Microsurgical Anatomy for Lateral Approaches to the Foramen Magnum with Special Reference to Transcondylar Fossa (Supracondylar Transjugular Tubercle) Approach

ABSTRACT—Microsurgical anatomy for lateral approaches to the foramen magnum, especially for transcondylar fossa (supracondylar transjugular tubercle) approach, was studied using cadavers. The transcondylar fossa approach is an approach in which extradural removal of the posterior portion of the jugular tubercle through the condylar fossa is added to the far lateral approach. Some differences between this approach and the transcondylar approach are demonstrated. The atlanto-occipital joint and the jugular tubercle are obstacles for the lateral approaches. The condylar fossa forming the external occipital surface of the jugular tubercle is located supero-posterior to the occipital condyle. The fossa is limited laterally by the sigmoid sulcus and the jugular foramen. The posterior condylar canal communicating anteriorly with the distal end of the sigmoid sulcus, the jugular foramen, or the hypoglossal canal opens at the bottom of the fossa. The condyle is situated inferior to the posterior condylar and hypoglossal canals, and the jugular tubercle is located superior to them. In the transcondylar fossa approach the posterior part of the jugular tubercle is extradurally removed, but the condyle and the atlanto-occipital joint are untouched. On the other hand, in the transcondylar approach the medial parts of the condyle and the lateral mass of C1 are removed. The latter approach offers better visualization of the inferior part of the foramen magnum. The essential difference of the two approaches is in the direction of looking and the extent of resection of the atlanto-occipital joint. Both approaches offer excellent view of the ventral dural space in the lower clivus and the foramen magnum, but the level of exposure differs somewhat between them. In the lateral approaches to the foramen magnum, the condylar fossa, the posterior condylar canal, and the posterior condylar emissary vein all play an important role as intraoperative anatomical landmarks.

Lateral approaches¹⁻⁸ have often been utilized to operate on lesions anterior to the medulla oblongata or lesions of the vertebral artery. The far lateral approach,^{3,4} transcondylar approach,¹ and extreme lateral approach⁸ are well known and popular as lateral approaches. Studies on the microsurgical anatomy of the foramen magnum⁹⁻¹¹ have been increasingly done, but differences among these various approaches have not yet to be analyzed from an anatomical view point. We recently used the transcondylar fossa (supracondylar transjugular tubercle) approach for surgery of VA (vertebral artery) aneurysms, glossopharyngeal neuralgia, and some tumors around the foramen magnum.^{6,12} Therefore, the microsurgical anatomies for the transcondylar fossa approach and the other lateral approaches to the foramen magnum were thus comparatively studied using cadavers, and the differences among these approaches were therefore clarified.

MATERIALS AND METHODS

A few formalin-fixed heads and skulls provided the materials for this study. The arteries and veins of the heads were perfused with colored latex to clarify the vessels. Both transcondylar fossa and transcondylar approaches were performed using the heads. In addition, obstacles in the surgical view and differences in the visualization in both approaches were investigated. The

appropriate removal of bone was also investigated using a few skulls. The examined bony structures included the atlanto-occipital joint, occipital condyle, condylar fossa, posterior condylar canal, hypoglossal canal (anterior condylar canal), and jugular tubercle. The arteries examined included the intra- and extracranial VA and the posterior inferior cerebellar artery (PICA). The veins included the venous channel system around the jugular tubercle and the condyle, that is, the vertebral venous plexus, posterior condylar emissary vein, vein in the hypoglossal canal, marginal sinus, and jugular bulb.

Basic Anatomy of the Lateral Part of the Foramen Magnum

The lateral wall of the foramen magnum is composed of the jugular tubercle, the occipital condyle and the lateral mass of the atlas (Figs. 1A and B). The most important structure is the occipital condyle, which forms the atlanto-occipital joint with the superior articular fovea of the lateral mass (Figs. 1A and 2A). The location of the occipital condyles differs in each case. The more posterior the condyle is located, the greater it becomes as an obstacle for the approaches. The condyle is limited laterally by the jugular bulb, and a concave area called condylar fossa is also situated posterior to it (Figs. 2B and C). The condylar fossa forms the external surface of the jugular tubercle (Figs. 2B-D, and 4D). The posterior

Figure 1. The right lateral wall of the foramen magnum. (A) Posterior view. The occipital bone has been partially removed, and the condyle, atlanto-occipital joint, posterior condylar canal, jugular tubercle, and hypoglossal canal are all clearly visible. The jugular tubercle is situated superior to the hypoglossal canal. The large posterior condylar emissary vein runs in the posterior condylar canal, which is located in the bone just posterior to the jugular tubercle. The sigmoid sinus courses just lateral to the posterior condylar emissary vein and the marginal sinus runs medial to the condyle. (B) A superior view of the cross section at the level of the hypoglossal canal. The jugular bulb, hypoglossal sinus and posterior condylar emissary vein can be seen. The vein courses in the posterior portion of the jugular tubercle between the sigmoid sinus and the foramen magnum. The 12th cranial nerves run in the hypoglossal canal.

Figure 2. The bony structures in the cranio-vertebral junction, especially the condylar fossa and posterior condylar canal. (A) A posterior view of the junction. From this view it is difficult to see the condylar fossa. A slight concave area is visible above the atlanto-occipital joint. (B) A right postero-inferior view of the skull. The skull is a little tilted anteriorly and the foramen magnum is observed from the right posterior-inferior side. The right condylar fossa which is located posterior to the occipital condyle is clearly visible. The posterior condylar canal can be also seen at the bottom of the fossa. (C) An inferior view of the right condylar fossa and the occipital condyle. (D) A superior view of the same part. The jugular tubercle, the sigmoid sulcus and the jugular foramen can be seen. The medial portion of the condyle is also seen inferior to the jugular tubercle.

condylar canal, through which the posterior condylar emissary vein runs, opens at the bottom of the fossa (Figs. 2B, 4B). The posterior condylar canal courses between the posterior part of the jugular tubercle and the occipital condyle and communicates anteriorly with the distal end of the sigmoid sulcus, the jugular foramen, or the hypoglossal canal (Figs. 1B, 4B–D). The jugular tubercle is situated superior to the posterior condylar and hypoglossal canals and the occipital condyle is situated inferior to them (Figs. 1A, 3A and B, and 4D). The posterior part of the jugular tubercle is limited laterally by the sigmoid sulcus and medially by the foramen magnum (Figs. 1A and B).

After passing the transverse foramen, the extracranial VA courses in the vertebral sulcus of the atlas running around the atlanto-occipital joint (Fig. 2A). There-

after it penetrates the dura mater. The artery courses somewhat inferior to the joint and is surrounded by the vertebral venous plexus (Fig. 1A). When it penetrates the dura mater, it branches the posterior spinal artery. The initial portion of the intracranial VA is fixed by the dentate ligament (Fig. 1A).

There are many veins in the lateral part of the foramen magnum, and they all look complicated. However, the venous system should be considered to be a systemic channel. First there are three large venous poolings—the vertebral venous plexus, the marginal sinus, and the jugular bulb. The posterior condylar emissary vein and the vein in the hypoglossal canal communicate with all three (Figs. 1B, and 4A). The posterior condylar emissary vein communicates posteriorly with the vertebral venous plexus at the condylar fossa and anteriorly

Figure 3. The relationship between the hypoglossal canal and the occipital condyle and the jugular tubercle. (A) A medial view of the right lateral wall of the posterior fossa. The acoustic meatus, jugular foramen, and hypoglossal canal are visible. The jugular tubercle is situated superior to the hypoglossal canal and the occipital condyle is inferior to the canal. (B) A posterior view of the cutting surface of the right occipital bone. The right foramen magnum has been removed to show the cutting surface of the jugular tubercle and the occipital condyle. The jugular tubercle is situated superior to the hypoglossal canal and the occipital condyle is inferior to the canal.

with the jugular bulb or the vein in the hypoglossal canal (Figs. 1B, and 4B and C). The occipital sinus also sometimes drains into the jugular bulb.

Anatomy for the Transcondylar Fossa and Other Lateral Approaches

Transcondylar Fossa Approach

In the lateral approach, the jugular tubercle remains a major obstacle (Figs. 3B, and 4C and D). In the transcondylar fossa approach, the jugular tubercle is extradurally removed while the occipital condyle remains intact. This is a key point regarding the transcondylar fossa approach which should be clearly distinguished from the transcondylar approach. In addition to the lateral suboccipital craniotomy, either with or without the removal of the arch of the C1, the condylar fossa and the posterior part of the jugular tubercle are extradurally removed up to the hypoglossal canal. The removal of the bone from the condylar fossa results in a defect in the posterior part of the jugular tubercle (Figs. 4A and 5A, B, and D). Therefore, this approach can also be called the supracondylar transjugular tubercle approach. During this procedure, the condylar fossa, the posterior condylar canal, and the posterior condylar emissary vein are used as anatomical landmarks.

This surgical procedure is performed with the patient in the prone position. A horse shoe skin incision and a muscle flap are made. When the rectus capitis posterior major and minor muscles are detached from the inferior nuchal line and posteriorly reflected, the condylar fossa and the posterior condylar emissary vein

appears (Fig. 4B). Thereafter, a suboccipital craniotomy is done. It extends from below the transverse sinus laterally to the sigmoid sinus and to the opposite side of the midline across the foramen magnum. The foramen magnum should be widely opened to extend the midline dural incision to the level of C1. At this step the posterior condylar emissary vein communicating with the vertebral venous plexus is coagulated and cut at the bottom of the condylar fossa, and the posterior condylar canal is confirmed. Following the canal and the vein in the canal anteriorly, the condylar fossa and the jugular tubercle superior to the canal are extradurally drilled to the hypoglossal canal. During the removal of the posterior part of the jugular tubercle, the sigmoid sinus is visible laterally, and the foramen magnum is noticed medially through the dura mater (Figs. 4C and D). It is particularly important that the bone medial to the posterior condylar canal be removed. After a triangle-shaped removal of the posterior part of the jugular tubercle, the dura mater exposed by bone removal is opened and a sufficient operative field is thus obtained. The low clivus region and the working space increases in size. The jugular foramen, the hypoglossal canal, the lower cranial nerves, the choroid plexus at the foramen of Luschka, the VA, and the PICA are thus exposed close to the surgeon. The entire courses of the lower cranial nerves and of the lateral medullary segment of the PICA are clearly visible, and furthermore, the distal portion of the VA can also be seen with a minimal retraction of the medulla oblongata. This approach therefore seems quite appropriate for the lesions of the VA and in the ventral intradural space in the lower clivus. The removal of the arch of the C1 allows for an increased visualization inferiorly.

Figure 4. The transcondylar fossa approach. (A) A schematic illustration of the right transcondylar fossa approach. The oblique lines indicate the removal of the posterior portion of the jugular tubercle in this approach, which is superior to the posterior condylar canal. The atlanto-occipital joint is thus kept intact. (B) A hemi-suboccipital craniectomy is performed. The posterior condylar emissary vein is exposed in the condylar fossa. It drains into the vertebral venous plexus. (C) The vertebral venous plexus has been removed, and the dura mater has been opened to show the relationship of the anatomical structures in the lateral wall of the foramen magnum. The cross section of the posterior condylar emissary vein is visible in the canal. The condyle and the atlanto-occipital joint are located inferolateral to the divided vein. The posterior condylar canal and the jugular tubercle are the biggest obstacles in the approach to the lower clivus. The 9th, 10th, 11th, and 12th cranial nerves can be seen. (D) The skull demonstrates the bony structure from the same view as that shown in (C).

Differences Between the Transcondylar Fossa and the Transcondylar Approaches

In the transcondylar approach the medial parts of the occipital condyle and the lateral mass of C1 are removed in addition to the transcondylar fossa approach mentioned above (Figs. 5A–C). This approach provides a good additional view of the anterior portion in the foramen magnum below the level of the hypoglossal canal. In some cases the contralateral VA or the VA-basilar artery union is visible. In this approach, however, some injury to the atlanto-occipital joint cannot be avoided.

Differences Among the Transcondylar Fossa, the Far Lateral, and the Posterolateral Approaches

The extent of the bone removal among the three approaches are a little different from each other. In the far lateral approach the condylar fossa is laterally removed as far as possible. In the transcondylar fossa approach the condylar fossa is removed not only laterally to the sigmoid sinus but also anteriorly to the hypoglossal canal. After performing the far lateral approach, the posterior part of the jugular tubercle between the sigmoid sinus and the foramen magnum is drilled away to the hypoglossal canal, but the occipital condyle is not

Figure 5. The difference in the bony removal among the lateral approaches. The vertical lines (blue) demonstrate the extent of the bony removal in the far lateral approach, the oblique lines (red) show the transcondylar fossa approach; and the transverse lines (yellow) show additional removal in the transcondylar approach.

touched (Figs. 5A,C, and D). The transcondylar fossa approach is almost the same approach as the posterolateral approach by Perneczky.⁷ Both approaches utilize the supracondylar transjugular tubercle approach thus avoiding the injury to the atlanto-occipital joint. In the posterolateral approach, however, the extent of the bone opening is not precise, and the medial portion of the foramen magnum is not opened. In the transcondylar fossa approach, the occipital bone, particularly the condylar fossa and the jugular tubercle, are precisely removed with the aid of the landmarks of both the posterior condylar canal and the vein. Furthermore, the suboccipital bony removal extends to the opposite side of the midline, and allows for the inferior extension of the dural incision to the level of the C1. When an inferior approach is required, a C1 laminectomy is added and then the dural incision should be extended infero-medially.

DISCUSSION

The lateral approaches to the foramen magnum include the far lateral,^{3,4} posterolateral,⁷ and transcondylar approaches.¹ Their differences are not always clear and

it is thus difficult to understand them. Therefore, in this study the definition of each approach was anatomically clarified using cadavers. Furthermore, the name "transcondylar fossa approach" is thus proposed to the described approach modified from a combination of the far lateral^{3,4} and posterolateral⁷ approaches.

The differences among the lateral approaches are based on the extent of the bony removal and opening. Heros investigated the far lateral approach, and stated that the most important aspect of the far lateral approach is a very radical removal of bone, going laterally as far as the condylar fossa just posterior to the occipital condyle and just above and behind where the vertebral artery enters the dura.³ In his approach the occipital condyle is untouched and the removal of the jugular tubercle was also not mentioned. Later, Bertalanffy and Seeger reported the transcondylar approach to the lower clivus and anterior portion of the craniocervical junction.¹ They stressed that the posteromedial portion (6–8 mm) of the occipital condyle and lateral mass of the atlas should be drilled away, and that the drilling should then be continued anteriorly to expose the hypoglossal canal and cranially until the jugular tubercle is resected. In their approach the essential part is a partial resection of the

occipital condyle and the lateral mass. They reported no morbidity in their approach. However, if the removal of the atlanto-occipital joint is not necessary, it had better be kept intact. The jugular tubercle is a greater obstacle than the condyle in many lesions of the vertebral artery or anterior to the medulla oblongata.¹⁰ Perneczky also offered the same opinion.⁷ We are now using the transcondylar fossa approach.^{6,12} In this approach, the condylar fossa superior to the posterior condylar canal is extradurally drilled anteriorly. This results in the extradural removal of the posterior portion of the jugular tubercle without injuring the occipital condyle. This approach differs from the far lateral approach³ and the transcondylar approach.¹ Only the supracondylar part, namely the jugular tubercle, is removed. This approach may also be called the supracondylar transjugular tubercle approach, and is almost the same as the posterolateral approach described by Perneczky.⁷ However, in the transcondylar fossa approach we anatomically show the precise and effective bone removal of the supracondylar transjugular tubercle approach. The name "transcondylar fossa approach" also seems to convey a more precise image of the actual procedure used in this approach. The most important procedure in this approach is the drilling of only the condylar fossa, and the posterior condylar canal and the emissary vein in the canal both play an important role as anatomical landmarks in differentiating between the jugular tubercle and the occipital condyle from outside. The bony opening in the approach is a little different from that in the posterolateral approach. In the transcondylar fossa approach the foramen magnum is opened to the opposite side of the midline to extend the dural incision inferomedially to the level of the C1. This is also important for obtaining a sufficient surgical field.

The transcondylar fossa approach is considered to be the first choice for lesions of the vertebral artery or those anterior to the medulla oblongata. It is a good approach for viewing lesions in the middle and lower clivus through the supero-medial direction of the surgical microscope. We are now using it for the surgery of VA-PICA aneurysms, glossopharyngeal neuralgia, and tumors around the hypoglossal canal. However, this approach cannot provide a sufficient visualization in lesions below the margin of the foramen magnum or those inferomedial to the VA. An additional C1 laminectomy offers a greater visualization inferiorly. It can also be

easily converted to the transcondylar approach during surgery, if necessary.

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