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Original Article

Microvascular decompression of trigeminal nerve through endoscopic retrosigmoid keyhole approach: Anatomical considerations of the trigeminocerebellar artery, technical pearls, and pitfalls

Nazmin Ahmed[1], Fuminari Komatsu[2], Yoko Kato[3]

[1]Department of Neurosurgery, Ibrahim Cardiac Hospital and Research Institute (A Centre for Cardiovascular, Neuroscience and Organ Transplant Units), Dhaka, Bangladesh, [2]Department of Neurosurgery, Fujita Health University Bantane Hospital, Nagoya, [3]Department of Neurosurgery, Fujita Health University, Toyoake, Aichi, Japan.

E-mail: *Nazmin Ahmed - nazmin.bsmmu@gmail.com; Fuminari Komatsu - fuminarikomatsu@gmail.com; Yoko Kato - kyoko@fujita-hu.ac.jp

***Corresponding author:**
Nazmin Ahmed,
Department of Neurosurgery,
Ibrahim Cardiac Hospital and Research Institute (A Centre for Cardiovascular, Neuroscience and Organ Transplant Units),
Dhaka, Bangladesh.

nazmin.bsmmu@gmail.com

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ABSTRACT

Background: Involvement of the trigeminocerebellar artery (TCA) in trigeminal neuralgia (TN) is rare, and reports of decompression using an endoscopic retro sigmoid keyhole approach are limited. This study, the largest of its kind, examines TCA-related TN cases to highlight the anatomical and surgical importance of the TCA, discuss technical difficulties in decompression, and review strategies for managing complications, along with a summary of previous cases.

Methods: Between April and September 2024, 56 endoscopic microvascular decompression (eMVD) procedures for TN were conducted using a 0° endoscope through the retrosigmoid keyhole approach in the Department of Neurosurgery, Fujita Health University Bantane Hospital, Japan. Among these, five cases involved the TCA as the compressive artery. We analyzed patient demographics, clinical presentations, neurovascular conflict (NVC) types, decompression techniques, surgical challenges, and outcomes, including a pictorial review of the TCA's developmental background, surgical anatomy, and clinical relevance.

Results: Of the 56 patients treated with eMVD, 5 (8.9%) were confirmed to have TCA-induced TN. These patients, predominantly female (60%) with an average age of 70.3 years, presented mainly with V2 or V3 distribution pain, primarily on the left side. Intraoperative analysis revealed multiple NVC points in 80% of cases due to the TCA's complex course, with variations in conflict type. Postoperative outcomes were positive, with immediate pain relief in all cases and 80% achieving complete symptom remission. No perioperative complications were observed. Preoperative imaging with 3D reconstruction and computed tomography angiography was valuable for planning, though intraoperative indocyanine green angiography was essential to confirm NVCs and the status of perforating arteries.

Conclusion: eMVD through a retro sigmoid keyhole approach is safe and effective for TCA-induced TN. Surgeons should consider potential TCA involvement and multiple NVCs to optimize decompression strategies.

Keywords: Keyhole surgery, Microvascular decompression, Root entry zone, Trigeminal neuralgia, Trigeminocerebellar artery

INTRODUCTION

Trigeminal neuralgia (TN) is a severe neuropathic condition marked by paroxysmal episodes of intense, electric shock-like pain, primarily affecting the second (V2) and third (V3) branches of the trigeminal nerve.[2,27] The condition is typically caused by neurovascular compression of the trigeminal nerve at its root entry zone (REZ), with the superior cerebellar artery (SCA) often identified as the most common offending vessel.[16,21] However, a rarer cause of TN has emerged in recent literature: compression by the trigeminocerebellar artery (TCA), an unusual arterial branch from the basilar artery (BA) that supplies both the trigeminal nerve root and cerebellar hemisphere.[10,17,25] Cases of TCA-related TN are infrequent, contributing to <1% of cases.[7]

The TCA was first characterized in detail by Marinkovic *et al.* (1996).[15] Unlike more commonly observed arteries, the TCA may take a tortuous course, occasionally encircling or penetrating the trigeminal nerve.[5] Such positioning makes TCA-induced TN particularly challenging to treat.[2,7] Conventionally, microscopic microvascular decompression (MVD) has been the preferred treatment for TN caused by vascular compression.[12] However, when dealing with the TCA's proximity to and, at times, intraneural course through the trigeminal nerve, an endoscopic approach may be advantageous.[7,16] Endoscopic MVD (eMVD), performed through a retro sigmoid keyhole approach, enhances the visibility of the REZ and permits improved access to complex neurovascular conflicts (NVCs). Studies have shown that eMVD can allow neurosurgeons to manage intricate compressions with greater precision, especially when using angled endoscopes to navigate the TCA's path and pinpoint areas of nerve conflict.[5,10,25]

Reported cases indicate that TCA-related TN may present with multiple compression points, requiring different decompression techniques such as vessel transposition, interposition with Teflon, or nerve-splitting. Wakuta *et al.* (2015) documented a case where the TCA followed an intraneural spiral course, compressing the trigeminal nerve at several sites. This was managed by transposing the vessel with Teflon felt and fibrin glue, achieving pain relief without extensive nerve manipulation. Similarly, Ichimasu *et al.* (2020) demonstrated successful decompression using a fascia wrap around the TCA, highlighting the efficacy of endoscopic techniques for managing challenging vascular compressions.[7,25]

The embryological background of the TCA can provide further insight into its unique course. The TCA is thought to represent a remnant of the primitive trigeminal artery (PTA), an anastomosis that connects the carotid and vertebrobasilar systems during early embryogenesis [Figure 1]. Although most remnants regress, in rare instances, the TCA persists in adults with an incidence of approximately 0.02–0.76% [Figure 2].[2,23] This persistent variant can exert significant pressure on the trigeminal nerve, particularly when it penetrates or encircles the nerve root, contributing to severe TN symptoms.[1,14]

We present a case series of TCA-induced TN treated through eMVD, focusing on clinical outcomes, anatomical considerations, and surgical challenges. This study offers valuable insights into optimizing decompression techniques for TCA-related TN. In addition, by reviewing previous case reports, we provide a comprehensive understanding of the complexities and effective solutions for managing TN arising from this rare vascular anomaly.

MATERIALS AND METHODS

Study design and participant selection

This cross-sectional study was conducted in the Department of Neurosurgery at Fujita Health University Bantane Hospital, Japan. A purposive sampling technique was employed to select patients for this study.

Inclusion and exclusion criteria

Patients were included if they underwent eMVD for TN and were confirmed intraoperatively to have TN caused by the TCA. Those undergoing eMVD for TN due to other vascular causes were excluded from the study. The management of venous bleeding within the context of the minimally invasive eMVD enables controlled and precise handling of venous bleeding, such as from the superior petrosal vein (SPV), by allowing targeted and limited exposure. This focused approach minimizes the risk of excessive bleeding while preserving critical venous structures, thereby enhancing intraoperative safety. The improved visualization provided by endoscopy further aids in the early identification and management of bleeding sources, reducing the need for extensive manipulation and retraction.

Indications for eMVD in TCA-related TN

Pure eMVD was chosen as a minimally invasive alternative to traditional microscopic MVD for patients with medication-resistant TN and NVC visible on imaging. This endoscopic approach provides enhanced visualization of the REZ, allows for detailed assessment of perforating vessels, facilitates mapping of the TCA's complex path, and identifies multiple NVC points using 0° endoscopic views.

Surgical management strategy

Preoperative neuroimaging

Preoperative three-dimensional (3D) imaging was performed using Ziostation-2 software (ZIOSOF, Tokyo, Japan) to merge

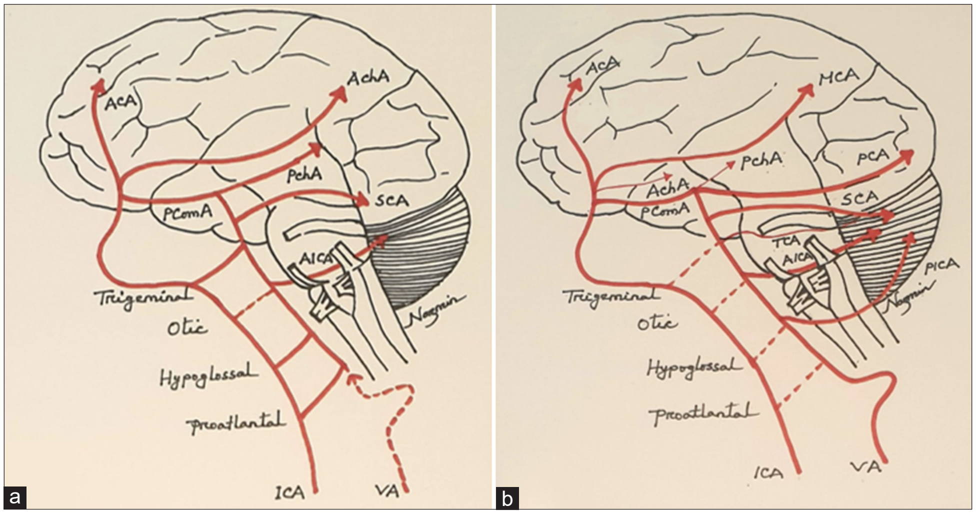

Figure 1: Schematic illustration of the development of the hindbrain arterial system (a) in the early stage (the CRL 4 mm) demonstrated the trigeminal, otic, hypoglossal, and proatlantal artery as carotid-basilar anastomoses system supplying the hindbrain. (b) At 7–8 weeks of age, the development of PcomA and vertebrobasilar arteries are formed, resulting in regression of primitive carotid-vertebrobasilar within a week. Despite regression, TCA can be developed as a distal continuation of primitive trigeminal artery. ACA: Anterior cerebral artery, AICA: Anterior inferior cerebellar artery, AchA: Anterior choroidal artery, CRL: Crown-rump length, ICA: Internal carotid artery, MCA: Middle cerebral artery, PICA: Posterior inferior cerebellar artery, PchA: Posterior choroidal artery, SCA: Superior cerebellar artery, TCA: Trigeminocerebellar artery, VA: Vertebral artery, PcomA: Posterior communicating artery.

computed tomography (CT) and magnetic resonance scans for precise anatomical mapping.

Patient's position and operating room setup

Patients were positioned in the park bench position, and a 3-cm incision was made in the retromastoid retro sigmoid area. A 1.5-cm keyhole craniotomy was performed at the junction of the transverse and sigmoid sinuses. After durotomy, a 4-mm, 0° endoscope was inserted, and the position of the endoscope was fixed with the help of the endoarm. An endoscope holder is used to allow bimanual dexterity, stabilize the endoscope to prevent unintended injury of the surrounding neurovascular structures, and allow adjustment of trajectory throughout the case.[3] Following sharp arachnoid dissection, gentle cerebellar retraction was achieved through cerebrospinal fluid (CSF) drainage from the cerebellopontine cistern, enabling retraction-free surgery. The patient's position and operating room setup are demonstrated in Figure 3.

Decompression techniques

A meticulous, sharp dissection of the arachnoid membrane was conducted between the SPV and the cranial nerve VII-VIII complex to optimize exposure of cranial nerve V. The REZ, the TCA's course, and all NVC points were evaluated, with indocyanine green (ICG) angiography used to confirm the offending vessel and assess perforators. While vascular contact with the trigeminal nerve may be visually apparent, ICG video angiography allows for real-time visualization of vessel dynamics, helping to distinguish the TCA from the SCA and confirming hemodynamic significance at the NVC points. This approach enhances the precision of vessel identification, ensuring that the true offending artery is targeted during MVD. Besides this, the status of perforating vessels was precisely determined. In five cases, the SCA was dissected to improve visualization of the TCA. This was performed exclusively to enhance visualization of the TCA rather than suggesting its direct involvement as the primary offending vessel in TN. This maneuver was necessary to optimize surgical exposure and accurately assess the NVC without misattributing causality to the SCA. The role of the SCA dissector in facilitating precise MVD lies in improving visualization and access to the trigeminal nerve by carefully mobilizing the s SCA when necessary in trigeminal neuralgia. Mobilization of the proximal TCA was challenging in four cases due to dense perforators requiring an interposition technique for effective decompression. In two cases with multiple NVC points, a combination of transposition and interposition techniques was employed.

Closure

Following decompression, the dura was closed, and Duragen was placed both in inlay and onlay fashion with adhesive

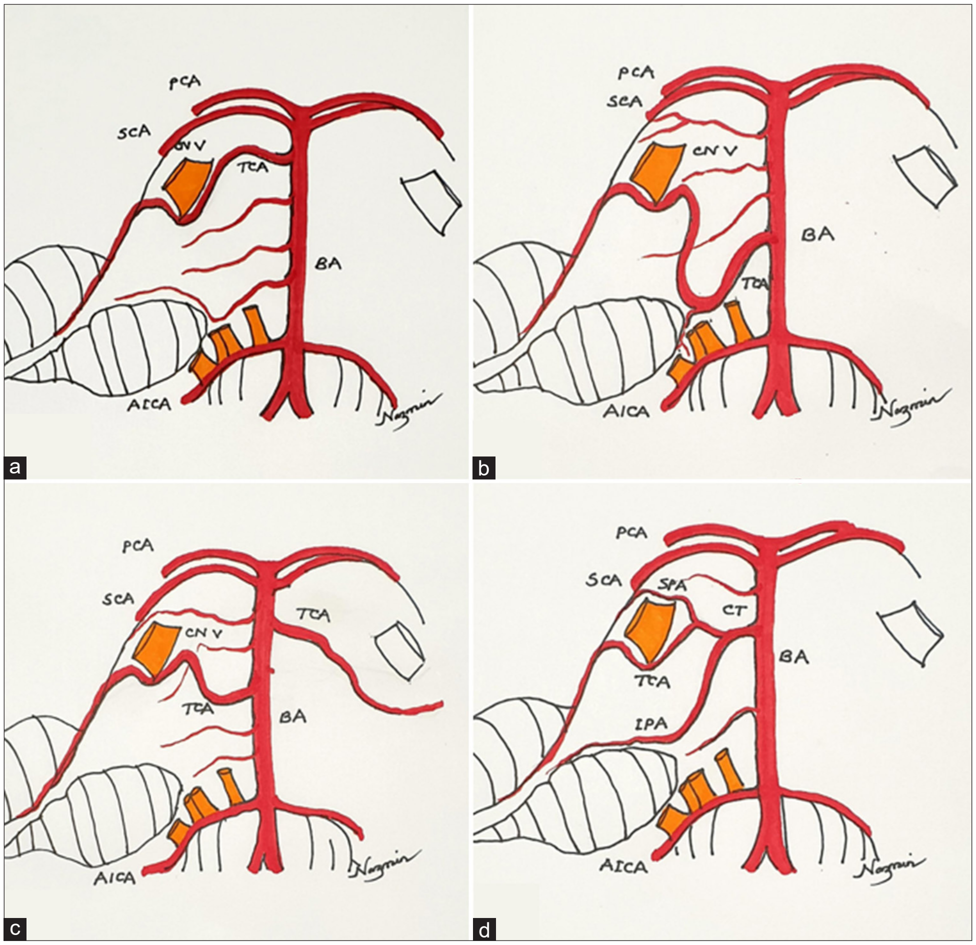

Figure 2: Schematic illustration depicted anatomical variations of TCA, according to the cadaveric observation by Tuccar *et al.*: (a) Curved TCA pressing the trigeminal nerve from the inferior aspect, (b) the TCA supplying the cranial nerves including the facial and vestibulocochlear nerves, (c) the TCA can be detected bilaterally whereas in the right side, its proximal course was similar to the inferolateral pontine artery, whereas on the left side, its course was similar to the superolateral lateral pontine artery, (d) very rarely, inferolateral pontine artery and superolateral pontine artery originating from the BA by a CT. The superior branch of the superolateral pontine artery continued to the posterior side of the pons. Here, PCA: Posterior cerebral artery, SCA: Superior cerebellar artery, SPA: Superolateral pontine artery, IPA: Inferolateral pontine artery, TCA: Trigeminocerebellar artery, V-trigeminal nerve, AICA: Anterior inferior cerebellar artery, BA: Basilar artery, CT: Common trunk.

glue, which was applied. Bone cement was used to seal the bone defect, and a layered closure was completed, ensuring anatomical precision. DuraGen is a safe and effective type I collagen matrix graft manufactured from bovine Achilles tendon. The collagen is highly purified to minimize the risk of immune response and infection. Considering the keyhole craniotomy, additional suturing is not ecesary, and final closure is achieved with sufficient tightness preventing CSF leakage; we are using this material. In addition, we can avoid another trauma in the donor site for harvesting fascia lata and fat graft.[22]

RESULTS

Patient demographics and clinical characteristics

From April 2024 to September 2024, 56 patients underwent eMVD for TN at our institution. Among these, 5 patients (8.9%) were intraoperatively confirmed to have TN induced by the TCA as the primary offending vessel [Table 1]. The mean age of these patients was 72.8 years, with a slight female predominance (60% female, 40% male). The duration of symptoms ranged from 8 months to 13 years, and most patients presented with TN pain in the V2 or V3 distributions, with a left-sided predilection (80% left, 20% right).

NVC patterns and intraoperative findings

Intraoperative assessment using ICG angiography revealed multiple points of NVC in four of the five cases (80%) due to the complex course of the TCA. The types of NVC varied, with Type II (juxtaposition/proximity) conflicts observed in three cases, Type III (compression) in one case and Type IV (distortion) in one case [Figure 4]. No relationship between the type of NVC and surgical outcome was observed.

Surgical techniques and challenges

Endoscopic visualization, facilitated by 0°endoscope, allowed precise mapping of the TCA's anatomical course and enhanced visualization of critical neurovascular structures. In four cases, the SCA was dissected to improve access to the TCA. In three cases, mobilization of the TCA's proximal segment was challenging due to the presence of dense perforators; hence, an interposition technique with a Teflon sponge was utilized. Both transposition and interposition techniques were applied in two cases where multiple NVC points were present [Table 1]. The intraneural course of the TCA was evident in one case, which necessitated careful vessel transposition with fibrin glue. This case highlights the value of customized decompression techniques in addressing multiple points of contact along the TCA and the importance of selecting techniques based on specific anatomical presentations.

Clinical outcomes and complications

Four cases (80%) achieved complete remission of neuralgic symptoms, while 1 patient (20%) was observed to have partial remission only and required carbamazepine to resolve the neuralgic symptoms. However, at 1-month follow-up in our outpatient department clinic, she achieved complete remission of pain. No other complications, such as masseter weakness, were noted following motor root retraction in cases involving nerve-splitting or transposition.

Comparison with previously reported cases

Table 2 provides an overview of previously reported cases of TCA-induced TN. Across studies, various surgical strategies, including microscopic decompression, transposition, and nerve-splitting techniques, have demonstrated high rates of

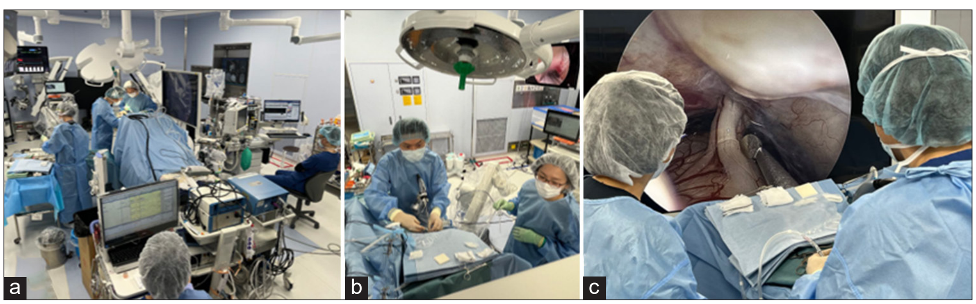

Figure 3: Intraoperative photograph (a) depicting set up in the operation theater and position of Surgeon, assistant, anesthesiologist, neurophysiologist, and monitors, (b) the position of endo arm and instrument set up, (c) the representative photograph of trigeminal nerve decompression.

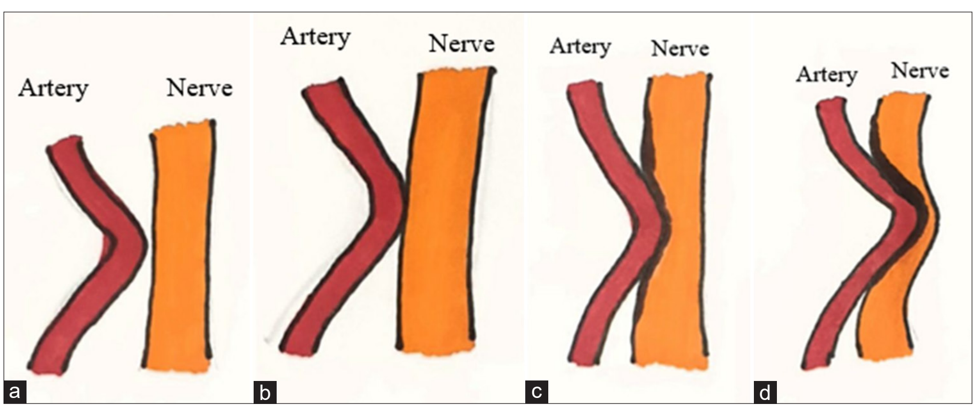

Figure 4: Schematic drawing demonstrating types of neurovascular conflict: (a) Type I- juxtaposition, (b) Type II-touching/proximity, (c) Type III-compression, and (d) Type IV-distortion.

Table 1: Summary of the TCA-induced TN cases done through endoscopic retrosigmoid keyhole approach.

Case No.	Age/sex	Symptom duration	Site/Distribution	NVC type	Intraoperative observation	Offending artery
1	72/F	12 months	Lt/V2, V3	II	TCA confirmed with ICGA	TCA
2	81/F	6 years on CBZ, become worse since 2022	Lt/V3	II	TCA confirmed with ICGA	TCA
3	85/F	13 years, self-discontinuation of CBZ	Rt/V3	II	TCA confirmed with ICGA	TCA
4	57/M	8 months, no improvement with Mirogabalin	Lt/V2	IV	TCA is an incidental finding	SCA
5	69/M	10 years, Gamma knife surgery in 2018, the pain worsened in 2024	Lt/V2	III	TCA is an incidental finding	SCA
Case No.	**Age/sex**	**Site of conflict**	**Decompression technique**	**Complication**	**Outcome**	
1	72/F	REZ	Interposition	None	Complete remission	
2	81/F	REZ	Transposition	None	Complete remission	
3	85/F	REZ	Interposition	None	Complete remission	
4	57/M	REZ	Transposition-SCA Interposition-TCA	None	Complete remission	
5	69/M	REZ	Transposition and interposition-SCA	None	Partial remission at immediate postoperative period. Complete remission at 1 month F/U	

M: Male, F: Female, Rt: Right, Lt: Left, REZ: Root entry zone, CBZ: Carbamazepine, NVC: Neurovascular conflict, TCA: Trigeminocerebellar artery, SCA: Superior cerebellar artery, ICGA: Indocyanine green angiography, F/U: Follow-up, TN: Trigeminal neuralgia

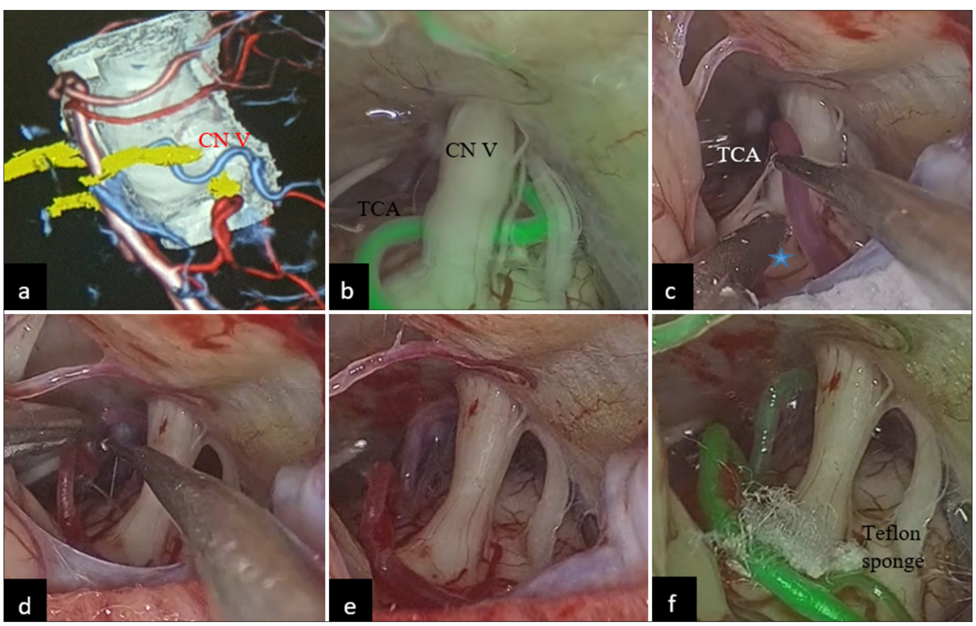

Figure 5: Preoperative 3D reconstruction CTA (case 1) (a) demonstrated no definite arterial compression in REZ of TN; (b) intraoperative visualization of TCA as offending artery, confirmed by ICG angiography; (c) separation of TCA from REZ of TN, perforating arteries are visible, arising from TCA which were marked with blue star; (d) dissection of TCA along its course; (e) appearance of the TCA after dissecting away from the nerve; (f) decompression of REZ by interposition technique with Teflon sponge. CTA: Computed tomography angiography, REZ: Root entry zone, TCA: Trigeminocerebellar artery, TN: Trigeminal nerve.

Table 2: Reported cases of TCA induced Trigeminal neuralgia to date.

Author	Year	Age/sex	Symptom duration	Distribution	Medication/invasive procedure	Choice of procedure
Amagasaki *et al.*[2]	2014	31/F	15 years	Rt/V2 > V1, V2, V3	CBZ-600 mg/day, pain becomes refractory	Microscopic
Shibao *et al.*[21]	2015	72/F	3 years	Lt/V3	CBZ-800 mg/day, pain becomes refractory	Microscopic
		80/M	1 year	Rt/V2	CBZ-300 mg/day > 450 mg/day, pain becomes refractory	Microscopic
Jito and Nozaki[10]	2016	82/F	10 years	Lt/V2, V3	CBZ, discontinued due to hepatic hypofunction Gabapentin started, but the pain became refractory	Microscopic
Wakuta *et al.*[25]	2015	70/F	5 years	Rt/V2	CBZ	Microscopic
Ichimasu *et al.*[7]	2020	53/F	4 years	Rt/-	CBZ, failure to improve satisfactorily	Microscopic
Goto *et al.*[6]	2020	-	-	-	-	-
Nakipuria *et al.*[16]	2023	-	-	-	-	Endoscopic
Onoda *et al.*[17]	2023	65/F	2 years	Lt/V2	Yes/no	Microscopic
Yokoyoma *et al.*[28]	2024	74/M	-	Lt/-	-	Microscopic
Author	**Offending vessel**	**NVC site/no**	**NVC type**	**Management**	**Complications**	**Outcome**
Amagasaki *et al.*[2]	SCA (duplication), TCA	REZ/encircle	II	Transposition with Teflon sling, some small perforators at REZ sacrificed	Transient hypesthesia along V2	Immediate post procedure pain relief. Transient hypesthesia resolved at 1 month F/U.
Shibao *et al.*[21]	TCA (nerve penetrating)	REZ/encircle	II	Transposition with shredded Teflon	None	Immediate post procedure pain relief and no recurrence at 24 months F/U
	TCA	REZ/2	II	Transposition with shredded Teflon and glue	None	Immediate post procedure pain relief and no recurrence at 24 months F/U
Jito and Nozaki[10]	TCA (nerve penetrating)	REZ/-	II	Transposition	None	Immediate post procedure pain relief and no recurrence at 5 years F/U
Wakuta *et al.*[25]	TCA (nerve penetrating)	REZ/ multiple	III	Transposition with Teflon felt, and glue, interposition with Teflon felt	None	Immediate post procedure pain relief
Ichimasu *et al.*[7]	TCA (nerve penetrating)	REZ/2	II	Transposition with Teflon felt and glue; the penetrating part was wrapped with fascia	None	Immediate post procedure pain relief and no recurrence at 48 months F/U

(Contd...)

Table 2: *(Continued)*.

Author	Offending vessel	NVC site/no	NVC type	Management	Complications	Outcome
Goto *et al*.[6]	TCA (nerve penetrating)	-	-	-	-	-
Nakipuria *et al*.[16]	TCA (nerve penetrating)	REZ	III	Transposition with gelatin sponge and glue	None	Immediate post procedure pain relief and no recurrence at 3 months F/U
Onoda *et al*.[17]	SCA, TCA	Nerve, REZ/2	IV	SCA- transposition with Teflon tape TCA- dissection from REZ and reposition	None	Immediate post procedure pain relief and no recurrence at 1 year F/U
Yokoyama *et al*.[28]	SCA, TCA, AICA	Nerve, REZ/5		3 decompression in the same sitting, transposition to the dura, transposition to the brain, interposition	None	Immediate post procedure pain relief

M: Male, F: Female, Rt: Right, Lt: Left, SCA: Superior cerebellar artery, TCA: Trigeminocerebellar artery, AICA: Anterior inferior cerebellar artery, NVC: Neurovascular conflict, REZ: Root entry zone, F/U: Follow-up, CBZ: Carbamazepine

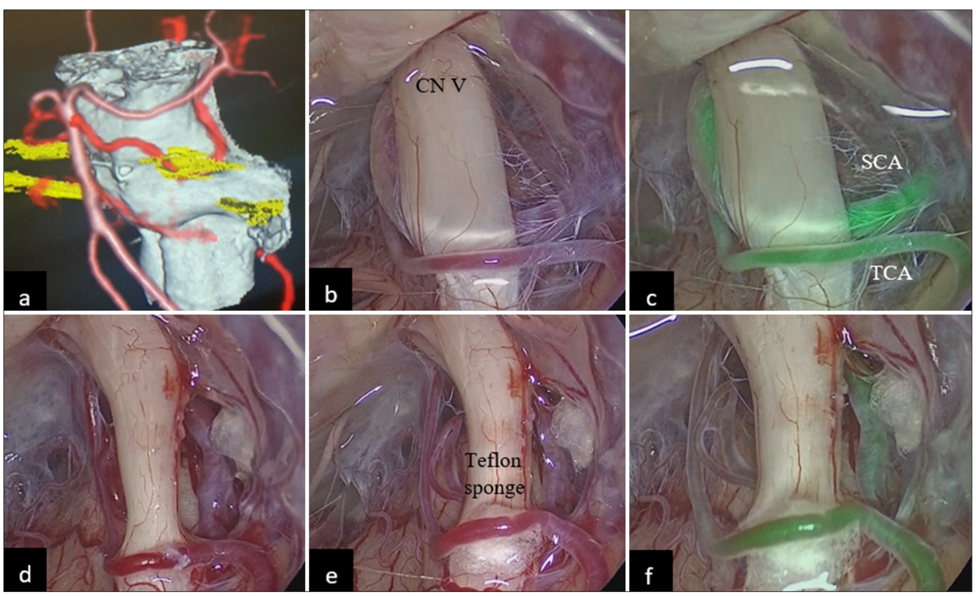

Figure 6: Pre-operative 3D reconstruction CTA (case 4) (a) demonstrated arterial compression by SCA in REZ of trigeminal nerve; (b) intraoperative visualization of SCA as offending artery with type IV NVC, TCA is observed as an incidental finding; (c) confirmation of arterial compression by ICG angiography; (d) dissection of SCA from REZ and successful transposition ensured with teflon sponge and fibrin glue; (e) TCA dissected away and decompression ensured with interposition technique; (f) final appearance of REZ after successful decompression of REZ of Cranial nerve V. CTA: Computed tomography angiography, SCA: Superior cerebellar artery, REZ: Root entry zone, NVC: Neurovascular conflict, TCA: Trigeminocerebellar artery, ICG: Indocyanine green angiography, REZ: Root entry zone

symptomatic relief. The novelty of our reported series is that, all of the previously reported cases were decompressed through microscopic route except the reported case by Nakipuria *et al.*[16] whereas the cases of the present series achieved favorable neurological outcomes following eMVD with 0° endoscope only. Comparing with these reports confirms the efficacy of eMVD in achieving symptom resolution in TCA-induced TN. In addition, the rate of transient postoperative symptoms, such as facial numbness, remains low across cases, underscoring the safety of endoscopic approaches for these complex anatomical presentations.

Imaging findings and three-dimensional reconstruction

Preoperative three-dimensional (3D) reconstruction and CT angiography (CTA) imaging were utilized in all cases, aiding in the detection and assessment of NVCs. However, 3D imaging alone proved insufficient in identifying all points of compression in three cases, which were only confirmed intraoperatively with ICG angiography [Figures 5 and 6]. Besides this, the status of brainstem perforators was crucial to avoid inadvertent injury and, consequently, postoperative ischemic deficit. These findings suggest that although preoperative imaging is invaluable for surgical planning, direct visualization remains critical for accurate identification and effective decompression of NVCs in TCA-induced TN.

DISCUSSION

Our findings align with previous studies that support eMVD as a safe and effective approach for TCA-induced TN. Symptomatic relief rates in this study were comparable to those reported in the literature, confirming the benefits of endoscopic visualization in addressing TCA's anatomical challenges. The low incidence of transient postoperative symptoms further supports the safety of endoscopic techniques in TN management. However, the limited literature on TCA-induced TN highlights the need for continued research to refine and standardize these techniques.

The PTA, a remnant of primitive carotid-vertebrobasilar anastomoses, persists in 0.5–0.7% of adults, making it the most common remnant among four primary anastomotic channels. Typically, the PTA originates from the intracavernous internal carotid artery and merges with the BA between the SCA and anterior inferior cerebellar artery (AICA). The PTA variant that exclusively supplies part of the cerebellum is termed the TCA or PTA variant, with a reported incidence of 0.02–0.76%. This variant can bypass the BA and directly supply portions of the brainstem and cerebellum, areas normally perfused by the SCA, AICA, or posterior inferior cerebellar artery. The TCA likely represents a caudal remnant of the PTA, embodying unique anatomical features that can be clinically significant in certain cases of TN.[4-6,25]

Anatomical complexity and surgical challenges

The TCA, though rare, presents unique anatomical challenges in TN cases. Due to its tortuous path and the multiple NVC points it can create, managing TCA-induced TN requires precise anatomical mapping and tailored decompression techniques. Traditional MVD may not be sufficient in cases where the TCA penetrates or encircles the trigeminal nerve. First characterized by Marinkovic *et al.* (1996), the TCA is a distinct BA branch that supplies the pons, trigeminal nerve root, and cerebellum.[15] The trigeminal segment of the TCA, in particular, often encircles or penetrates the nerve root, leading to complex NVC patterns and potentially causing TN.[7,16]

In this study, multiple NVC points and sharp arterial turns were observed, consistent with previous reports. The TCA's intraneural variants, while not fully understood, may arise from embryological development, potentially due to the fusion of the ophthalmic and maxillomandibular nerves before they form the three branches of the trigeminal nerve.

Imaging analysis and role of imaging in surgical planning

Advanced three-dimensional (3D) imaging, combined with CTA, enhances preoperative assessment by aiding in the identification of NVC points and guiding surgical strategies. In this study, 3D fusion imaging was utilized for all patients, revealing NVC in four out of five TCA cases. However, 3D imaging alone proved insufficient in certain cases; additional intraoperative ICG angiography was essential to confirm compression points, underscoring the importance of integrating real-time intraoperative imaging with preoperative data to improve diagnostic accuracy. For complex TCA cases, such comprehensive imaging strategies are invaluable, as they help reveal the full extent of neurovascular involvement and optimize the surgical approach.[8,19,24]

Management strategy

The intraneural TCA variant presents unique challenges in decompression, as standard transposition techniques are often inadequate when the vessel penetrates the trigeminal nerve root. In our series, careful mobilization of the motor root and selective dissection of perforators were necessary to increase TCA movability while preserving critical vascular structures. For cases with both external and intraneural compression, we found that straightening the TCA effectively relieved symptoms without requiring more invasive procedures like nerve-splitting.[9,12,28]

For TCA variants involving dense perforators, transposition is typically preferred due to its lower recurrence rates. However, the nerve-penetrating nature of the TCA limits this approach's feasibility. While some literature suggests a microscope-assisted nerve-splitting technique, our experience demonstrates that a pure endoscopic approach can achieve equally effective outcomes, allowing for safe nerve-splitting in certain configurations.[20,26]

In cases where the TCA's spiral configuration caused both internal and external compression, simple wrapping with Teflon felt inadequate and even risked exacerbating compression. In one patient, we straightened the TCA's path to alleviate compression, achieving pain relief without complications. Similarly, Ichimasu *et al*.[7] reported successful pain relief by wrapping the TCA's intraneural portion with fascia. Our findings highlight the importance of customized decompression techniques in managing these complex cases.[13,26]

Endoscopic decompression techniques and customization

The endoscopic retro sigmoid keyhole approach offers advantages over traditional MVD, particularly in visualizing the TCA's complex anatomy. Using endoscopes facilitated precise mapping of the REZ and TCA, allowing for tailored decompression. For cases with restricted vessel mobility due to dense perforators, interposition with a Teflon sponge provided effective decompression without compromising perforator integrity. In addition, cases with multiple NVC points or spiral TCA configurations benefited from a combination of transposition and interposition techniques adapted to each patient's anatomy.[11,18,20]

Complication management and prevention

Complication prevention is critical in TCA cases, especially given the proximity to vital brainstem perforators. Preoperative imaging combined with intraoperative ICG angiography was crucial for confirming blood flow and reducing the risk of perforator injury. Venous bleeding, commonly encountered intraoperatively, was managed with gentle compression using oxycel balls, underscoring the need for a meticulous, minimally invasive approach. These strategies, including preserving blood flow in both the main trunk and perforators, were essential to avoid postoperative deficits.[1,14]

Limitations and future directions

This study provides important insights into the management of TCA-induced TN, but it is limited by a relatively small sample size and the absence of long-term follow-up. The study was not designed as a comparative analysis between eMVD and traditional microscopic MVD. As such, we refrain from making definitive claims regarding the superiority of one technique over the other. Instead, our findings highlight eMVD as a viable and effective alternative in selected cases, particularly where enhanced visualization is beneficial. In addition, the lack of a direct control group and the relatively small sample size limit the generalizability of our conclusions. Future studies incorporating larger cohorts and direct comparative analyses will be essential to establish the relative advantages and long-term outcomes of eMVD versus traditional MVD. Additional research on advanced preoperative imaging modalities, such as enhanced 3D imaging and intraoperative virtual simulation, could further improve TCA identification accuracy and optimize surgical planning for these complex cases.

Learning points

3D reconstructive imaging

Three-dimensional imaging is essential for identifying compression sites, pinpointing the offending vessel, and facilitating preoperative planning. However, 3D imaging can yield false negatives. In angionegative cases, surgical exploration may be necessary to confirm the diagnosis and enable therapeutic intervention.

Minimally invasive access

A 1.5 cm retro sigmoid keyhole craniotomy provides an effective surgical corridor. Early CSF drainage at the beginning of the procedure enables a retractor-less approach, reducing the risk of brainstem injury.

Precise dissection technique

Blunt dissection is discouraged due to the risk of damaging perforating vessels. Sharp arachnoid dissection is preferred for exposing the REZ, mapping the TCA's course, and preserving the integrity of perforating vessels. Meticulous sharp arachnoid dissection is needed for effective mobilization of the offending artery from the TN. Blunt dissection or pulling of an offending vessel without arachnoid dissection may result in vasospasm and inadvertent injury to the surrounding structures.

Utility of ICG angiography

ICG angiography is invaluable for identifying NVCs, visualizing arteriovenous shunts, distinguishing between arteries and veins, and assessing the condition of perforator vessels.

Enhanced endoscopic visualization

A 0-degree endoscope significantly improves visualization of multiple NVCs, especially in anatomically complex cases where conventional microscopic viewing is restricted.

Perforator assessment

A *c*omprehensive evaluation of brainstem perforators' position and condition is crucial for selecting the appropriate decompression technique. In certain cases, interposition with Teflon is recommended. Post-procedural verification of adequate blood flow in both interpositioned arteries and brainstem perforators is essential to ensure effective decompression.

Adequacy of decompression

If any uncertainty remains regarding the adequacy of nerve decompression, internal neurolysis can be performed in conjunction with the interposition technique to achieve optimal outcomes.

Intraoperative flexibility

Real-time adjustments during surgery, guided by intraoperative findings and imaging, are crucial in complex TCA cases. Surgeons should be prepared to modify their approach based on unexpected anatomical variations or NVCs not fully revealed by preoperative imaging.

Patient positioning

Optimal patient positioning, such as the park bench position, enhances access to the retrosigmoid area, improves anatomical orientation, and reduces cerebellar compression, facilitating a safer and more effective keyhole approach.

Customized decompression techniques

Standard decompression methods may not be effective in cases involving the TCA. Techniques such as transposition, interposition, or straightening of the vessel should be selected based on the precise location and type of NVC, especially in cases of intraneural or spiral TCA variants.

Complication anticipation and management

Awareness of potential complications specific to TCA decompression, such as perforator injury or venous bleeding from the SPV, is essential. Utilizing tools like oxycel balls for controlled compression and minimizing manipulation near perforators are key preventive measures.

Integration of preoperative and intraoperative data

Combining preoperative 3D imaging data with intraoperative findings, particularly ICG angiography, enhances the surgeon's ability to precisely locate and assess NVC points, allowing for a more targeted and thorough decompression strategy.

Postoperative monitoring for complications

Given the intricate anatomy involved, careful postoperative monitoring is essential to detect any transient complications which may arise from minor brainstem ischemia or motor root retraction.

Long-term follow-up for recurrence

Regular long-term follow-up is recommended to monitor for recurrence of TN symptoms, particularly in cases involving complex decompressions of the TCA, where adhesions or residual compression may lead to symptom recurrence.

CONCLUSION

eMVD through the retro sigmoid keyhole approach provides a minimally invasive, effective solution for managing TN caused by the rare involvement of the TCA. Our findings highlight the critical roles of advanced imaging, particularly three-dimensional (3D) reconstructive imaging, and intraoperative ICG angiography, in identifying and confirming NVC points for precise decompression planning. Tailoring decompression strategies – such as vessel transposition, interposition with Teflon, and selective nerve-splitting – to accommodate the TCA's unique anatomical course enhances surgical efficacy while minimizing complications. The success of these targeted approaches supports the endoscopic retro sigmoid keyhole approach as a valuable technique in the neurosurgical management of TN arising from this rare vascular anomaly. Further research, with larger cohorts and long-term follow-up, is essential to refine these decompression techniques and establish comprehensive best practices for treating TCA-induced TN. The continuous development of imaging technology and intraoperative visualization will also enhance our ability to address this challenging and intricate etiology, potentially improving outcomes and expanding the applicability of eMVD in similar neurovascular conditions.

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