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Original Article

뇌교 및 연수 해면상혈관종에 대한 telovelar 접근법의 수술 결과 및 뉘앙스: 다기관 사례 연구

홍인서[1], 김경환[1], 오혁진[2], 권세민[3], 정희원[1], 정은오[1], 이한주[1], 권현조[1], 최승원[1], 김선환[1], 고현송[1], 염진영[1]

[1]충남대학교병원 신경외과, [2]순천향대학교 천안병원 신경외과, [3]계명대학교 동산의료원 신경외과

The surgical outcomes and nuances of the telovelar approach for pontine and medullary cavernous malformations: A multi-institutional case series

Inseo Hong[1], Kyung Hwan Kim[1], Huyk-Jin Oh[2], Sae Min Kwon[3], Hee-Won Jeong[1], Eun-Oh Jung[1], Han-Joo Lee[1], Hyon-Jo Kwon[1], Seung-Won Choi[1], Seon-Hwan Kim[1], Hyeon-Song Koh[1], Jin-Young Youm[1]

[1]Department of Neurosurgery, Chungnam National University Hospital, Daejeon, Korea
[2]Department of Neurosurgery, Soonchunhyang University Cheonan Hospital, Cheonan, Korea
[3]Department of Neurosurgery, Keimyung University Dongsan Medical Center, Daegu, Korea

Background: Brainstem cavernous malformations (CMs) are characterized by dilated sinusoidal channels related to capillary telangiectasia and developmental venous anomalies. Brainstem CM hemorrhages present with focal neurological symptoms, according to their invasive lesions. Surgical removal should be considered for symptomatic and recurrent bleeding of brainstem CMs. Despite the risk of surgery with highly eloquent tissue, surgical removal should be performed to protect patients from stepwise decline due to recurrent hemorrhage. The approaches for treating brainstem CMs are retrosigmoid, far lateral, midline suboccipital with or without telovelar, orbitozygomatic, and supracerebellar-infratentorial. Pontine and medullary CMs are approached via retrosigmoid, far lateral, and suboccipital craniotomies, with or without the telovelar approach.
Materials and Methods: The telovelar approach is the standard approach used for pontine brainstem CMs. Patients with brainstem CMs treated using the telovelar approach were enrolled from three institutions.
Results: All three patients had no further neurological deficits after surgery.
Conclusions: The surgical results suggest that the telovelar approach for pons and pontomedullary junction brainstem CMs is safe and effective.

Key Words: Cavernous hemangioma, Hemorrhage, Telovelar approach

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Corresponding author
Kyung Hwan Kim
E-mail lastbreak0@gmail.com
ORCID
https://orcid.org/0000-0003-1244-6969

INTRODUCTION

Cavernous malformations (CMs) are characterized by dilated sinusoidal channels lined with a single layer of endothelium and are related to capillary telangiectasias and developmental venous anomalies.[1] CMs affect 0.4%-0.5% of the population, which is relatively common. Symptoms result from recurrent hemorrhage or thrombosis in supratentorial lesions, such as seizures or focal neurological symptoms in the brainstem, basal ganglia, or spinal cord.

The annual risk of hemorrhage associated with CM in patients with no history of previous hemorrhage ranged from 0.6% to 1.1% per year.[2] With prior hemorrhage, the incidence increased from 4.5% to 60% per year.[3-8] The risk of rebleeding was higher in recent hemorrhage, extralesional hemorrhage, mass effects, and edema.

Although surgery can eliminate the potential for recurrent hemorrhage from CMs of the brainstem, resection can cause dangerous complications. To determine the patients who should undergo surgery, the risk and natural history of CM should be balanced. The surgical indications were as follows: (1) history of multiple hemorrhages, (2) severe progressive symptoms, and (3) acute or subacute hemorrhage with a significant mass effect.[9]

For brainstem CMs, the following surgical approaches are used: retrosigmoid, far lateral, midline suboccipital with or without telovelar, orbitozygomatic, and supracerebellar-infratentorial. Specific approaches were selected on a case-by-case basis depending on the anatomical location of the lesion.[10]

The telovelar approach was first used by Matsushima et al. [11] in the early 1980s. This approach avoids the cerebellar vermis while providing wide operative exposure to the fourth ventricle.[12-14] The advantage of the telovelar approach is exceptional access to the superolateral and lateral recesses and the foramen of Luschka.[12,14]

Here, we reviewed three cases of pontine and medullary CMs with surgical resection performed using the suboccipital telovelar approach.

METHODS

1. Patient characteristics

Between January 2019 and December 2022, patients with brainstem CMs treated using the telovelar approach were enrolled from three institutions. Despite the variations in technical details, three neurosurgeons followed the same key steps. All CMs were diagnosed using brain computed tomography and magnetic resonance imaging (MRI) scans. The demographic features, radiographic images, and operative videos were thoroughly reviewed. Postoperative neurological deficits were assessed using postoperative images. All procedures involving human participants performed in this study were in accordance with the ethical standards of the Institutional Review Board of Chungnam National University Hospital (IRB No. CNUH 2023-09-002), and the 1964 Helsinki Declaration and its later amendments, or comparable ethical standards. The requirement for formal consent was waived.

2. Telovelar approach and technical nuances

The telovelar approach has been previously described in the literature.[15] A standard midline suboccipital craniotomy was performed with unroofing of the foramen magnum in the prone position. Exposure of the transverse sinus was not necessary. If the lesion extended upward into the cerebral aqueduct and lateral recess, C1 laminectomy may be beneficial for visualization through an extended inferior-to-superior operative trajectory. The dura mater was incised in a curvilinear or Y-shaped manner and retracted superiorly. After the arachnoid membrane was incised at the midline, the inferior cerebellar surface, cerebellar tonsils, and the pyramid of the vermis were exposed (Fig. 1). The arachnoid membranes were tacked to the dura mater using metal ligation clips (Horizon™ clip; Teleflex Medical Incorporated, Wayne, PA, USA). The medullotonsillar space of the cerebellomedullary fissure and the uvulotonsillar space were sharply dissected to release the tonsils from the uvula and medulla oblongata, bilaterally. The medial surface of the two tonsils was then retracted supralaterally, and the uvula was retracted superomedially to expose the floor of the fissure, that is, the inferior medullary velum and tela choroidea. The tela choroidea, which forms the caudal part of the lower half of the roof of the fourth ventricle, was coagulated and incised superolaterally from the foramen of Magendie, and the inferior medullary velum was further divided to

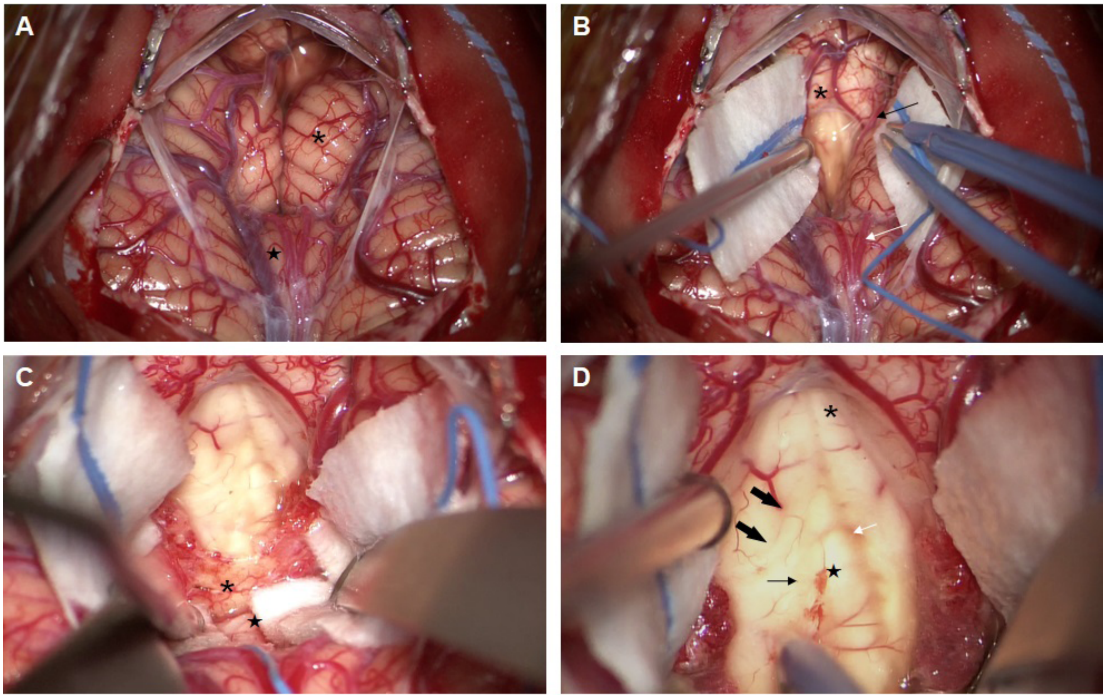

Fig. 1. Stepwise illustration of the exposure of the fourth ventricle floor. (A) After the arachnoid membrane is incised at midline, the cerebellar tonsils (asterisk) and the pyramid of vermis (star) are exposed. Note that the arachnoid membranes are tacked up to the dura mater using metal ligation clips. (B) The cerebellar tonsils are retracted, and the fourth ventricle floor and the obex and area postrema (asterisk) are exposed. The tonsilomedullary segment of the posterior inferior cerebellar artery (PICA, black arrow) can be traced along the posterolateral medulla and inferior cerebellar peduncle, which ascends between the tonsils and medulla to reach the interval between the tonsils and uvula. The PICA and its cortical branches (white arrow) should be preserved. (C) After arachnoid dissection between the tonsils and uvula (star) with the retraction of the tonsils, the tela choroidea (asterisk) and choroid plexus are exposed. (D) The tela choroidea and part of the inferior velum are incised to widely expose the fourth ventricle. The median sulcus (white arrow) is deviated towards the contralateral side of the pontine hematoma. The landmarks include the hypoglossal triangle (asterisk), stria medullaris (black thick arrows), facial colliculus (star), and sulcus limitans (black arrow).

access the fourth ventricular floor and lateral recesses. Subsequently, the uvula was free to retract to expose the fourth ventricle, and dynamic retraction was used to expand and secure the uvulotonsillar space. The posterior inferior cerebellar artery (PICA) is closely associated with these spaces. The telovelotonsillar segment of the PICA turns upward along the medial surface of the tonsil and passes through the cleft between the tonsils and tela choroidea and later between the tonsils and inferior medullary velum. Most PICAs bifurcate into the medial and lateral trunks around the tonsils. The medial trunk ascends to supply the vermis, and the lateral trunk passes laterally over the tonsils to supply most of the hemispheric and tonsillar surfaces. During dissection, meticulous tracing and release of the PICA are mandatory to avoid vascular damage.

After floor exposure, surgical landmarks, including the obex, median sulcus, striae medullaris, vagal triangle, hypoglossal triangle, median eminence, and facial colliculus, were carefully identified (Fig. 2). In many cases, it may be difficult to inspect and identify structures because of lesions. A neuronavigation system and intraoperative brainstem mapping using a monopolar probe are essential for confirming a safe surgical trajectory while avoiding unnecessary brainstem damage. In this case series, the infrafacial collicular safety zone was used as the entry point. The hematoma was removed after exposing the CM through a minimal incision in the brainstem. Usually, the brainstem decompresses rapidly after hematoma evacuation, and the CM can be

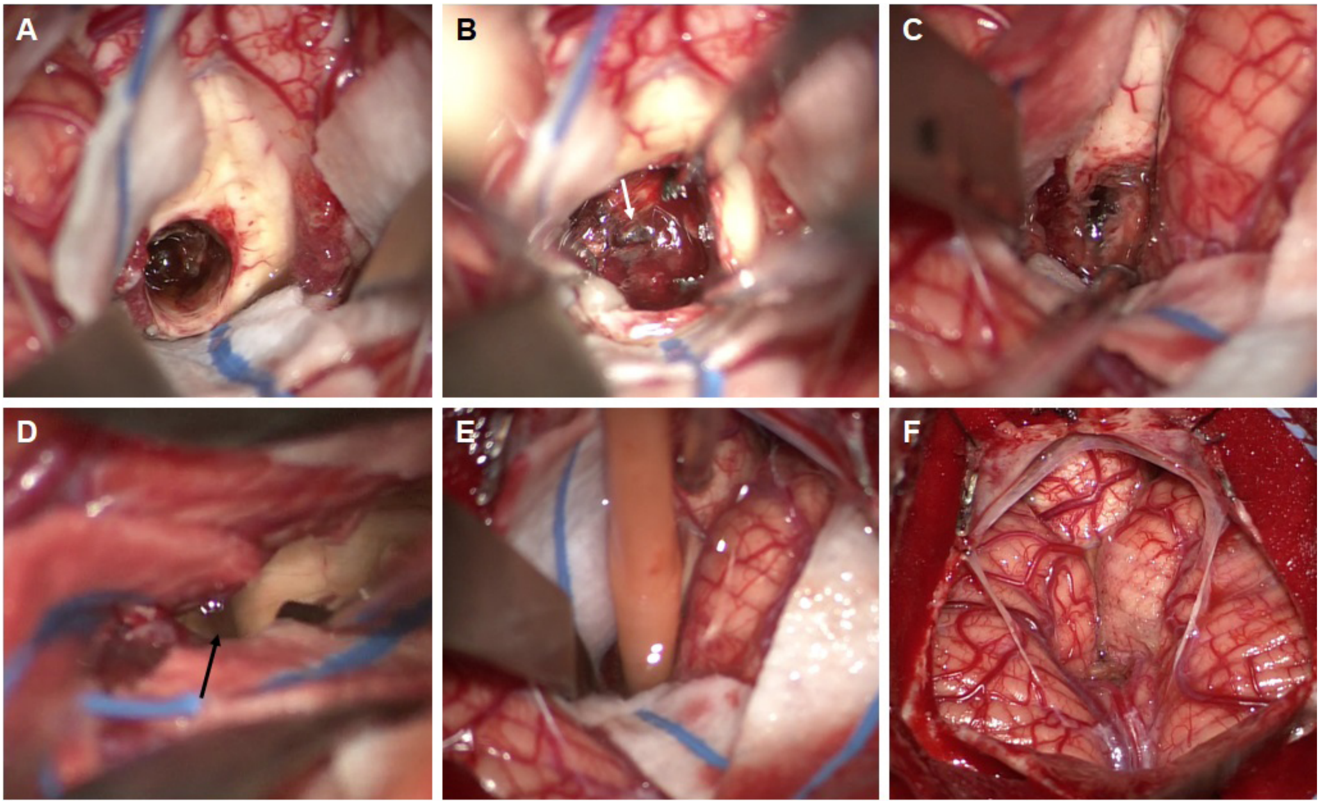

Fig. 2. Operative findings and surgical nuances. (A) An initial incision is made and widened in the infrafacial collicular zone, which is inferior to the facial colliculus, lateral to the median eminence and sulcus limitans, and superior to the stria medullaris. (B) After the removal of hematoma, a typical appearance of cavernous malformation (CM) is noted (white arrow). (C) CM is completely removed using a unilateral telovelar approach. (D) The cerebral aqueduct (black arrow) can be identified by adjusting the microscope viewing angle. (E) Continuous warm saline irrigation using a Nelaton catheter situated in the operative field is advantageous to clear hematoma and surgical debris. (F) The tonsils and vermis are intact without any retraction injuries.

exposed and removed using conventional microsurgical techniques. Minimal coagulation around the normal brainstem tissue is required. To visualize the rostral portion of the lesion, the microscope was rotated to an orthogonal or inverted angle (Fig. 3). After the removal of the CM, routine watertight dural closure was performed.

RESULTS

1. Surgical outcomes

Three patients with brainstem CM underwent successful resection using the telovelar approach without noticeable complications. The surgeries were performed by three different neurosurgeons in the respective institutions. One neurosurgeon performed each operation on one patient. Patient demographics and surgical outcomes are summarized in Table 1.

2. Clinical presentation

1) Case 1

A 49-year-old man presented with a CM with recurrent bleeding. He had been diagnosed with pontine CM one year ago. The maximum diameter of the lesion was 0.3 cm when it was first diagnosed incidentally after a traffic accident. The tumor size increased to a maximum diameter of 1.2 cm during the follow-up period. On clinical examination, the patient had dizziness, diplopia, and paresthesia of the left side of the face and the upper and lower extremities. The patient was hos-

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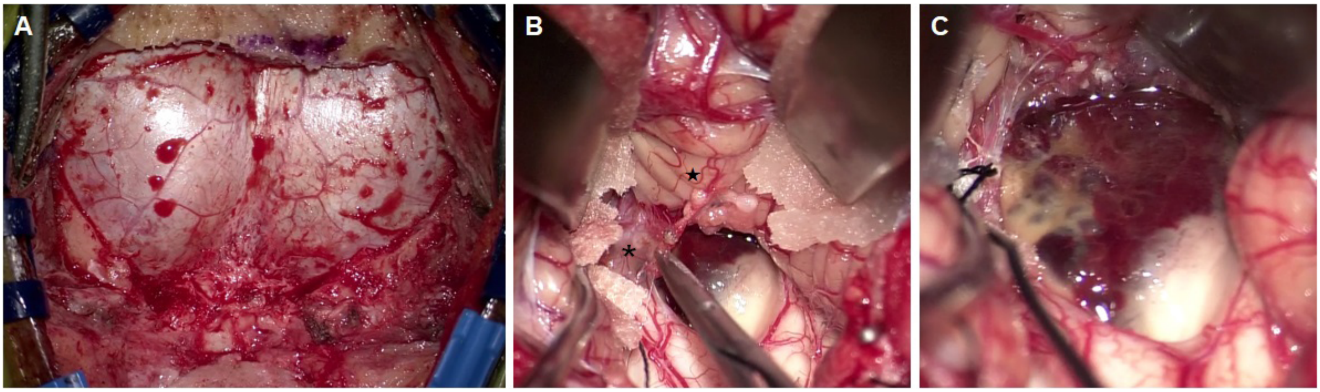

Fig. 3. Medullary cavernous malformation (CM) resected via the telovelar approach. (A) A conventional suboccipital craniotomy without C1 laminectomy is performed. Note that the surgeon looks at the surgical field through a microscope from the back of the patient in the prone position. (B) The uvula (start) and tela choroidea (asterisk) are widely exposed because of the retraction of the tonsils on both sides. The tela choroidea is coagulated and divided superolaterally between the tonsils and uvula. (C) A typical CM with an old hematoma protruding towards the fourth ventricular floor is well visualized.

Table 1. Summary of patient demographics and clinical outcomes

Variable	Case No.		
	1	2	3
Age (yr)	49	68	51
Sex	Male	Male	Female
Location	Pons	Pons	Medulla
Size (cm)	2.9	2.0	2.1
Hemorrhagic event	3	2	1
Previous intervention	Radiosurgery	None	None
Neurologic symptoms	Dizziness, paresthesia, diplopia, hemiparesis	Dizziness, paresthesia	Dizziness
Cranial nerve paresis	6, 7, 8, and lower cranial nerves	None	12
Extent of resection	Total	Total	Total
New deficit after surgery	None	None	None
Follow-up period (mo)	12	52	16
Initial mRS	5	4	3
mRS at follow-up	4	1	2

mRS: modified Rankin Scale.

pitalized and was managed conservatively. However, he experienced progressive neurological deficits, including right hemiparesis with complete facial palsy, dysarthria, swallowing and voiding difficulties, hearing loss and gaze palsy on the right side. After symptom stabilization, the patient underwent Gamma Knife radiosurgery. The radiation dose was 13 Gy in a 50% isodose line, and the target volume was 0.22 mm^3. The target volume only included the CM without the hematoma volume, which was delineated in the previous MRI images. Nevertheless, the CM showed rebleeding after radiosurgery and became larger, up to a diameter of 2.9 cm. In addition, the neurological symptoms worsened, which led us to decide to perform surgery (Fig. 4A-4C). The patient underwent a suboccipital craniotomy using the telovelar approach. The CM was completely removed, and no new neurological deficits were observed. The patient was successfully extubated one day after surgery and

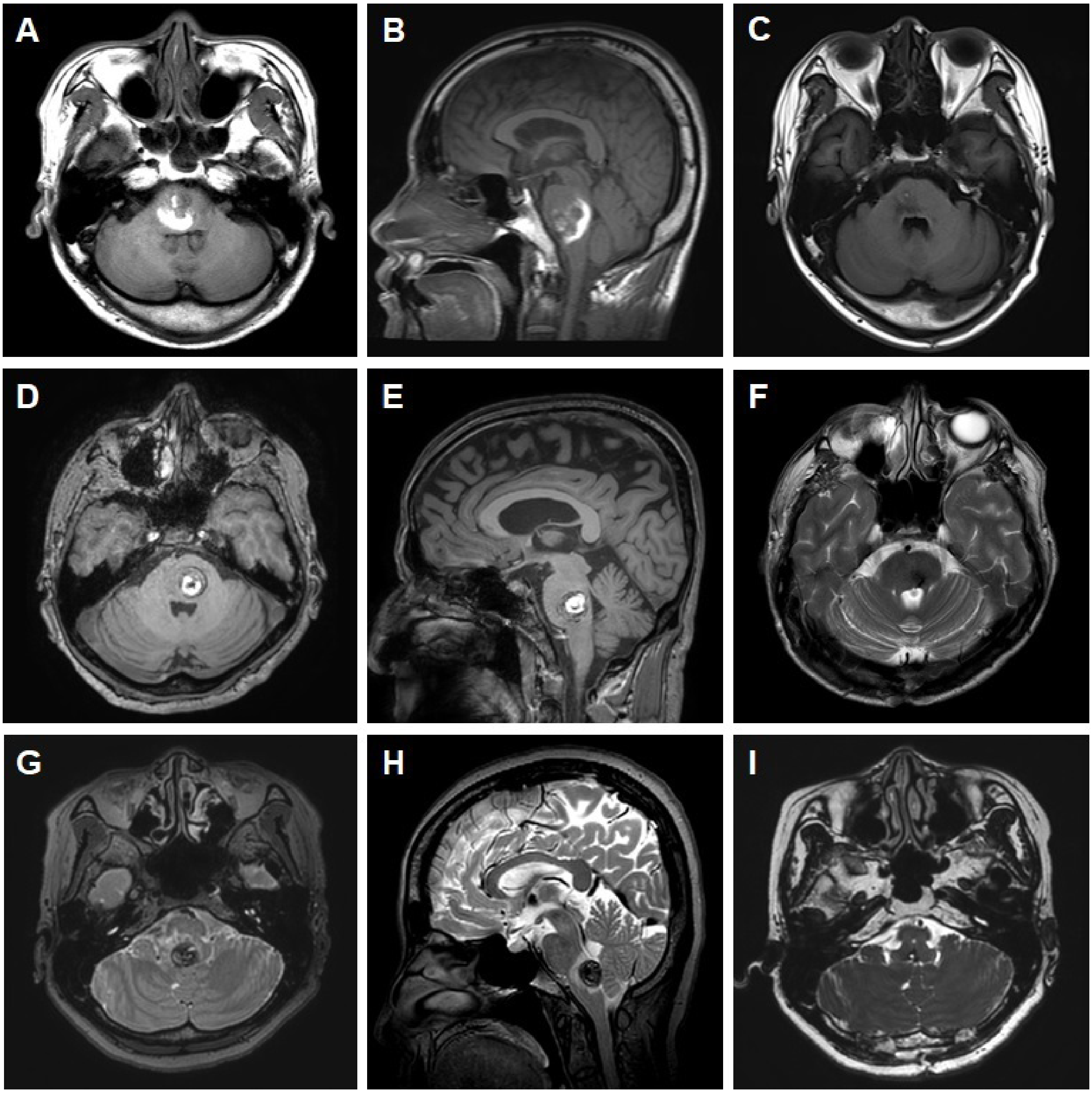

Fig. 4. Preoperative and postoperative images of the cavernous malformation (CM) resected via the telovelar approach. (A, B) Axial and sagittal T1 images of preoperative magnetic resonance imaging reveal that the CM is located in the pons with recurrent bleeding; hemorrhage is near the fourth ventricle, which makes the telovelar approach suitable. (C) Postoperatively, CM is completely removed without any surgical complication. (D, E) The CM is in the lower pons, close to the floor of the fourth ventricle. (F) The lesion is resected via the telovelar approach. (G, H) Axial and sagittal T2 images show that the CM is located mainly in the medulla, and is protruded to the fourth ventricle. (I) The lesion is completely removed using the telovelar route.

transferred to the Department of Rehabilitation without a remarkable postoperative course. One year after the surgery, the patient became ambulatory with assistance. Although dysarthria and dysphagia resolved, grade 3 facial palsy, and right lateral and left medial gaze palsies improved gradually.

2) Case 2

A 68-year-old man presented to the outpatient clinic with progressive paresthesia in the left upper and lower

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extremities and dizziness. Brain MRI findings revealed pontine CM with recurrent bleeding (Fig. 4D-4F). The patient underwent a suboccipital craniotomy using the telovelar approach, and the lesion was completely removed. After surgery, the patient developed a focal hemorrhage in the cerebellar hemisphere and vermis without any newly developed neurological deterioration. The patient was transferred to the Department of Rehabilitation and showed complete remission of neurological symptoms during the last follow-up.

3) Case 3

A 51-year-old woman presented with a sudden onset of severe dizziness. Physical examination revealed right hypoglossal nerve palsy with dysphagia. Nystagmus was observed on upward gaze, and esotropia was observed in the right eye. MRI findings revealed a CM in the medulla with bleeding (Fig. 4G-4I). The patient underwent a suboccipital craniotomy using the telovelar approach, and the lesion was completely removed. No new neurological deficits developed postoperatively. However, tongue deviation, esotropia, and nystagmus persisted for one year after surgery.

DISCUSSION

This study presented 3 cases of brain stem CM with surgical management. All three cases were done by suboccipital craniotomy with telovelar approach. The lesions of CM were pons and pontomedullary junction. For pontine and medullary lesions at the floor of the fourth ventricle, suboccipital approach with telovelar is a suitable surgical approach.[2] With telovoelar approach, lesions that involve the inferomedial middle cerebellar peduncle can be managed.[1]

The surgical approach for fourth ventricle was conventionally done by transvermian approach and through cerebellomedullary fissure was not an option because it was not complex or poorly understood.[11] Transvermian approach can improve access to the rostral reaches of fourth ventricle and can be a safe approach and provide surgeon to avoid dentate nucleus, however, vermian incision can cause equilibratory disturbances with truncal ataxia, staggering gait, oscillation of the head and trunk, and nystagmus on erect position, without ataxia on voluntary movement of the extremities.[12,16-18]

In the telovelar approach, the patient is placed in a prone position, and a suboccipital craniotomy is performed, followed by cerebellar hemispheric and tonsillar retraction.[12,19] A delicate and meticulous dissection of the cerebellomedullary fissure is performed.[12-14] The cerebellomedullary fissure was opened, and the uvulotonsillar and medullotonsillar spaces are dissected. Dissection of the cerebellomedullary fissure and opening the tela choroidea and/or inferior medullary velum provide surgical corridors to the fourth ventricle by.[19-21]

Opening the tela and velum can provide adequate approach for whole floor of the fourth ventricle. Incision of tela choroidea can gain access to the lateral recesses,[12,13,22] with velar incision, accesses to superolateral recesses and upper half of the fourth ventricular roof and floor can be done.[23,24] The exposure of fourth ventricle can be improved with C1 laminectomy,[12] bilateral opening of the telovelum,[13,23,24] and tonsilar retraction or resection.[13] Compared to tonsilar retraction, tonsilar resection improves exposure to the lateral recess and cerebral aqueduct.[13]

If the tela choroidea or inferior medullary velum is opened correctly, there are no neurological deficits. However, injuries to the dentate nucleus, cerebellar peduncles, cranial nuclei in the fourth ventricle, and PICA, which are eloquent structures, can result in neurological deficits during fissure dissection, tonsillar dissection, or lesional extirpation.[25] Deficits typically result from aggressive resection of infiltrating lesions,[26] from the lesional infiltration proper, as well as from the surgical dissection.

The safety zone with telovelar approach is suprafacial and infrafacial entry zone.[27] The midline and lateral extensions in middle longitudinal fasciculus and the lateral aspect of the central tegmental tract should be avoided for both entry zones. Injury of the structures can lead to conjugate gaze palsy, extrapyramidal symptoms, or palatal myoclonus.[28,29] The medullary stria and lateral recess are the landmarks to avoid facial colliculous from cranial nerve VII. Use of the landmarks, intraoperative neurophysiological monitoring, and neuronavigation can help avoid the structures.

In telovelar approach, PICA is frequently exposed during surgery. Occlusion of the branches of the distal medullary branch of PICA at the level of the fourth ventricle can induce rotatory nausea, vomiting, dizziness, inability to stand or walk, and nystagmus without appendicular dysmetria.[30] The choroidal branches of PICA which can be sacrificed while opening the tela, however these branches rarely have neural branches.[22] Liu and Kasper [23] reports 3 cases of ventricle tumor removal with telovelar approach, each patient with meningioma, solitary fibrous tumor of the central nervous system, and ependymoma. In all cases PICAs were preserved.[23] Eissa [31] reported 40 cases of fourth ventricular tumors undergoing telovelar approach with early exposure of PICAs and conservation of the artery. There has been no reports of neurological deficits after telovelar approach.[22]

Despite the vermian sparing approach, cerebellar mutism can occur in cases where the telovelar unit is opened bilaterally.[23,24] Intention tremor, dysmetria, and decomposition of movement can occur in injuries to superior cerebellar peduncle while operating the rostral reaches of the fourth ventricle.[22] Ataxia, dysmetria during voluntary movement, and hypotonia can occur in lesions of middle cerebellar peduncle.[17,18]

All three patients had neurological deficits with brainstem CM, and the telovelar approach was used for its removal. After surgery the patients reported no further neurological deficits with the use of intraoperative neurophysiological monitoring and neuronavigation. Despite our cases were few, the patients had no surgical complications after surgery, suggesting that the telovelar approach a safe approach for brainstem CM in posterior pons and pontomedullary junction.

This study had some limitations which included small sample size and the fact that the surgeries were performed by different surgeons. The lack of a control group also made it difficult to compare the advantages and disadvantages of the telovelar approach with those of other surgical approaches.

In conclusion, the telovelar approach is safe and effective for the treatment of posterior pons and medullary CMs. Further studies are warranted to validate this surgical approach for pons and medullary CMs.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

ORCID

Inseo Hong, https://orcid.org/0000-0002-4773-8921
Kyung Hwan Kim, https://orcid.org/0000-0003-1244-6969
Huyk-Jin Oh, https://orcid.org/0000-0001-7189-1267
Sae Min Kwon, https://orcid.org/0000-0001-9720-6037
Hee-Won Jeong, https://orcid.org/0009-0007-1950-8698
Eun-Oh Jung, https://orcid.org/0000-0003-4326-8499
Han-Joo Lee, https://orcid.org/0000-0003-4518-9057
Hyon-Jo Kwon, https://orcid.org/0000-0003-1077-2461
Seung-Won Choi, https://orcid.org/0000-0001-8610-887X
Seon-Hwan Kim, https://orcid.org/0000-0002-5600-2801
Hyeon-Song Koh, https://orcid.org/0000-0003-2659-5535
Jin-Young Youm, https://orcid.org/0000-0001-9609-0415

REFERENCES

1. Abla A, Wait SD, Uschold T, Lekovic GP, Spetzler RF. Developmental venous anomaly, cavernous malformation, and capillary telangiectasia: Spectrum of a single disease. Acta Neurochir (Wien) 2008;150:487-9; discussion 489. https://doi.org/10.1007/s00701-008-1570-5
2. Garrett M, Spetzler RF. Surgical treatment of brainstem cavernous malformations. Surg Neurol 2009;

72 Suppl 2:S3-9; discussion S9-10. https://doi.org/10.1016/j.surneu.2009.05.031
3. Ferroli P, Sinisi M, Franzini A, Giombini S, Solero CL, Broggi G. Brainstem cavernomas: Long-term results of microsurgical resection in 52 patients. Neurosurgery 2005;56:1203-12; discussion 1212-4. https://doi.org/10.1227/01.neu.0000159644.04757.45
4. Fritschi JA, Reulen HJ, Spetzler RF, Zabramski JM. Cavernous malformations of the brain stem. A review of 139 cases. Acta Neurochir (Wien) 1994;130:35-46. https://doi.org/10.1007/BF01405501
5. Kondziolka D, Lunsford LD, Kestle JR. The natural history of cerebral cavernous malformations. J Neurosurg 1995;83:820-4. https://doi.org/10.3171/jns.1995.83.5.0820
6. Kupersmith MJ, Kalish H, Epstein F, Yu G, Berenstein A, Woo H, et al. Natural history of brainstem cavernous malformations. Neurosurgery 2001;48:47-53; discussion 53-4. https://doi.org/10.1097/00006123-200101000-00007
7. Porter RW, Detwiler PW, Spetzler RF, Lawton MT, Baskin JJ, Derksen PT, et al. Cavernous malformations of the brainstem: Experience with 100 patients. J Neurosurg 1999;90:50-8. https://doi.org/10.3171/jns.1999.90.1.0050
8. Wang CC, Liu A, Zhang JT, Sun B, Zhao YL. Surgical management of brain-stem cavernous malformations: Report of 137 cases. Surg Neurol 2003;59:444-54; discussion 454. https://doi.org/10.1016/s0090-3019(03)00187-3
9. Rajagopal N, Kawase T, Mohammad AA, Seng LB, Yamada Y, Kato Y. Timing of surgery and surgical strategies in symptomatic brainstem cavernomas: Review of the literature. Asian J Neurosurg 2019;14:15-27. https://doi.org/10.4103/ajns.AJNS_158_18
10. Brown AP, Thompson BG, Spetzler RF. The two-point method: Evaluating brain stem lesions [Internet]. Phoenix (AZ): Barrow Neurological Institute; BNI Quarterly 1996 [cited 2023 Apr 18]. Available from: https://www.barrowneuro.org/for-physicians-researchers/education/grand-rounds-publications-media/barrow-quarterly/volume-12-no-1-1996/the-two-point-method-evaluating-brain-stem-lesions/
11. Matsushima T, Rhoton AL Jr, Lenkey C. Microsurgery of the fourth ventricle: Part 1. Microsurgical anatomy. Neurosurgery 1982;11:631-67. https://doi.org/10.1227/00006123-198211000-00008
12. Deshmukh VR, Figueiredo EG, Deshmukh P, Crawford NR, Preul MC, Spetzler RF. Quantification and comparison of telovelar and transvermian approaches to the fourth ventricle. Neurosurgery 2006;58(4 Suppl 2):ONS-202-6; discussion ONS-206-7.
13. Jittapiromsak P, Sabuncuoglu H, Deshmukh P, Spetzler RF, Preul MC. Accessing the recesses of the fourth ventricle: Comparison of tonsillar retraction and resection in the telovelar approach. Neurosurgery 2010;66(3 Suppl Operative):30-9; discussion 39-40. https://doi.org/10.1227/01.NEU.0000348558.35921.4E
14. Tanriover N, Ulm AJ, Rhoton AL Jr, Yasuda A. Comparison of the transvermian and telovelar approaches to the fourth ventricle. J Neurosurg 2004;101:484-98. https://doi.org/10.3171/jns.2004.101.3.0484
15. Rhoton AL; Congress of Neurological Surgeons. Rhoton cranial anatomy and surgical approaches. New York: Oxford University Press; 2020.
16. Holmes G. The Croonian Lectures on the clinical symptoms of cerebellar disease and their interpretation. Lecture II. 1922. Cerebellum 2007;6:148-53; discussion 141.
17. Fulton JF, Dow RS. The cerebellum: A summary of functional localization. Yale J Biol Med 1937;10:89-119.
18. Larsell O. The cerebellum: A review and interpretation. Arch Neurol Psychiatry 1937;38:580-607. https://doi.org/10.1001/archneurpsyc.1937.02260210146011
19. Yasargil MG. Microneurosurgery: Vol. IVB. New York: Thieme; 1996. pp.63-4.
20. Matsushima T, Fukui M, Inoue T, Natori Y, Baba T,

Fujii K. Microsurgical and magnetic resonance imaging anatomy of the cerebello-medullary fissure and its application during fourth ventricle surgery. Neurosurgery 1992;30:325-30. https://doi.org/10.1227/00006123-199203000-00003

21. Kellogg JX, Piatt JH Jr. Resection of fourth ventricle tumors without splitting the vermis: The cerebellomedullary fissure approach. Pediatr Neurosurg 1997;27:28-33. https://doi.org/10.1159/000121221
22. Mussi AC, Rhoton AL Jr. Telovelar approach to the fourth ventricle: Microsurgical anatomy. J Neurosurg 2000;92:812-23. https://doi.org/10.3171/jns.2000.92.5.0812
23. Liu R, Kasper EM. Bilateral telovelar approach: A safe route revisited for resections of various large fourth ventricle tumors. Surg Neurol Int 2014;5:16. https://doi.org/10.4103/2152-7806.126081
24. Tomasello F, Conti A, Cardali S, La Torre D, Angileri FF. Telovelar approach to fourth ventricle tumors: Highlights and limitations. World Neurosurg 2015;83:1141-7. https://doi.org/10.1016/j.wneu.2015.01.039
25. Telovelar approach to the fourth ventricle. Neurosurgery 2007;61:S4-193-S4-210.
26. El-Bahy K. Telovelar approach to the fourth ventricle: Operative findings and results in 16 cases. Acta Neurochir (Wien) 2005;147:137-42; discussion 142. https://doi.org/10.1007/s00701-004-0407-0
27. Serrato-Avila JL, Paz Archila JA, Silva da Costa MD, Riechelmann GS, Rocha PR, Marques SR, et al. Three-dimensional quantitative analysis of the brainstem safe entry zones based on internal structures. World Neurosurg 2022;158:e64-74. https://doi.org/10.1016/j.wneu.2021.10.100
28. Párraga RG, Possatti LL, Alves RV, Ribas GC, Türe U, de Oliveira E. Microsurgical anatomy and internal architecture of the brainstem in 3D images: Surgical considerations. J Neurosurg 2016;124:1377-95. https://doi.org/10.3171/2015.4.JNS132778
29. Yagmurlu K, Rhoton AL Jr, Tanriover N, Bennett JA. Three-dimensional microsurgical anatomy and the safe entry zones of the brainstem. Neurosurgery 2014;10 Suppl 4:602-19; discussion 619-20. https://doi.org/10.1227/NEU.0000000000000466
30. Lister JR, Rhoton AL Jr, Matsushima T, Peace DA. Microsurgical anatomy of the posterior inferior cerebellar artery. Neurosurgery 1982;10:170-99.
31. Eissa EM. The role of the telovelar approach in fourth ventricular surgery: A new perspective. Turk Neurosurg 2018;28:523-9. https://doi.org/10.5137/1019-5149.JTN.21209-17.1