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Original Article

Anatomical insights and clinical implications of the persistent trigeminal artery: A cadaveric study utilizing latex injection techniques

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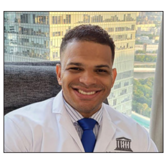

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ABSTRACT

Background: The persistent trigeminal artery (PTA) is a rare embryonic connection between the internal carotid and basilar arteries. While typically regressing during development, it remains in some individuals, potentially leading to clinical concerns such as cerebrovascular complications or cranial nerve compression. A clear understanding of PTA anatomy is essential for neurosurgical planning and intervention, as its presence can affect blood flow dynamics and influence surgical strategies.

Methods: This study involved a cadaveric analysis using a latex injection technique on a single male specimen. The brain was carefully removed, and a detailed seven-step injection process was employed to map the PTA. Microsurgical dissection was performed to document the artery's origin, path, branching patterns, and relationships with nearby structures. Measurements were taken using digital calipers, and high-resolution images were captured for further analysis.

Results: The PTA was traced back to its origin at the posterior curve of the cavernous segment of the internal carotid artery. It traveled posterolaterally into the posterior cranial fossa, dividing into medial and lateral branches. Variations observed included slight twisting near its origin. The medial branch contributed to the posterior circulation, while the lateral branch supplied the superior cerebellar artery. These findings provide valuable insights into the PTA's anatomy and its clinical implications.

Conclusion: This study expands the understanding of PTA anatomy, emphasizing its importance in neurosurgical planning and procedures. Larger sample studies are needed to validate and broaden these findings.

Keywords: Anatomy, Neurosurgery, Trigeminal nerve

INTRODUCTION

The trigeminal artery is a key embryonic connection between the internal carotid artery (ICA) and the basilar artery (BA) during the brain's vascular development. This temporary anastomosis supports the formation of the posterior circulation before the vertebrobasilar system fully develops. Typically, the trigeminal artery regresses by the 6^{th}–7^{th} week of gestation as the posterior communicating artery and vertebrobasilar system take over their roles in the posterior circulation. However, in rare cases, the artery persists into adulthood as a persistent trigeminal artery (PTA), which may lead to clinical concerns such as cerebrovascular disorders or cranial nerve compression syndromes.[1,2] Sometimes, PTA is called fetal trigeminal artery, a term that highlights its embryologic origins.

PTA is estimated to occur in 0.1–0.6% of individuals, based on angiographic studies. This prevalence may be underreported, as many cases are asymptomatic.[1] The presence of a PTA can significantly affect cerebrovascular hemodynamics, increasing the risk of conditions such as aneurysms, arteriovenous malformations, and ischemic events. Its existence also presents challenges in surgical and interventional procedures involving the carotid and BAs, emphasizing the importance of understanding its anatomical variations and relationships with adjacent structures.[2,3]

Imaging techniques such as magnetic resonance angiography (MRA), computed tomography angiography (CTA), and digital subtraction angiography (DSA) have been instrumental in studying PTA prevalence and anatomy.[4] However, these modalities often lack the resolution to capture intricate three-dimensional anatomical details. In contrast, cadaveric studies offer unparalleled insights into the PTA's detailed anatomy, revealing information that imaging alone cannot provide.[1,5]

This study aims to explore the anatomy of the trigeminal artery through cadaveric analysis using latex injection techniques. By employing this approach, we sought to map the PTA's course, branches, and anatomical relationships, thereby contributing valuable data to the existing knowledge on this rare but clinically significant vascular anomaly. The investigation focused on a single cadaver specimen, enabling a meticulous examination of the PTA's unique features and variations.[3]

The latex injection method is widely recognized in anatomical research for its ability to provide a detailed visualization of vascular structures. Latex preserves vessel patency, highlights even the smallest branches, and allows for a thorough examination of the vascular system. In this study, a seven-step brain injection technique was employed, ensuring a precise representation of the trigeminal artery and its associated structures.[6,7]

Understanding the trigeminal artery's anatomy is critical for clinicians, particularly in the context of neurovascular interventions. The presence of a PTA can influence surgical approaches, endovascular treatments, and the management of cerebrovascular conditions. In addition, recognizing PTA variations can aid in diagnosing and treating disorders such as trigeminal neuralgia, where arterial compression of the trigeminal nerve may cause characteristic facial pain.[8,9]

The study's objectives were threefold: to document the PTA's anatomical course and branches in a cadaveric specimen, to identify variations in its origin, path, and termination; and to discuss the clinical implications of these findings for neurosurgical and interventional procedures. By achieving these goals, this study aims to enhance the understanding of PTA anatomy and provide valuable insights for clinicians managing this vascular anomaly.

MATERIALS AND METHODS

The study was conducted using a single cadaver specimen obtained from the Department of Anatomy at the University Autonomous of Mexico. The specimen was a 65-year-old male with no known history of cerebrovascular diseases or cranial surgeries. The institutional review board granted ethical approval, and all procedures adhered to relevant ethical guidelines for cadaveric research.

Preparation of the specimen

The cadaver was positioned supine on the dissection table, and the head was stabilized to allow easy access to the cranial cavity. A midline incision was made from the nasion to the inion, and the scalp was reflected laterally to expose the cranial vault. The calvaria was removed using an oscillating saw to reveal the brain and its vascular structures. The brain was carefully extracted to expose the base of the skull and the dural vessels.

Brain injection technique

A seven-step brain injection method was employed to ensure clear visualization of the vascular system:

Extraction

The brain was carefully removed from the cranial cavity, ensuring minimal damage to the cerebral vascular system. Cranial nerves, arteries, veins, and venous sinuses were severed close to the base of the skull to preserve vascular structures as much as possible. Key structures, including the ICA, internal auditory artery, vertebral artery (V4), superficial middle cerebral vein, superior petrosal sinus, major petrosal vein, and transverse sinus, were identified and preserved.

Wash out

One vertebral artery and one ICA were catheterized using 5 French (Fr) catheters, while their contralateral counterparts were securely closed. The arterial system was flushed with saline to clear blood and clots, with care taken to avoid excessive pressure that might damage small vessels. Leakage points, especially in the internal auditory artery, were identified and sealed.

Fixation by perfusion-immersion

The vascular system was fixed by perfusing 15 mL of pure formaldehyde through the vertebral and ICAs over 5 min. The brain was then immersed in 3 L of 10% formaldehyde solution for 15 min, followed by an additional liter of the solution perfused through the ICA with the vertebral artery left open. This method ensured the thorough preservation of vascular architecture.

Latex injection

After fixation, a latex mixture was prepared using white latex (Poliformas Plásticas®) mixed with carmine 319 acrylic paint (Politec®). Fifteen milliliters of this mixture were injected into the vertebral artery and 20 mL into the ICA. Any leakage was rinsed with running water to prevent staining of the arachnoid or pia mater.

Fixation by immersion

Postinjection, the brain was submerged in 10% formaldehyde solution for 24 h, which was then replaced with fresh 10% formaldehyde. The brain remained in this solution for 2 months before dissection.

Preservation

After the 2 months, the brain was rinsed with running water for 24 h to remove residual formaldehyde. It was then preserved in a 60% isopropyl alcohol solution.

Microsurgical dissection

Using a microsurgical microscope, Rothon's dissectors, fine scissors, and microsurgical tweezers, the brain was dissected to study the vascular system. Photographic documentation was performed at each stage for subsequent analysis.

Dissection and anatomical analysis

Following the preparation, the trigeminal artery was meticulously traced from its origin at the ICA through the cavernous sinus to the posterior cranial fossa. The artery's branches were identified, and their relationships with surrounding anatomical structures were documented.

Photographic documentation and measurements

High-resolution photographs captured the anatomical details of the trigeminal artery at different stages of dissection. Digital calipers were used to measure the artery's diameter, length, and distances from key anatomical landmarks. These measurements formed the basis of a quantitative analysis of the PTA's anatomy.

Data analysis

The data from the dissection and measurements were analyzed to identify any anatomical variations in the trigeminal artery. The findings were compared with existing literature to highlight unique observations or deviations from previously reported descriptions. The clinical implications of these anatomical features were discussed in the context of neurosurgical and interventional procedures.

RESULTS

The findings of this cadaveric study provide a detailed analysis of the PTA, shedding light on its anatomical course, branching patterns, variations, and clinical relevance. Using a comprehensive latex injection technique followed by meticulous dissection, the study enabled precise visualization and documentation of this rare vascular anomaly.

Identification and origin of the trigeminal artery

The PTA was identified as originating from the posterior bend of the cavernous segment of the ICA. This finding aligns with previous descriptions, reaffirming the typical emergence of the PTA from the cavernous ICA. At its origin, the artery measured approximately 1.5 mm in diameter, and its initial segment ran parallel to the abducens nerve (cranial nerve VI) within the cavernous sinus.

Course and branching pattern

The PTA was observed coursing posterolaterally from its origin, passing between the abducens nerve and the lateral wall of the cavernous sinus. It then traversed the dura mater, entering the posterior cranial fossa. Throughout its trajectory, the artery maintained a relatively consistent diameter with minimal tapering.

In the posterior cranial fossa, the PTA bifurcated into two primary branches:

- Medial branch: This branch followed a medial path, running adjacent to the BA and contributing to the

posterior circulation. It supplied small perforating arteries to the pons and medulla, which are critical brainstem structures.
- Lateral branch: The lateral branch extended toward the cerebellopontine angle and contributed to the superior cerebellar artery (SCA). In addition, it gave rise to several smaller arteries that vascularized the cerebellar hemisphere.

Anatomical relationships

The PTA's relationships with surrounding structures were carefully documented. Within the cavernous sinus, the artery was closely associated with the abducens nerve, which it crossed anteriorly. In the posterior cranial fossa, the medial branch of the PTA ran near the BA, while the lateral branch was positioned close to the trigeminal nerve (cranial nerve V) at its root entry zone.

Variations and anomalies

Anatomical variations were observed during the dissection. The PTA displayed slight tortuosity in its course, with a minor loop near its origin from the ICA. In addition, the bifurcation pattern showed variability, with the lateral branch occasionally giving rise to an accessory artery that supplied the anterior inferior cerebellar artery.

Clinical implications

The anatomical characteristics of the PTA carry significant clinical implications. The artery's close association with the abducens nerve within the cavernous sinus suggests a potential for neurovascular compression, which could result in abducens nerve palsy, especially in cases of PTA enlargement or aneurysm formation. Furthermore, its role in posterior circulation highlights its potential involvement in cerebrovascular events, such as ischemic strokes, particularly in the brainstem and cerebellum.

Measurements and quantitative analysis

The study recorded the following key measurements of the PTA:
- Diameter at origin: 1.5 mm
- Length from origin to bifurcation: 23 mm
- Medial branch diameter: 1.2 mm
- Lateral branch diameter: 1.3 mm
- Distance from ICA origin to posterior clinoid process: 7 mm.

These measurements provide a quantitative framework for understanding the PTA's anatomical dimensions and can serve as valuable references for future research and clinical applications.

Photographic documentation

High-resolution photographs were taken to document the course, branching patterns, and anatomical relationships of the PTA at various stages of dissection. These images serve as a visual aid, complementing the descriptive findings and offering a detailed representation of the artery's anatomy. They provide a valuable resource for both educational and clinical applications, helping to illustrate the complexity of this vascular anomaly [Figures 1-3].

DISCUSSION

The PTA represents a rare vascular anomaly with notable clinical relevance, especially in the fields of cerebrovascular disease and neurosurgery. This cadaveric study used latex injection techniques to delve into the anatomical intricacies of the PTA, detailing its pathway, branches, and spatial relationships.[10]

Our findings revealed that the PTA's prevalence in cadaveric specimens corresponds with earlier reports, estimated at 0.2–0.32% in angiographic studies.[10,11] This low frequency

Figure 1: Brain specimen injected with latex, highlighting the persistent trigeminal artery (PTA). The PTA is clearly visible, originating from the cavernous segment of the internal carotid artery and bifurcating into medial and lateral branches. The latex injection vividly shows the artery's course and its anatomical relationships, providing crucial insights for neurovascular analysis.

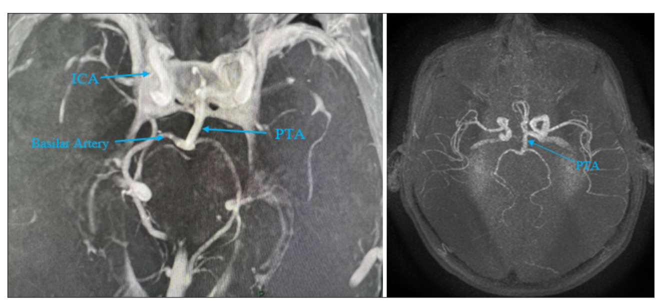

Figure 2: Axial contrasted magnetic resonance imaging showing the persistent trigeminal artery (PTA). The image clearly demonstrates the PTA's path, emerging from the internal carotid artery (ICA) and coursing posteriorly. The contrast enhancement highlights the artery's trajectory and its relationship with adjacent cranial structures, providing essential visual information for assessing the clinical implications of this vascular anomaly.

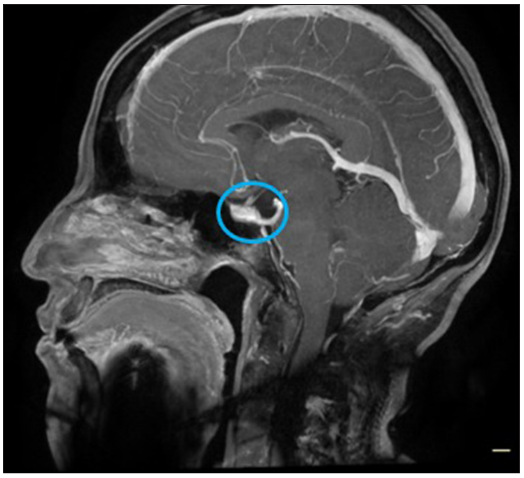

Figure 3: Sagittal contrasted MRI revealing the persistent trigeminal artery (PTA). The image distinctly shows the PTA's vertical course, emphasizing its anatomical positioning and connection between the internal carotid artery and basilar artery within the cranial cavity. The blue circle highlights the PTA, illustrating its trajectory and anatomical relevance.

highlights the rarity of this anomaly, which often remains undetected until clinical symptoms manifest. In addition, our identification of Saltzman type I and type II PTAs underscores the known anatomical variability of this artery.[12] These classifications are crucial for understanding the hemodynamic effects and potential risks unique to each type, particularly concerning blood flow in the posterior circulation.

Anatomical course and variations

In this study, the PTA originated from the posterior bend of the ICA cavernous segment, aligning with prior descriptions.[5,13] It traversed the cavernous sinus and entered the posterior cranial fossa, where it divided into medial and lateral branches.[14] The medial branch contributed to the BA, while the lateral branch supplied the SCA and other smaller cerebellar vessels. These findings, including the bifurcation pattern and consistent diameter, align with previous anatomical studies.[5,6,11,12]

Notably, our study documented slight tortuosity and minor loop formations near the artery's origin variations that have been minimally reported in prior literature.[11] These anomalies could hold clinical significance, particularly in neurovascular compression syndromes and endovascular interventions.

Clinical implications

The anatomical features of the PTA carry several clinical implications. Its proximity to the abducens nerve within the cavernous sinus suggests a risk for neurovascular compression, potentially leading to abducens nerve palsy. This is especially relevant in cases of PTA enlargement or aneurysm development, a concern supported by earlier studies documenting aneurysm and arteriovenous malformation risks associated with the PTA.[2,4,6,15]

Moreover, the PTA's contribution to the posterior circulation highlights its role in cerebrovascular events like ischemic strokes.[16,17] The medial branch, supplying perforating arteries to the pons and medulla, serves critical brainstem structures. Pathological changes in the PTA could significantly impact these regions, corroborated by studies such as those by Aguiar *et al*. (2011)[2] and Takigawa *et al*. (2014),[28] which emphasized its role in cerebrovascular pathology.[18,19]

Surgical and interventional considerations

Detailed anatomical knowledge of the PTA is essential for neurosurgeons and interventional radiologists. Its presence can influence approaches to surgical procedures involving the carotid and BAs. For example, understanding the PTA's location and branching pattern is critical during aneurysm clipping or endovascular coiling to prevent inadvertent damage to vital vascular structures.[20] This perspective aligns with findings from Gaughen *et al*. (2014)[12] and Chen *et al*. (2015),[7] who stressed the importance of precise anatomical understanding in surgical planning.[21,22]

In cases of carotid artery stenosis or occlusion, the PTA's role in altering cerebral hemodynamics and collateral circulation is pivotal for determining therapeutic strategies.[23] Recognizing its contribution can aid in selecting optimal revascularization approaches, potentially improving outcomes in cerebrovascular insufficiency cases. In addition, our cadaveric insights may guide the development of safer surgical techniques.[24] For instance, identifying the PTA's potential to complicate surgical access to the carotid or BAs can help mitigate risks. Preoperative imaging such as DSA, MRA, and CTA should routinely evaluate the PTA's presence for accurate planning.[10,11]

Comparison with imaging studies

Our cadaveric analysis complements imaging-based studies, offering unparalleled insight into spatial relationships and anatomical nuances. While imaging techniques like angiography are noninvasive, cadaveric dissections provide unmatched detail, enabling a three-dimensional understanding of the PTA.[9,12] Integrating high-resolution imaging with cadaveric data enhances diagnostic accuracy and informs tailored treatment strategies.[25]

Comparison with existing literature

Our findings align with previous anatomical descriptions while adding nuanced insights into the PTA's variations. For instance, our measured diameter of 3.5 mm at its origin and its consistent cavernous sinus pathway align with earlier measurements by Suzuki *et al.* (2023) and Battista *et al.* (1997).[4,26,27] However, our observations of detailed bifurcation patterns and branch dimensions provide a deeper understanding of its anatomy, enriching the knowledge base for clinical application.

In addition, this study highlights methodological distinctions across research. While earlier studies heavily relied on imaging techniques like MR and digital subtraction angiography, our use of latex injection allowed a more vivid, three-dimensional anatomical visualization. This approach reveals relationships that may otherwise be overlooked in imaging studies alone [Table 1].

Clinical and educational implications

This cadaveric study offers significant insights into clinical and educational applications.[29-32] For clinicians, particularly neurosurgeons and interventional radiologists, understanding the anatomy and variations of the PTA is vital for managing complex cerebrovascular cases effectively.[28,34] Incorporating this knowledge into practice can refine diagnostic processes and enhance surgical outcomes, especially in cases involving rare vascular anomalies.[35,36]

In medical education, these findings can enrich training programs by emphasizing the importance of anatomical variations. Combining hands-on dissection with advanced imaging techniques equips future healthcare professionals to navigate vascular complexities confidently. Highlighting the clinical relevance of such variations fosters a deeper understanding of anatomy's impact on patient care.[37,38]

Functional assessment

While this study provides detailed anatomical data on the PTA, functional assessments are essential for a more comprehensive understanding. These evaluations can reveal the artery's physiological and hemodynamic behavior under different conditions, clarifying its role in cerebral circulation and potential clinical implications.

Limitations

This study, while valuable, has several limitations:

- Single specimen limitation: Conducted on a single cadaver, the findings lack broader generalizability. A larger sample size is needed to capture the full spectrum of anatomical variability.
- Absence of clinical correlation: Without clinical data, the direct implications of observed variations, such as their connection to neurological symptoms or surgical outcomes, remain speculative.
- Specimen characteristics: The cadaver was a 65-year-old male with no cerebrovascular disease or cranial

Table 1: Comparative table summarizing the findings from our study alongside relevant findings from other key articles

Study	Sample Size	Methodology	Origin of PTA	Course	Branches	Clinical Implications	Unique Findings
Arakawa *et al.*, 2007[3]	2 cadavers	Autopsy	Cavernous segment of ICA	Through cavernous sinus, into posterior cranial fossa	In First case , Medial branch to basilar artery, lateral branch to SCA In the second case PPTA branched from the internal carotid artery, and passed lateral to the abducens nerve, giving off an artery connecting with the AICA	N/A	Detailed bifurcation pattern, quant. measurements
Lam *et al.* (2018)[19]	Case report and literature review	Surgical neuroangiography	Cavernous segment of ICA	Through cavernous sinus	Not specifically detailed	Risk of aneurysm formation, surgical approach considerations	Detailed origin and general course descriptions
Onizuka *et al.* (2006)[21]	Case report	Angiography	Cavernous segment of ICA	Through cavernous sinus	Not specifically detailed	Risk of aneurysms, arteriovenous malformations	Identification of PTA prevalence in imaging studies

(Contd...)

Table 1: *(Continued)*

Study	Sample Size	Methodology	Origin of PTA	Course	Branches	Clinical Implications	Unique Findings
Chen *et al.* (2015)[7]	1 Case serie	MR angiography	Cavernous segment of ICA	Through cavernous sinus	Not specifically detailed	thrombosed Aneurysm association, presenting with trigeminal neuralgia	Confirmation of PTA variants via MR angiography
Salas *et al.* (1998)[25]	Cadaveric study	Anatomical dissection	When the PTA originates from the posterolateral aspect of the posterior bend of the Cavernous segment of ICA	Through cavernous sinus	Not specifically detailed	Neurovascular relationship between the abducens and trigeminal nerves.	Detailed neurovascular relations with nerve Abducens and Trigeminal
Suttner *et al.* (2000)[26]	Cadaveric study	Anatomical dissection and latex injection	Cavernous segment of ICA	Through cavernous sinus	two branches, the inferior hypophyseal artery and the dorsal meningeal artery to the clivus.	Neurovascular relationships and compression syndromes	Detailed neurovascular relations at root entry zone
Diana *et al.* (2019)[9]	Case report and systematic review	Angiography and surgical intervention	Cavernous segment of ICA	Through cavernous sinus	Not specifically detailed	Aneurysm association, surgical challenges	PTA variant associated with aneurysm
Yoshida *et al.* (2011)[33]	Case report and	MR angiography and surgical intervention	Cavernous segment of ICA	Through cavernous sinus	Not specifically detailed	carotid-cavernous fistula (CCF) manifesting as left abducens nerve palsy	PTA identified with MR angiographic findings
Aguiar *et al.* (2011)[2]	Surgical case	Angiography and clinical assessment	Cavernous segment of ICA	Through cavernous sinus	Not specifically detailed	Digital arteriography showed a saccular aneurysm in the middle third of the basilar artery, adjacent to the junction with a persistent trigeminal artery.	Angiographic and clinical features of PTA variants with rupture aneurysm
Gaughen *et al.* (2014)[12]	Surgical case	Microsurgical decompression	Not specified	Not specified	persistent trigeminal artery *in situ* thrombosis and associated perforating vessel infarction	patient with progressive brainstem infarction despite medical therapy	Persistent trigeminal arteries are commonly associated with an atretic basilar artery and interventional treatment can result in significant morbidity and mortality.

N/A: Not available, ICA: Internal carotid artery, PTA: Persistent trigeminal artery

surgeries. This may not reflect PTA anatomy in younger individuals, females, or those with underlying conditions.
- Technical constraints: Latex injection visualizes vessels well but may not replicate natural conditions accurately. Factors such as vessel elasticity and smaller branches may differ from i*n vivo* anatomy.
- Preservation artifacts: Formaldehyde fixation and long-term storage can distort tissue, potentially affecting measurements and structural accuracy.
- Lack of Dynamic Data: Cadaveric studies provide static three-dimensional perspectives but lack the dynamic insights available through imaging techniques like MRA or DSA, which show blood flow and vascular dynamics.
- Limited exploration of adjacent structures: While the study noted relationships between the PTA and nearby cranial nerves, these were not examined in exhaustive detail. Further research could offer deeper insights into these interactions.
- Potential observer bias: The precision required for cadaveric dissection leaves room for technical errors or bias, which could impact the accuracy of anatomical descriptions.

CONCLUSION

This study contributes substantially to the understanding of the PTA, highlighting its clinical importance. The detailed anatomical findings and documented variations serve as a valuable resource for both future research and clinical applications, particularly in neurosurgery and interventional radiology. Expanding this research with larger sample sizes and incorporating advanced imaging techniques will enhance our knowledge of its variations and clinical implications. Such efforts aim to improve patient care and optimize the success of surgical and interventional procedures for this rare vascular anomaly.

Ethical approval: The article has been approved by the University Autonomous of Mexico, February 2, 2024, Mexico City, Approval number: (UNAM- FM/DI/083-2023).

Declaration of patient consent: Patient's consent is not required as there are no patients in this study.

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