the risk of air embolism and abundant bleeding [30]. The trajectory is also perpendicular to the long axis of the VA that is more risky compared to the layer-by-layer technique, where the plane of dissection between the vessel and surrounding tissue runs parallel to its axis. In addition, the retraction of dissected muscles in a single flap while identifying the V3 in the SOT may cause the rupture of the AVV or tributaries of the SVP contributing thus to ongoing bleeding [30]. Finally, the V3 can bulge through the SOT posteriorly; therefore, the VA can be easily damaged if one expects to find the V3 in the depth of the SOT [36]. Contrary to the blind dissection in a single flap, the muscle dissection in layers enables careful inspection of the underlying fibrofatty tissue over the VA following the reflection of the LCM and SmCM. Moreover, as the AVV and SVP course in the clefts between the suboccipital muscles, a careful dissection of the layers permits their clear identification, and their subsequent obliteration by bipolar coagulation and cutting ultimately prevents air influx into them in ongoing procedure. In the event of revascularization procedure intended, undeniable advantage of this method is the easiness and reliability in identifying the OA. Dissection of the artery is generally considered as one of the most difficult part of these procedures and its damage during dissection as one of the most serious complications [12]. Contrary to the standard procedure [12], the dissection of the OA starts proximally at the mastoid groove following retraction of the SCM and SpCM and continues distally in a layer between the SpCM and SmCM. Utilising a transcutaneous Doppler probe for identification of its course is of little benefit, as the OA is identified based on unmistakable anatomical landmarks, such as mastoid groove, LCM, and intermuscular layer between the SpCM and SmCM. The last potential source of severe bleeding is the DVP that cushions the V3 [3]. Due to similarities with the cavernous sinus, it is called the suboccipital cavernous sinus [3]. One of the methods how to avoid venous bleeding while dissecting the V3 is to preserve the fibrous membrane surrounding the DVP itself [3]. If bleeding does occur, frequently utilised technique is to pack it with a haemostatic blood-clot-inducing material. However, handling the artery still besieged with a rich/packed venous plexus while proceeding surgery (e.g., its transposition), may increase the risk of (re) bleeding or air embolism and thus make surgery more risky and less comfortable. In order to avoid the complications, we prefer the bloodless identification of the plane between the V3 and its surrounding venous plexus with initial small hole made into it by bipolar forceps set at a low coagulating power followed by the bloodless VA dissection off the plexus by means of repeated sequential obliteration of the DVP with its cutting. The V3 is finally stripped off the plexus throughout its course, and the risk of complications in the ongoing procedure is thus minimised to almost zero. Furthermore, a clean, bloodless operating field facilitates the preservation of the C1 nerve and the origin of the posterior spinal artery if present. After adoption of the surgical concept, no clinically significant air embolism, bleeding from the venous structures, or injured VA or OA have been recorded in our practice.

Conclusion

The proposed surgical concept embracing the individual muscle dissection in layers overcomes the drawbacks inherent in a blind dissection of the V3 while dissecting the suboccipital muscles in a single layer. The understanding of anatomical relationship between the suboccipital muscles is especially important for a clear identification of the SOT and V3, as each of the muscles represents substantial landmark aiding each subsequent step of the procedure and thus helping identify underlying structure. This technique along with a bloodless identification of the plane between the VA and DVP followed by a bloodless VA dissection off the plexus is, therefore, the prerequisite for a safe V3 exposure while performing craniovertebral junction surgeries.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approved The study was performed according to the ethical standards of the Institutional Review Board of the Asahikawa Red Cross Hospital.

Informed consent Patients' consents were obtained from all participants, even though their identity was concealed and anonymity guaranteed in the publication.

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