



Evolution of cerebellomedullary fissure opening: its effects on posterior fossa surgeries from the fourth ventricle to the brainstem

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Received: 10 March 2020 / Revised: 10 March 2020 / Accepted: 30 March 2020 / Published online: 12 April 2020
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Abstract

Surgical approaches to the fourth ventricle and its surrounding brainstem regions have changed significantly in the previous 30 years, after the establishment of cerebellomedullary fissure (CMF) opening. With the development of CMF opening techniques, CMF opening surgeries have become widely used for the treatment of various pathologies and have contributed to the improvement of surgical results in posterior fossa surgeries. We here review the historical progress of CMF opening surgeries to help the future progression of neurosurgical treatments. The authors studied the available literature to clarify how CMF opening surgeries have developed and progressed, and how much the idea and development of CMF opening techniques have affected the advancement of posterior fossa surgeries. With the establishment of angiography, anatomical studies on CMF in the 1960s were performed mainly to clarify vascular anatomy on radiological images. After reporting the microsurgical anatomy of CMF in a cadaveric study in 1982, one of the authors (T.M.) first proposed the clinical usefulness of CMF opening in 1992. This new method enabled wide exposure of the fourth ventricle without causing vermian splitting syndrome, and it took the place of the standard approach instead of the conventional transvermian approach. Several authors reported their experiences using this method from the end of the twentieth century to the early twenty-first century, and the naming of the approach, “telovelar approach” by Mussi and Rhoton in 2000 contributed to the global spread of CMF opening surgeries. The approach has become widely applied not only for tumors but also for vascular and brainstem lesions, and has assisted in the development of their surgical treatments, and brought up the idea of various fissure dissection in the posterior fossa. Studies of microsurgical anatomy of the fourth ventricle, including the CMF, has led to new surgical approaches represented by the transCMF/telovelar approach. The CMF opening method caused a revolution in posterior fossa surgeries. The idea was developed based on the experience gained while dissecting the CMF (the roof of the fourth ventricle) in the laboratory. Anatomical studies using cadaveric specimens, particularly their dissection by surgeons themselves, together with a deep understanding of brain anatomy are essential for further advancements in neurosurgical treatments.

Keywords Brainstem surgery · Cerebellomedullary fissure · Fourth ventricular tumor · Telovelar approach · Transcerebellomedullary fissure approach

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Introduction

Since Dandy's report in 1945 [8], the transvermian approach has been utilized as the standard approach for surgeries of the fourth ventricle [7, 24]. The surgical approach to the fourth ventricle and its surrounding regions significantly changed at the end of the twentieth century, owing to development of the transcerebellomedullary fissure (transCMF)/telovelar approach. Similar to the Sylvian fissure in the supratentorial areas, opening of the cerebellomedullary fissure, which is the largest fissure in the posterior fossa, can be used as a safe and wide gateway in posterior fossa surgeries. The CMF began to be studied in the

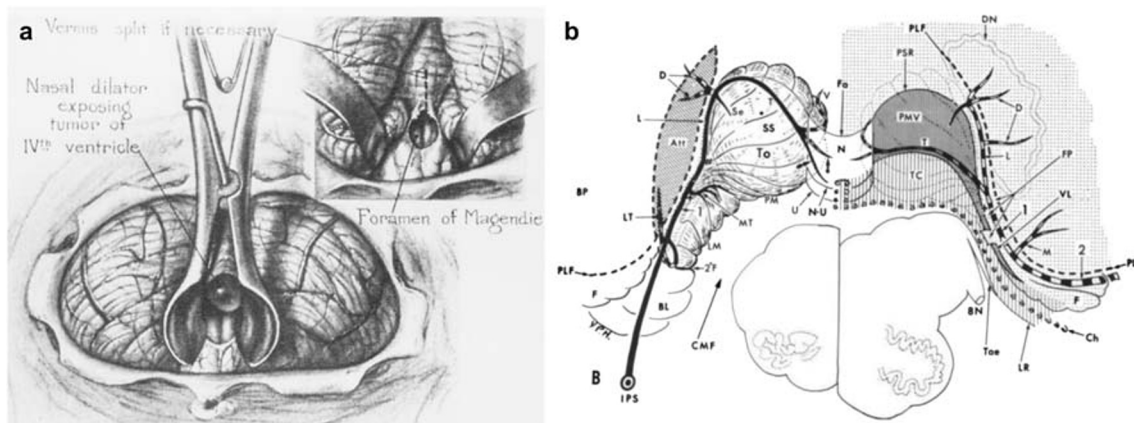


Fig. 1 Diagrams from the beginning of fourth ventricular surgery and of anatomical studies of cerebellomedullary fissure (CMF). **a** Illustration of Dandy's transvermian approach. Modified with permission from Cohen

AR: Surgical approach to the fourth ventricle, 1996 [7]. **b** Illustration showing the CMF and veins coursing in the fissure. Modified with permission from Huang and Wolf: *Am J Roentgenol* 101:1–21, 1967 [17]

1960s for understanding angiography [17]. The surgical anatomy of the CMF was clarified in our study of the fourth ventricle, when we started research on its microsurgical anatomy lead by Rhoton [36]. One of the authors (T.M.), based on his own experience of dissection around the tonsil in that fourth ventricle study, began in the 1980s to open the CMF to expose fourth

ventricular and/or brainstem lesions, instead of incising the inferior vermis [29, 31]. Subsequently, at the end of the twentieth century, the CMF opening method began to be applied to various lesions in and around the fourth ventricle [19, 23, 34, 44, 46]. The name telovelar approach, which was proposed by Mussi and Rhoton [37] in 2000, contributed to the spread of this method

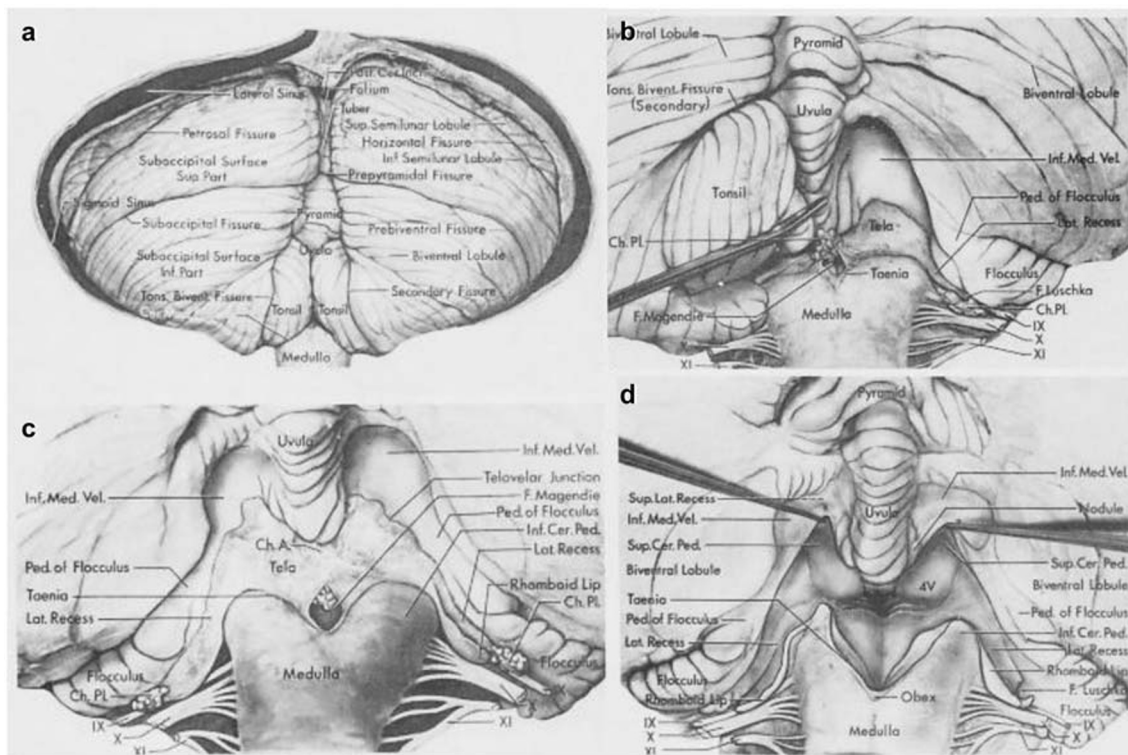


Fig. 2 Diagrams showing step-by-step cadaveric dissection to expose CMF in an anatomical study of the fourth ventricle, which subsequently led to the idea of CMF opening. **a** Suboccipital surface of the cerebellum. **b** Enlarged view with the right tonsil and the adjacent part of the biventral lobule removed to expose the external surface of the lower part of the roof of fourth ventricle which is the floor of the CMF. **c** Whole view of the

bilateral CMFs after removing both tonsils and the medial part of the biventral lobules. **d** The superolateral recesses after removing the tela choroidea and lifting up the inferior medullary velum by right-angled nerve hooks. Modified with permission from Matsushima T et al.: *Neurosurgery* 11:631–667, 1982 [36]

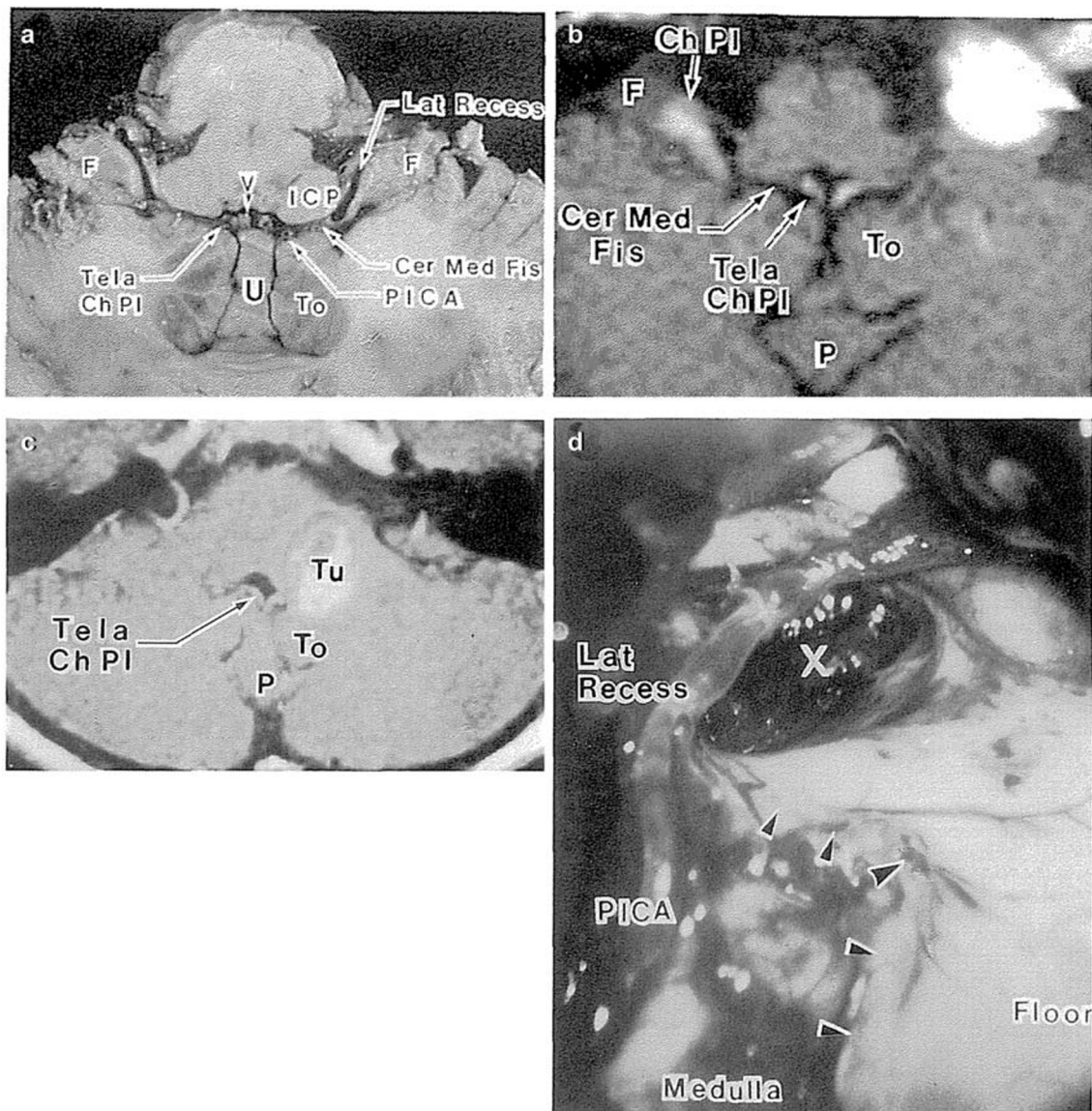


Fig. 3 Results of the first report of successful treatment utilizing CMF opening, cadaveric and MRI anatomy of CMF, and a representative case of a pontine cavernoma removed through this approach. **a** Axial section of an autopsied normal cerebellum at the level of the upper part of the medulla oblongata. **(b)** T1-weighted enhanced axial MR image showing almost the same view as that seen in Fig. 3a. **c** T1-weighted enhanced

axial view of the MR image of a patient with a cavernoma in the pons. **d** Intraoperative view near the ventricular entrance of the left lateral recess in the fourth ventricular floor. F, flocculus; ICP, inferior cerebellar peduncle; P, pyramis; U, uvula; To, tonsil; Tu, tumor; V, fourth ventricle; X, hematoma cavity. Modified with permission from Matsushima T et al.: *Neurosurgery* 30:325–330, 1992 [31]

widely around the world. At approximately the same time, brainstem surgery began to develop rapidly, and roles of the CMF opening technique increased [4, 6, 43]. The establishment and development of MRI, navigation systems, and endoscopy supported the development and advancement of CMF opening surgeries. Recently, the opening of various fissures in the posterior fossa has been used for safe and wide surgical exposure, as like CMF opening [3, 26, 28].

In this manuscript, we will review the development of CMF opening surgeries based on anatomical studies. The effects of the CMF opening method on posterior fossa surgeries will also be discussed.

History of anatomical studies of the cerebellum and establishment of fourth ventricular surgeries

The cerebellum was studied in detail by anatomists from the viewpoint of embryology in the early twentieth century [25]. The posterolateral fissure, which becomes the cerebellomedullary fissure in adults, was also investigated. The posterolateral fissure appears in the early stage of cerebellar development, and separates the flocculus and nodules from the uvula and tonsil, and forms the border of the region corresponding to the cranial part of the CMF [17].

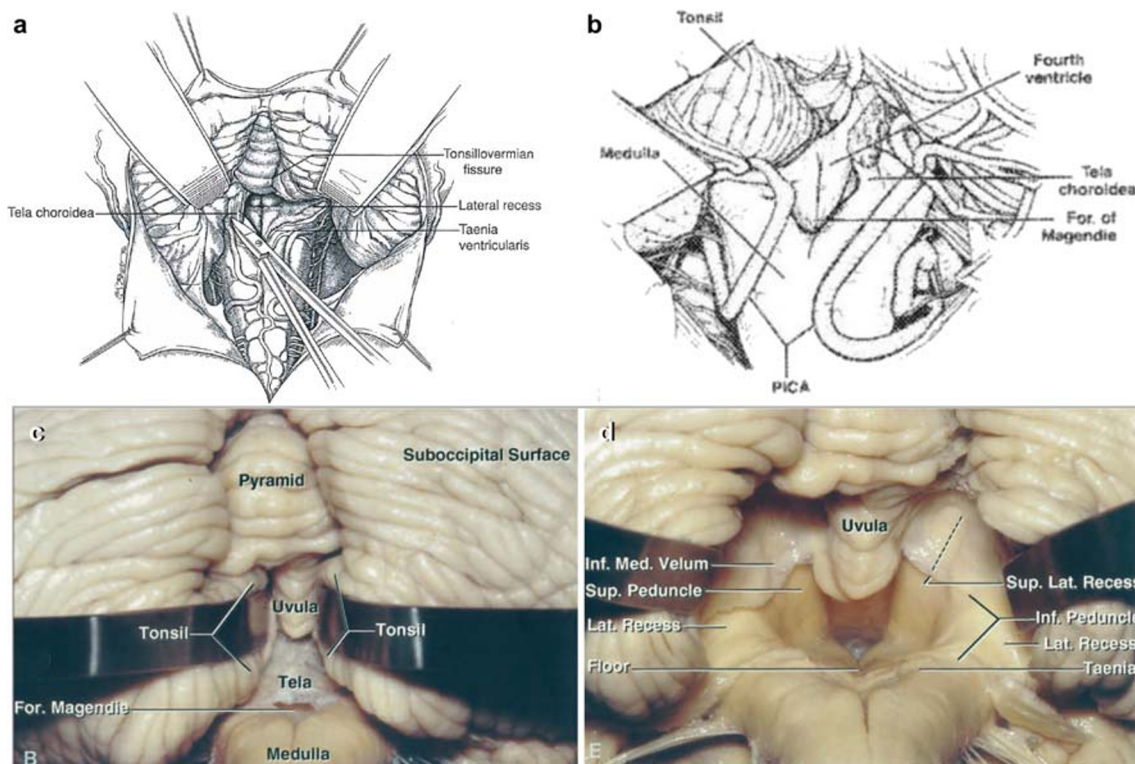


Fig. 4 Dissemination of the CMF opening. **a** An illustration from Kellogg's report on the cerebellomedullary fissure approach. The cadaveric dissection illustrates division of the tela choroidea and retraction of the tonsil to expose the fourth ventricle through the approach. Modified with permission from Kellogg and Piatt: *Pediatr Neurosurg* 27:28–33, 1997 [23]. **b** An illustration from Ziyal's report on the subtonsillar-transcerebellomedullary approach. The drawing of the anatomical study demonstrates opening of the cerebellomedullary

fissure, the distal posterior inferior cerebellar artery (PICA), and the lateral recess in the cadaveric specimen. Modified with permission from Ziyal et al.: *Br J Neurosurg* 13:276–284, 1999 [46]. **c, d** Photographs of cadaveric dissection from Mussi and Rhoton's report on the telovelar approach. These figures of beautiful stepwise dissection photographs are easy to understand and made a significant contribution to the spread of the approach. Modified with permission from Mussi and Rhoton: *J Neurosurg* 92:812–823, 2000 [37]

No discussion about the history of fourth ventricular surgery would be complete without describing the contribution of Dandy. He believed that complete midsagittal division of the cerebellar vermis was safe, and performed the transvermian approach to expose the interior fourth ventricle, and reported his achievement (Fig. 1a) [8]. The transvermian approach was widely utilized for fourth ventricular lesions, and was a standard approach to the fourth ventricle for approximately 50 years until the late twentieth century [7, 24]. Subsequently, with the accumulation of experience, problems of the transvermian approach such as the vermian splitting syndrome became clear [14].

Anatomical studies of the CMF and the beginning of CMF opening surgeries

In the 1960s, the anatomy of the cerebellum and the cerebellar vessels were studied in detail by neuroradiologists with the establishment of angiography. To our knowledge, the term “CMF” was first described in the study of the veins of the posterior fossa by Huang et al. [17] in 1967. He paid special attention to the

veins, which was underestimated at that time, and investigated the vascular anatomy in detail from the viewpoint of angiographical understanding (Fig. 1b). Subsequently, one of the authors of this review (T.M.) and Rhoton, the pioneer of microsurgical anatomy, revised the classification of the cerebellar fissures from the viewpoint of clinical surgery [36]. Following Rhoton's “rule of 3”, we defined the CMF as one of the 3 cerebellar-brainstem fissures. The “rule of 3” includes all major brainstem parts, cranial nerves, cerebellar peduncles, arteries, and veins in the posterior fossa, and helped neurosurgeons' understanding of microsurgical posterior fossa anatomy [28, 29]. In 1982, we reported the detailed surgical anatomy of the CMF in the fourth ventricle project, as this fissure was the posterior roof of the fourth ventricle (Fig. 2) [36].

Based on this experience of CMF dissection in the laboratory and a deep understanding of its microsurgical anatomy, one of the authors (T.M.) started CMF opening instead of incision of the inferior vermis in surgeries for fourth ventricular tumors. His previous experience of unexpected small residual tumors in the lateral recess after transvermian resection of a large fourth ventricular ependymoma was a stepping

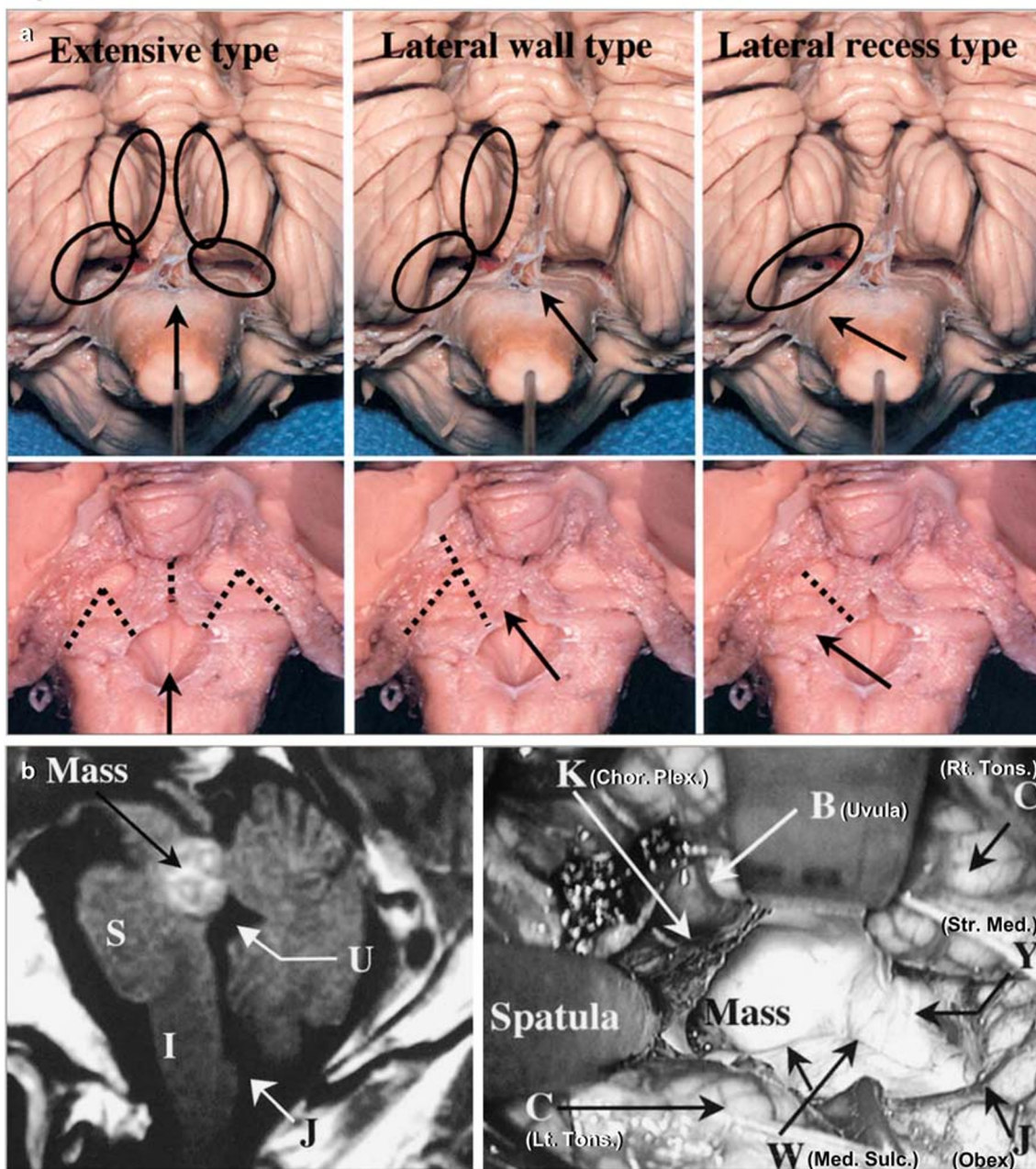


Fig. 5 Establishment of the medial route of the transCMF approach. **a** Figure showing three types of the CMF opening method. **b** Figures showing a preoperative midsagittal T1-weighted MR image and

an intraoperative view in a case of upper pontine cavernoma removed through the medial route of the approach. Modified with permission from Matsushima T et al.: *J Neurosurg* 94:257–264, 2001 [32]

stone to the development of this new surgical approach [29]. In 1992, we first reported 9 cases of patients operated on this CMF opening, including intrinsic pontine cavernoma, from 1987 to 1992 (Fig. 3) [31]. This method has the following 2 advantages: to reduce the possibility of leaving residual tumors around the lateral recess by wide lateral exposure, and to avoid postoperative vermin splitting syndrome using fissure opening. We discussed the idea and initial experience of CMF opening surgeries with Rhoton, and introduced the surgical technique in textbooks together in 1996 [35].

Worldwide dissemination of the CMF opening technique and the establishment of the medial route of the transCMF/telovelar approach

After our first report, Yasargil [44] reported surgery for distal posterior inferior cerebellar artery (PICA) aneurysms through the opening of a part of the CMF, as the median inferior suboccipital transfissure approach. Kellogg et al. [23] emphasized their good surgical results without vermian splitting

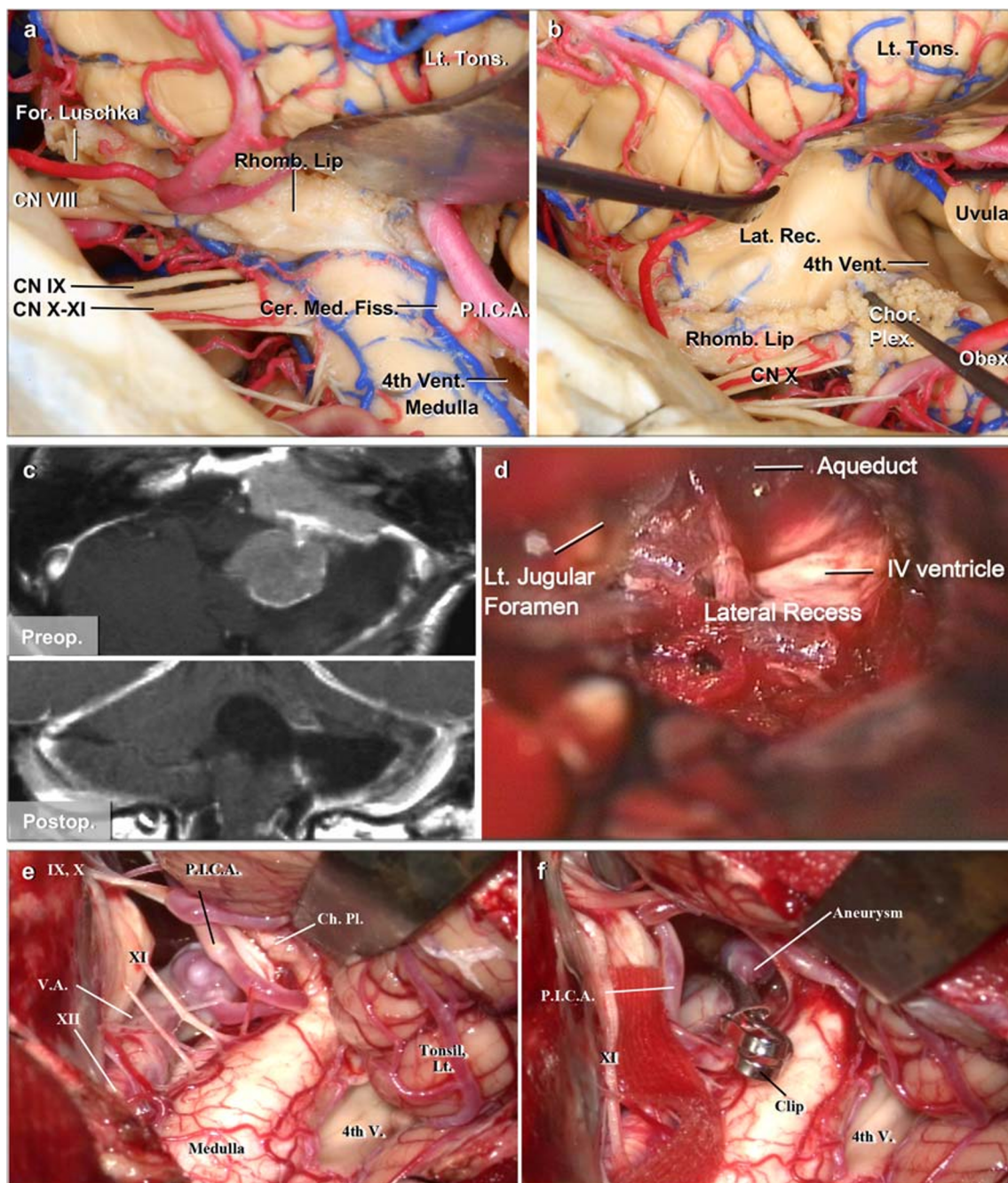


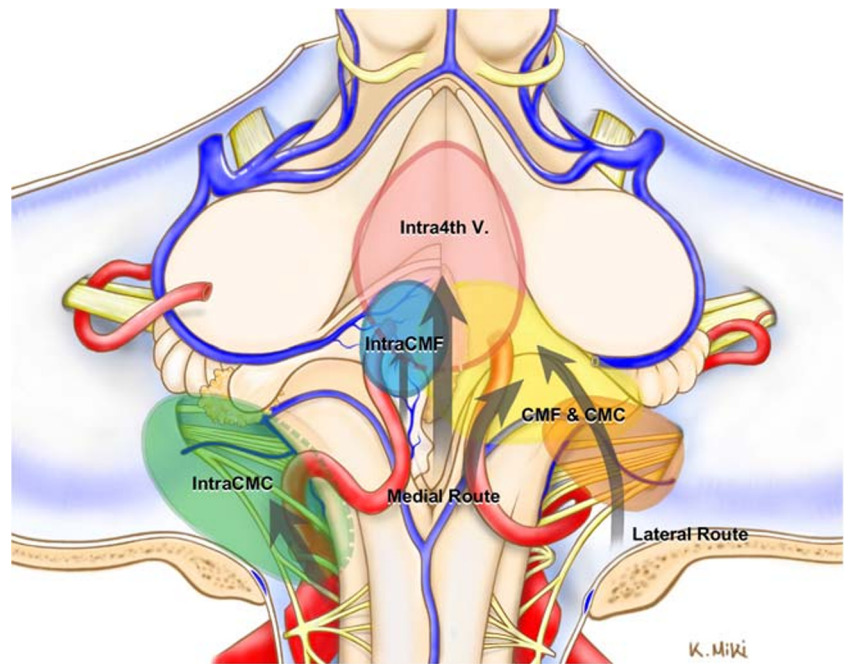
Fig. 6 Lateral route of the transCMF approach and unilateral transCMF approach. **a, b** Photographs of cadaveric stepwise dissection demonstrating the lateral route of the transCMF approach from Akiyama's report on the lateral recess. The fourth ventricle is exposed from the cerebello-medullary cistern side by incision of the lateral recess. Modified with permission from Akiyama et al.: *J Neurosurg* 129:740–751, 2018 [2]. **c, d** A case of recurrent meningioma removed through the lateral route of the transCMF approach from Kawashima's report on the lateral route of the transCMF approach, Preoperative and postoperative MRIs (**c**) and an intraoperative

photograph (**d**) of a recurrent meningioma operated through the lateral route. Modified with permission from Kawashima et al.: *Neurosurg Rev.* 32:457–464, 2009 [21]. **e, f** Intraoperative photographs of vertebral artery (VA)-PICA aneurysm surgery via the unilateral transCMF approach from Matsushima's report on the unilateral transCMF approach. Even for pure cerebellopontine angle lesions, such as this VA-PICA aneurysm, the unilateral CMF opening was used to help gentle cerebellar elevation. Modified with permission from Matsushima T et al.: *World Neurosurg* 82: e615–621, 2014 [33]

syndrome in 11 patients with fourth ventricular tumors surgically treated through the CMF approach (Fig. 4a). Ziyal et al. [46] also reported the subtonsillar-transCMF approach to

laterally placed fourth ventricle lesions and brainstem lesions, including ependymoma, brainstem cavernous angioma, and distal PICA aneurysm (Fig. 4b). In 2000, Mussi and Rhoton

Fig. 7 Illustration showing 4 regions exposed by medial and lateral routes of the transCMF approach. The targets of the transCMF approach can be classified into the following 4 types: intraCMF lesions (outside of the ventricle, highlighted in blue), intrafourth ventricular lesions (highlighted in pink), lesions extending to both the CMF and cerebellomedullary cistern (highlighted in yellow and orange), and pure cerebellomedullary cistern lesions (in the lower cerebellopontine angle outside of the CMF, highlighted in green). Modified with permission from Matsushima T et al.: World Neurosurg 82: e615–621, 2014 [33]



[37] presented the beautiful cadaveric demonstrations of fourth ventricular exposure through the CMF opening, and called it the telovelar approach (Fig. 4c, d). This report made a significant contribution to the spread of this approach all over the world. They emphasized the importance of the additional opening of the velum based on cadaveric dissection, as suggested by its name of telovelar approach. However, intentional velum opening may not be necessary in most clinical cases, as subsequently reported by other groups as well as ourselves [16, 30, 32]. These CMF opening surgeries were reported with various names as mentioned above from the late twentieth to the early twenty-first century, which are the so-called “medial route” of the transCMF approach, through midline suboccipital craniotomy (Fig. 5) [19, 20, 23, 32, 34, 37, 44, 46].

As this transCMF/telovelar approach became widely used, advantages and limitations of the approach were anatomically and clinically searched. With cadaveric specimens and neuronavigation, Tanriover and Rhoton [40] concluded that the telovelar approach provided additional lateral exposure, such as of the lateral recess and the foramen of Luschka, but the transvermian approach provided slightly better visualization of the medial part of the superior half of the roof of the fourth ventricle. Deshmukh et al. [9] reported in their cadaveric study that removal of the C1 posterior arch solved this limitation of superomedial exposure of the transCMF/telovelar approach. Initial clinical reports using the transCMF/telovelar approach did not always demonstrate favorable results, but the outcomes gradually improved and the usefulness of the approach has gradually been recognized [12, 39, 45]. In addition to not causing postoperative vermian splitting syndrome, it was generally accepted that the approach provided advantages of

early identification and preservation of the brainstem and PICA and additional lateral exposure, such as of the lateral recess. On the other hand, however, deep rostral tumor attachment was found to be the main limitation of the telovelar approach compared with the transvermian approach, as in the cadaveric studies [11, 16, 41].

More detailed variations of this approach have also been investigated (Fig. 5) [29, 32]. We first classified the CMF into 2 parts: the uvulotonsillar and medullotonsillar spaces, and now consider 3 parts, adding the supratonsillar space [29, 32]. Incision of the tela choroidea, particularly the taenia, was introduced as the key step to enable wide exposure with this approach, and incision of the lateral recess did not cause any neurological deficits [30]. Han et al. [16] investigated their 50 cases of patients who underwent CMF opening, and found that inferior medullary velum incision was required only in 18 of the 50 patients.

Even at present, at a time when the transCMF/telovelar approach has been well established, in some cases of fourth ventricular tumors, it is still necessary to partially incise the inferior vermis to completely remove a tumor, particularly those originating from the area near the fastigium, such as medulloblastomas and astrocytomas.

Advancements in the transCMF approach and further utilization of the CMF opening technique

After establishment of the medial route of the transCMF approach, the lateral route of the approach from the

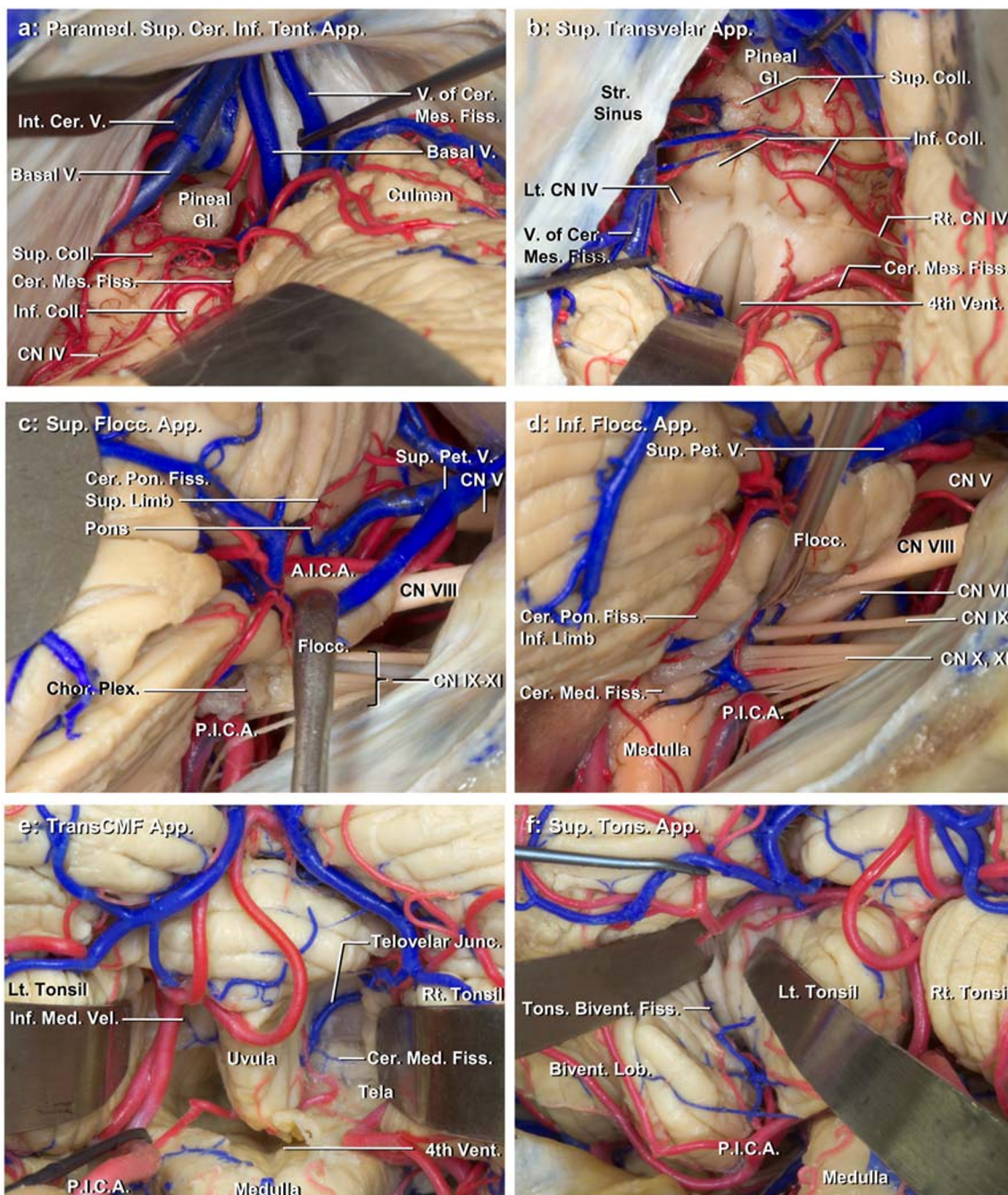


Fig. 8 Photographs of cadaveric dissection showing various fissure openings in the posterior fossa. Following the transCMF approach (e), the concept of fissure dissection for the posterior fossa became widespread, including the supracerebellar infratentorial (a) and superior velum approach (b) with opening of the cerebellomesencephalic fissure,

the suprafloccular (c) and infrafloccular approach (d) with opening of the cerebellopontine fissure, and the supratonsillar approach (f) with opening of the tonsillobiventricular fissure. Modified with permission from Matsushima K et al.: *J Neurosurg* 124:248–263, 2016 [28]

cerebellomedullary cistern (lower cerebellopontine angle) to the fourth ventricle was proposed (Fig. 6a–d). We reported the surgical experience of cases in which tumors originating near the jugular foramen extended into the fourth ventricle from the lateral side (Fig. 6c, d) [21, 29]. With the development of lateral foramen magnum surgeries, such as the transcondylar and

transcondylar fossa approaches, the CMF has been opened from the lower cerebellopontine angle to access the fourth ventricle.

The CMF opening has been used not only for the surgery of tumors but also of some vascular lesions and brainstem lesions [1, 4, 6, 18, 22, 29, 33, 43]. Abe et al. [1] reported treatment of an occipital artery-PICA anastomosis inside the CMF using

the unilateral transCMF approach. Unilateral CMF openings have also been used to lift up the cerebellar hemisphere gently and obtain a wide operative field in the cerebellomedullary cistern (Fig. 6e, f) [15, 16, 33]. In the vertebral artery-PICA aneurysm surgery, as well as microvascular decompressions for the glossopharyngeal neuralgia and hemifacial spasms, wider exposure can be achieved without aggressive cerebellar retraction by the CMF dissection [18, 22, 29, 33].

Brainstem surgery has significantly advanced in the early twenty-first century, and the medial route of the transCMF/telovelar approach was utilized in many such surgeries [4, 43]. A recent review article showed that 94 out of 129 pontine cavernomas (78%) were resected through the floor of the fourth ventricle and the CMF opening was utilized in most of them [6, 43]. Not only for such common approaches through the floor of the fourth ventricle, but also for lateral approaches through the recently proposed safe entry zones, such as the inferior cerebellar peduncle and the perifacial zone near the lateral portion of the pontomedullary junction, unilateral CMF dissection for gentle cerebellar retraction was also essential [5, 10, 27].

Now we consider 4 types of lesions exposed through the transCMF approach: intraCMF lesions (outside of the ventricle), intrafourth ventricular lesions, lesions extending to both the CMF and cerebellomedullary cistern, and pure cerebellomedullary cistern lesions (in the lower cerebellopontine angle outside of the CMF) (Fig. 7) [29, 33].

The recent use of endoscopy for CMF opening surgery has been investigated, and we expect that the development of more advanced equipment will improve this method of surgery in the future [42].

Effects of opening of other fissures in the posterior fossa

Following the establishment of CMF opening techniques, utilization of other fissures in the posterior fossa has been reported, similarly to Sylvian or interhemispheric fissures in the supratentorial regions. These include the supracerebellar infratentorial and superior velum approaches with opening of the cerebellomesencephalic fissure and the suprafloccular or infrafloccular approach with opening of the cerebellopontine fissure (Fig. 8) [3, 13, 28, 38]. Lawton et al. [26] introduced the supratonsillar approach through the tonsilloventral fissure to access the inferior cerebellar peduncle or the region near the lateral recess.

In summary, CMF opening, which substantially improved the efficacy of posterior fossa surgeries, was developed based on the experience gained by surgeons while dissecting the CMF (the roof of the fourth ventricle) in the laboratory. Anatomical studies using cadaveric specimens, particularly cadaver dissections by surgeons themselves, and a deep understanding of brain anatomy is essential for further advancements in surgical treatments.

Acknowledgments We would like to thank Mrs. Sumiko Matsushima for her valuable secretarial assistance in the preparation of this manuscript.

Compliance with ethical standards

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

Not required/applicable.

Informed consent Not required/applicable.

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