Transcondylar Fossa (Supracondylar Transjugular Tubercle) Approach: Anatomic Basis for the Approach, Surgical Procedures, and Surgical Experience

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ABSTRACT

The authors clarify the anatomic basis and the usefulness of the transcondylar fossa approach (T-C-F A), in which the posterior portion of the jugular tubercle is removed extradurally through the condylar fossa with the atlanto-occipital joint intact. The authors first performed an anatomic study to identify the area to be removed using cadaveric specimens and then applied the T-C-F A to foramen magnum surgeries. The surgeries included clipping a vertebral artery–posterior inferior cerebellar artery aneurysm in 11 cases, microvascular decompression for glossopharyngeal neuralgia in 15 cases, and removing intradural foramen magnum tumors in 17 cases. Only the condylar fossa was removed, but the approach offered very good visualization of the lateral part of the foramen magnum and sufficient working space. These surgeries were performed safely without major complications. This skull base approach is minimally invasive and is not difficult. Therefore, it can be a standard approach for accessing intradural lesions of the foramen magnum. It can be combined with the transcerebellomedullary fissure approach from the lateral side and can also be easily changed to the transcondylar approach, if necessary.

KEYWORDS: Foramen magnum, lateral approaches, VA-PICA aneurysm, glossopharyngeal neuralgia, foramen magnum tumor

Lateral approaches to the foramen magnum,^{1–11} which have often been utilized to operate on lesions anterior to the medulla oblongata or lesions of the vertebral artery (VA), are very useful. The far lateral approach,⁴ transcondylar approach (T-C A),¹ and extreme lateral approach¹¹ are well-known lateral approaches. However, differentiating from the T-C A,¹ we have used the transcondylar fossa

approach (T-C-F A)^{6,7} as a variation for VA aneurysm surgery, microvascular decompression (MVD) for glossopharyngeal neuralgia (GPN), and intradural tumor surgery around the jugular tubercle.^{12–15} Recently, a few authors^{8,16} have also reported that it is not necessary to resect the occipital condyle to remove foramen magnum tumors in intradural cases. Here, we explain the anatomic idea of how to precisely

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remove only the jugular tubercle and introduce our surgical procedures of the approach. We also present our surgical experience to demonstrate its application. The advantages, disadvantages, and indications of the approach are discussed through a comparison with other lateral approaches to the foramen magnum.

MICROSURGICAL ANATOMY OF THE LATERAL PART OF THE FORAMEN MAGNUM AND ANATOMIC BASIS FOR THE T-C-F A

The lateral bony wall of the foramen magnum is composed of the jugular tubercle and the occipital condyle, which are both obstacles.^{7,17-19} The jugular tubercle is superior to the hypoglossal canal, and the occipital condyle is inferior to it (Fig. 1A). On the external surface of the skull, the condylar fossa is situated just superior to

the occipital condyle (Fig. 1B). The posterior condylar canal, through which the posterior condylar emissary vein runs, opens at the bottom of the fossa. 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 or the jugular foramen at the level of the hypoglossal canal (Fig. 1C,D). It is very important for surgeons who perform surgery on the lateral portion of the foramen magnum to understand the venous anatomy (Fig. 1E). The lateral portion of the foramen magnum is surrounded by the sigmoid sinus and jugular bulb laterally and the marginal sinus medially. The venous channels in the hypoglossal canal communicate between the jugular bulb and the marginal sinus. The posterior condylar emissary vein running in the canal communicates between the distal end of the sigmoid sinus and the vertebral venous plexus. Because the condylar fossa

Figure 1 The lateral wall of the foramen magnum, left side. (A) The bony structure, posterior view with the skull removed partially. The occipital bone has been partially removed, and the posterior condylar canal, jugular tubercle, hypoglossal canal, and condyle are all clearly visible. The jugular tubercle is situated superior to the hypoglossal canal and the condyle is inferior to it. The posterior condylar canal can be seen on the drilled surface of the posterior portion of the jugular tubercle. Oblique lines demonstrate removal of the bone with the transcondylar fossa approach. The green arrow indicates the transcondylar fossa approach. (B) Skull showing the condylar fossa and the condyle, left posteroinferior view. The skull is tilted a little anteriorly and the lateral portion of the foramen magnum is observed. The left condylar fossa, which is located posterior to the occipital condyle, is clearly visible. The posterior condylar canal can also be seen at the bottom of the fossa. (C) The craniovertebral junction. Posterior view in the cadaveric specimen. The occipital bone has been partially removed, and the condyle and atlanto-occipital joint are clearly visible. 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 laterally and the marginal sinus runs medially. (D) Lateral wall of the foramen magnum at the level of the hypoglossal canal, superior view in a cross section of the cadaveric specimen. The jugular bulb, hypoglossal sinus, and posterior condylar emissary vein can be seen. The vein courses in the posterior portion of the jugular tubercle. (E) A schematic illustration showing the venous system in the left lateral wall of the foramen magnum, superior view. (F) A schematic illustration indicating the bone removed through the left transcondylar fossa approach, superior view. The oblique lines indicate removal of the posterior portion of the jugular tubercle in the approach. A-O, atlanto-occipital; Cond., condylar; Em., emissary; Inf., inferior; Jug., jugular; Marg., marginal; Pet., Petrosal; Post., posterior; V., vein.

forms the external surface of the jugular tubercle, removing only the fossa will result in removing the posterior portion of the jugular tubercle (Fig. 1F). The posterior condylar canal and the posterior condylar emissary vein can be used as anatomic landmarks for precisely removing the bony structure and then the atlanto-occipital joint can be kept intact.^{6,7,17} Even in the T-C-F A, a sufficient operative field is obtained in most cases of intradural lesion of the foramen magnum. This is the reason it is better to use the T-C-F A differentiated from the T-C A. The lateral part of the cerebellomedullary fissure (CMF) is situated just in front of the jugular tubercle. It includes the foramen of Luschka and the lateral recess. When the lateral part of the fissure is dissected after the T-C-F A and the biventral lobule and the tonsil are lifted up, the operative working space becomes larger.

SURGICAL PROCEDURES OF THE T-C-F A

The park bench position or the prone position can be utilized. A paramedian vertical straight incision is also

available, but we prefer to employ a horseshoe skin incision. The skin and the muscle are cut together in the shape of a horseshoe and then entirely reflected posteriorly from the suboccipital surface (Fig. 2A). As a result, another muscle dissection is not necessary. When the rectus capitis posterior major muscle covering the extracranial VA and the vertebral venous plexus is detached from the inferior nuchal line and reflected, the posterior condylar emissary vein is found in the condylar fossa without touching the vertebral venous plexus (Fig. 2A). Because the vein communicates with the vertebral venous plexus, it should be coagulated and cut before the venous plexus is injured.

Next, a unilateral suboccipital craniotomy is done. The craniotomy extends from the midline superomedially to the sigmoid sinus laterally and along the foramen magnum across the midline to the opposite side inferiorly (Fig. 2B). The posterior part of the foramen magnum is completely opened but the C-1 laminectomy differs from case to case. The posteroinferior portion of the occipital bone is removed continuously while

Figure 2 Schematic illustrations showing step-by-step surgical procedures of the transcondylar fossa approach. (A) Skin incision and the burr hole making. (B) Bony opening. (C) Sigmoid-magnum triangle, the operative view just after the bony opening, posterior view. The cutting surface of the posterior condylar emissary vein can be seen at the bottom of the condylar fossa. When the dura mater covering the cerebellum is detached and retracted, an exposed bone looks like triangle between the sigmoid sinus and the foramen magnum. (D) Removing the jugular tubercle. The condylar fossa has been drilled and the posterior portion of the jugular tubercle is removed with the atlanto-occipital joint intact, and then the dura mater of the hypoglossal canal is exposed. (E) Incision of dural opening. (F) Intracranial view in a case of meningioma. A-O, atlanto-occipital; Dent. Lig., dentate ligament; Jug., jugular; P.I.C.A., posterior inferior cerebellar artery; Post. Cond. Em. V., posterior condylar emissary vein; V.A., vertebral artery.

leaving only the condylar fossa in place (Fig. 2B,C). When the posterior condylar emissary vein is cut, the condylar fossa can be confirmed. When the dura mater covering the cerebellar hemisphere is elevated with a spatula, the removed bone looks like a triangle between the sigmoid sinus laterally and the foramen magnum medially, which we call the sigmoid-magnum triangle (Fig. 2C). The apex of the triangle is the narrow portion of the jugular tubercle. The condylar fossa superior to the posterior condylar canal, which is the posterior portion of the jugular tubercle, is drilled extradurally and removed with the canal in sight as an anatomic landmark (Fig. 2D). Bone wax is packed when venous bleeding occurs from the posterior condylar canal. This process is essential for the approach when extradurally removing only the jugular tubercle. The bony removal along the canal anteriorly results in removing the posterior part of the jugular tubercle (Fig. 2D,E). First, the center of the sigmoid-magnum triangle is drilled and the lateral margin of the drilled hole is left for protection. Finally, the shell of this thin bony margin is removed.

The dura mater is opened along an oblique line, starting superolaterally and coming down toward the midline at the level of the foramen magnum and then straight down further to the C1 level (Fig. 2E). The dural flap is reflected inferolaterally. With a slight retraction of the cerebellum after the lateral portion of the CMF is dissected, the origin of the posterior inferior cerebellar artery (PICA) and the entire courses of the 9th and 10th cranial nerves are visible (Fig. 2F). The operating space is large and the lesion is close to a surgeon. Dissection of the lateral part of the CMF depends on the case. If necessary, the T-C-F A can also be changed easily to the T-C A after the occipital condyle and lateral mass are partially removed.

SURGICAL EXPERIENCE (CASES AND RESULTS)

VA-PICA Aneurysm Surgery

For the past 15 years one of the authors (T.M.) has performed a direct neck clipping of a saccular VA-PICA aneurysm in 13 cases via lateral approaches to the foramen magnum. Some of these cases have already been reported.^{14,15} In 11 of the 13 cases, the aneurysm was completely clipped through the T-C-F A. However, in one of the two remaining cases, the T-C-F A had to be changed to the T-C A because of the low midline location of the aneurysm. In the other case, the midline suboccipital approach associated with C1 laminectomy was selected due to the aneurysmal location just at the hypoglossal canal. The 11 cases included 6 ruptured and 5 unruptured ones.

In all cases, the aneurysm was easily clipped without any problems. The postoperative complications in these cases were mild and temporary. They included mild hypoglossal nerve paresis in two cases and temporary dysphagia in one case. All patients, except for one with severe spasm after SAH, were discharged ambulant, and their Glasgow outcome scale score was 1. The remaining case, who suffered from severe spasms due to subarachnoid hemorrhage, demonstrated a score of 3 on the Glasgow outcome scale postoperatively and died of cardiac failure 20 months after surgery.

ILLUSTRATIVE CASE OF ANEURYSM

A 69-year-old woman received neck clipping of the unruptured aneurysm, which was found by a brain examination. Three-dimensional computed tomography angiography confirmed a 5-mm saccular aneurysm at the VA-PICA junction, which was located anterosuperior to the jugular tubercle (Fig. 3A). The aneurysmal neck was clipped uneventfully through the T-C-F A (Fig. 3B,C). The patient was discharged without any neurological deficits.

MVD for GPN

During the past 12 years, 15 patients with GPN have received surgery by MVD through the T-C-F A. Radiological characteristics and surgical results of some of the 15 patients have been reported.^{13,20} In 10 of the 15 patients, the lateral medullary segment of the high-origin PICA formed an upward loop in the supraolivary fossa. These findings strongly suggest that the PICA should be compressing the glossopharyngeal nerve. During surgery, the offending vessels were confirmed to be the PICA in 10 cases, the AICA in 2 cases, and both arteries in 3 cases. In the cases with an upward loop of the PICA, it was transposed using a stitched sling retraction technique. All patients had complete pain relief immediately after MVD. One patient had a mild pain recurrence 1 year after surgery because of the interposing technique used for the offending AICA. Among surgical complications, two have mild hoarseness and dysphagia, which are not problems for their daily lives.

ILLUSTRATIVE CASE OF GPN

A 57-year-old woman was admitted with a diagnosis of GPN because of paroxysmal violent pain in the left pharynx. On the MRA, the left PICA with a high origin formed a loop in the supraolivary fossa (Fig. 4A,B). Through a left T-C-F A, the PICA was found to make a loop between the glossopharyngeal and vagal nerves, compressing the glossopharyngeal nerve (Fig. 4C,D). The loop of the PICA was pulled out and then fixed to the dura mater on the posterior portion of

Figure 3 A case of unruptured vertebral artery (VA)-posterior inferior cerebellar artery (PICA) aneurysm, left. (A) Preoperative three-dimensional computed tomography angiography (3D-CTA), posterosuperior view, demonstrating a saccular aneurysm (red arrow) at the left VA-PICA junction. (B) Intraoperative microscopic view, posterior view. The saccular aneurysm can be seen behind the PICA. The VA and the cranial nerve 11th and 12th are clearly visible. (C) Postoperative 3D-CTA, posterior view, demonstrating the aneurysmal clip (green arrow) parallel to the VA and the drilled jugular tubercle (red arrow). PICA, posterior inferior cerebellar artery; VA, vertebral artery.

the jugular tubercle (Fig. 4E,F). After surgery, complete remission of the neuralgia was obtained. She had no neurological deficits and has been doing well without pain for 2 years after surgery.

Surgery for Intradural Tumors around the Jugular Tubercle or the Hypoglossal Canal

In 17 cases of foramen magnum tumor, the main intradural tumor was removed through the T-C-F A. Eleven of the 17 cases had only intradural tumor, and the remaining six had extradural extension of a small part of the tumor in addition to a main intradural mass. In the latter group, the tumor extended extradurally through the jugular foramen and/or the hypoglossal canal. The 17 cases included 6 of meningioma, 6 of jugular foramen neurinoma, 2 of hypoglossal nerve neurinoma, 1 of ependymoma, 1 of hemangioblastoma, and 1 of chordoma. In the two cases of hypoglossal neurinoma, most of the tumor in the hypoglossal canal was also removed extradurally. In four cases, the tumor extended into the fourth ventricle. There was one case of

ependymoma, one neurinoma, and two meningioma, and the T-C-F A was combined with the trans-CMF approach from the lateral side. The four cases have already been reported.¹² Gross total removal was achieved in two cases, subtotal removal in 11, and partial removal in four of the 17 cases. We did not remove the tumors aggressively, particularly in cases of neurinoma, because of postoperative neurological deficits. The most frequent complications were temporary dysphagia and hoarseness. Permanent complications occurred in one patient with a jugular foramen neurinoma who could not eat or drink by herself for 6 months after surgery and still has small problems, and another patient with a meningioma who needs a cane to walk because of small infarction of the lateral medulla oblongata.

ILLUSTRATIVE CASE OF TUMOR TO WHICH THE T-C-F A COMBINED WITH THE TRANS-CMF APPROACH WAS APPLIED

A 56-year-old man developed a gait disturbance 12 years before visiting us. A huge left cerebellopontine angle meningioma had been subtotally removed through a left

Figure 4 A case of glossopharyngeal neuralgia, left. (A) Preoperative magnetic resonance angiography (MRA), anterior view, demonstrating the loop of the posterior inferior cerebellar artery (PICA; red arrow) with a high origin. (B) Preoperative magnetic resonance imaging (MRI), anterior view, demonstrating the loop of the PICA (red arrow) in the supraolivary fossa. (C) Intraoperative microscopic view, posterior view. The loop of the PICA is situated between the 9th cranial nerve and the 10th cranial nerve. (D) Intraoperative microscopic view. The loop of the PICA has been pulled out. (E) Postoperative MRA, anterior view, demonstrating the shift of the loop of the PICA. (F) Postoperative MRI, anterior view, demonstrating the shift of the PICA in the supraolivary fossa. PICA, posterior inferior cerebellar artery.

Figure 5 A case of recurrent meningioma growing into the fourth ventricle. (A) Preoperative enhanced magnetic resonance imaging (MRI), coronal view, demonstrating the tumor (red arrow). (B) Preoperative enhanced MRI, axial view, demonstrating the tumor (red arrow) growing into the fourth ventricle. (C) Postoperative enhanced MRI, coronal view, demonstrating the cavity after removing the tumor. (D) Postoperative enhanced MRI, axial view, demonstrating subtotal removal of the tumor.

lateral suboccipital approach during the first operation. The patient had right hemiparesis and symptoms related to cranial nerves V–X postoperatively, all of which gradually improved. This time, a recurrent tumor was found. The recurrent tumor was located in the foramen magnum, extending into the fourth ventricle through the left CMF (Fig. 5A,B). Therefore, we subtotally removed the tumor through the T-C-F A combined with the lateral route of the trans-CMF approach (Fig. 5C,D). After the T-C-F A, with retraction of the tonsil, the lateral part of the CMF was dissected and opened. This dissection provided views of not only the cerebellomedullary cistern but also the interior of the fourth ventricle. Postoperative course was uneventful.

DISCUSSION

The differences among lateral approaches to the foramen magnum are not always clear, thus it is difficult to understand them.^{1,4,11} The differences should be based on the extent of the bony opening. Salas et al¹⁰ demonstrated six variations of the extreme-lateral craniocervical approach based on the bone removed. In the T-C A, Bertalanffy and Seeger¹ stressed that the posteromedial portion (6 to 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. Furthermore, they reported no

morbidity due to drilling. It was an epoch-making report because they introduced the possibilities of partially removing the atlanto-occipital joint without any problems. However, the jugular tubercle is a greater obstacle than the condyle, especially in cases of intradural lesion of the foramen magnum.^{7,8,14,15} There are some cases in which it is not necessary to remove the atlanto-occipital joint.^{5,8,14,16} In such cases, the joint should be kept intact.

As a variation of the T-C A, we proposed the T-C-F A,^{6,7} which can also be called the supracondylar transjugular approach. Gilsbach et al,² who surgically treated three cases of tumor, also reported the supracondylar approach as a minimally invasive extradural approach. In a cadaveric study, Wen et al¹⁹ demonstrated the supracondylar approach as one of three approaches related to the occipital condyle. Perneczky's posterolateral approach and Salas' retrocondylar approach are also almost similar to the T-C-F A.^{9,10} We have applied the T-C-F A to intradural lesions for the past 15 years.^{12–15} When applying this approach, the condylar fossa, namely, the posterior portion of the jugular tubercle, is extradurally drilled anteriorly. The posterior condylar canal and the emissary vein in the canal both play an important role as intraoperative anatomic landmarks differentiating the jugular tubercle and the occipital condyle from outside.^{6,7,17} Therefore, the name "T-C-F A" seems to convey a more precise image of the actual procedure used in this approach.⁶ When applying the T-C-F A, the foramen

magnum should be 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 sufficiently wide surgical field. The T-C-F A provides an entire view of the cerebellomedullary cistern including the VA, the anterior and lateral medullary segments of the PICA, and the cisternal portion of the 9th, 10th, 11th, and 12th cranial nerves. Furthermore, when the CMF is dissected, the surgical field becomes larger and the lateral part of the fourth ventricle can be exposed.¹² This approach, which gives a wider operative field and closer access to the lesion, makes surgery easier and also reduces postoperative complications. We have applied the T-C-F A to surgery for VA-PICA aneurysm,^{14,15} MVD for GPN,¹³ and removal of intradural tumors around the jugular tubercle or the hypoglossal canal.¹²

In VA-PICA aneurysm surgery, serious postoperative complications have been reported.^{21–23} In the conventional lateral suboccipital approach, the operative field is narrow and deep, and the lower cranial nerve rootlets and operative instruments are often crossed perpendicularly, and therefore, the incidence of new postoperative deficits seems to be high. Kawase et al²⁴ and Bertalanffy et al,²⁵ who used the skull base approaches, reported that operative morbidity and mortality were relatively low. We have also employed either the T-C-F A or the T-C A depending on the locations of aneurysms, and subsequent new postoperative deficits were small in number.¹⁴ In 11 of our 13 cases, neck clipping of aneurysms could be done through the T-C-F A. Neck clipping was done from the inferior side parallel to the VA. As a result, it was easy to handle the lower cranial nerve rootlets. However, when an aneurysm was located in the midline or below the hypoglossal canal, the approach had to be changed to the T-C A.¹⁴

The surgical procedure of MVD for GPN has some difficult aspects compared with those for hemifacial spasm and trigeminal neuralgia. MVD for GPN has been reported to possibly be associated with more serious surgical complications than those for hemifacial spasm or trigeminal neuralgia.^{26–28} A conventional lateral suboccipital approach is not appropriate for MVD of GPN. Kondo²⁶ pointed out that a greater retraction of the cerebellar hemisphere was usually required to explore the root exit zones of the glossopharyngeal and vagus nerves. Therefore, we utilized the T-C-F A for GPN and obtained good surgical results.¹³ This approach has some advantages. First, the approach clearly shows the relationship between the glossopharyngeal nerve and the PICA. Second, it provides close access to the surgical field with a smaller retraction of the cerebellum. Finally, in this wide surgical field, we can pull out and transpose the offending loop of the PICA. In most GPN cases, the offending artery is the PICA with a high origin making an

upward loop.²⁰ The T-C-F A makes MVD for GPN both safe and reliable. Furthermore, the approach combined with the stitched sling retraction technique improves the surgical results. Therefore, this approach seems to be best for MVD for GPN.

In tumor cases, the surgical approach is completely different when removing an intradural tumor and a tumor including the extradural part. Margalit et al⁵ stated that VA mobilization and occipital condyle resection may be needed, depending on the extent and location of the foramen magnum tumor and its specific pathological characteristics. On the other hand, Nanda et al⁸ and Tange et al¹⁶ reported total removal of the intradural foramen magnum meningioma without resection of the occipital condyle. Margalit et al⁵ also removed the meningiomas without resecting the condyle in half of their cases. In most intradural tumor cases, removing the condyle seems to be unnecessary. Most of the cases to which we applied the T-C-F A for removing the intradural tumor were meningioma or neurinoma. During dissection and removal of the mass in the CMF, the lower cranial nerves and the PICA and its branches have to be taken into consideration. While avoiding damage to these delicate structures, complete resection of the tumor and improving operative outcome depend on a clear visualization of the relationships between the tumor and surrounding structures. The T-C-F A provides a sufficient operative field and good visualization of an intradural tumor. This approach can furthermore be combined with the trans-CMF approach for removing the special types of tumor.¹² When the tumor is located mainly in the unilateral cerebellomedullary cistern and extends to the lateral part of the ventricular cavity partially, we use the combined approach. This is quite natural when inferior and inferolateral extensions of the ependymomas through the CMF are considered.

The T-C-F A provides a sufficient operative field and good visualization of various kinds of intradural lesion in the foramen magnum. Therefore, the approach should be considered the first choice for such lesions. It is a minimally invasive skull base approach based on the surgical anatomy.

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