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RESEARCH ARTICLE

Surgical Anatomy of the Trigeminal Nerve: From the Cisternal Part to the Trigeminal Ganglion and Surgical Involvement

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ABSTRACT
Introduction: The objective of the study is to briefly present the surgical anatomy of the cisternal segment of the trigeminal nerve and its neurovascular relationships. **Materials and Methods:** Three previously fixed heads of adult male cadavers of different ages underwent a macroscopic and microscopic anatomical examination. During the dissection of the root territory, photos were taken tracing the nerve from its apparent origin to the trigeminal ganglion. **Results and discussion:** The descriptive and functional anatomy of the segment selected for the study were understood and detailed. The photos taken were used as a support to reproduce the nerve pathways, first illustrating the descriptive anatomy of this part of the nerve and the associated neurovascular anatomical structures, then its functional anatomy, highlighting its two sensory and motor contingents. A brief reflection, which focused on the surgical management of trigeminal neuralgia, highlighted the importance of knowledge of anatomical landmarks in mastering microsurgical approaches. **Conclusion:** The use of dissection of the cisternal segment of the trigeminal nerve on cadaveric specimens in order to detail a root part that is difficult to access during surgical interventions, constitutes a practical and useful alternative for better preoperative assessment and mastery of surgical procedures without major complications.

KEYWORDS: anatomy, trigeminal nerve, Gasser's ganglion, trigeminal root, trigeminal neuralgia.

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INTRODUCTION
The trigeminal nerve provides sensory innervation to the face and motor input to the masticatory muscles [1,2]. It emerges from the anterior surface of the pons of the brainstem and features, along its sensory pathway, a prominent ganglionic enlargement known as the trigeminal (Gasserian) ganglion [3,4]. Examination of the intracranial root segment reveals that anatomical exploration of the cisternal portion—particularly from its apparent origin to the trigeminal ganglion—is complex and carries postoperative risks. To overcome this challenge, cadaveric dissection serves as an appropriate alternative. The present work therefore adopts this technique to review and illustrate the descriptive anatomy of the nerve's course in this region, as well as the associated neurovascular structures. It also aims to address the functional anatomy of the nerve, emphasizing its sensory and motor components. A focused reflection on the surgical management of classical trigeminal neuralgia highlights the importance of mastering microsurgical approaches.

MATERIALS AND METHODS
For the purposes of this study, three adult cadaveric heads of varying ages, previously fixed in formalin, were examined both macroscopically and under an operating microscope in the anatomy laboratory of the Faculty of Medicine in Fez (Morocco). The surgical procedure began with the dissection of the nuchal muscles. A wide retrosigmoid and subtemporal craniectomy was then performed to allow proper access to the cerebellopontine angle and the middle cranial fossa. Finally, the trigeminal nerve was dissected with particular attention to its neurovascular relationships. During the dissection of the cisternal segment of the trigeminal nerve, photographs were taken to document the nerve from its apparent origin to the trigeminal ganglion.

RESULTS AND DISCUSSION
Descriptive Anatomical Observations
The trigeminal nerve is a encephalic nerve composed of five segments: the brainstem, the cisternal segment, Meckel's cave, the cavernous segment, and the peripheral branches [3,5]. Precise knowledge of the surgical

landmarks of the nerve and its relationships with associated anatomical structures is essential. Anatomical dissection of the root portion of the nerve, from its apparent origin to the trigeminal ganglion, was carried out. The results obtained, which corroborate data reported in numerous studies, were documented through photographs and supplemented by illustrations depicting the key descriptive anatomical features of the nerve's trajectory in the examined segment, as well as its associated neurovascular structures.

Trigeminal Root

Dissection of the root portion (Figure 1) confirmed that the apparent origin of the trigeminal root is located at the junction of the lower two-thirds and the upper third of the anterolateral surface of the pons. The nerve emerges from the neuraxis via the trigeminal root, which consists of two components: a sensory root and a motor root. The larger sensory root, measuring approximately 5 mm in diameter, lies inferior and lateral to the slender motor root, which measures around 2 mm [6,7].

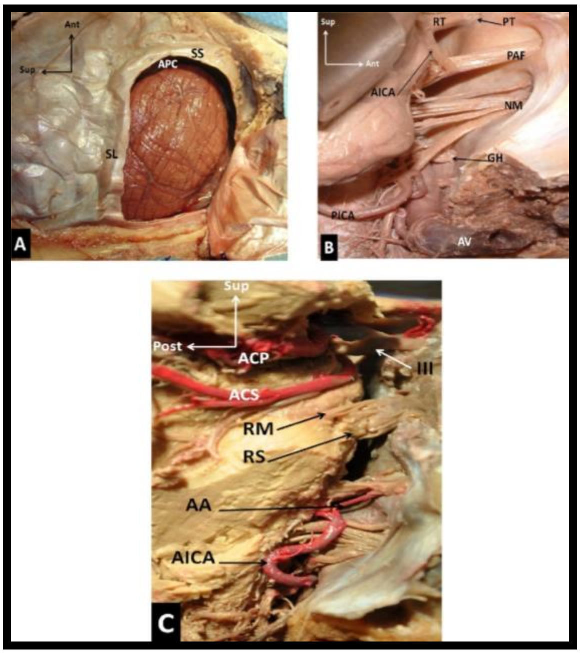

Figure 1 : Dissection images, from the opening of the dura mater to the exposure of the apparent origin of the trigeminal nerve. **A.** Opening of the dura mater along the posterior margin of the sigmoid sinus and the inferior margin of the transverse sinus, revealing the entry into the cerebellopontine angle (APC). **B.** Posterior retraction of the cerebellum exposes, in addition to the posterior cerebral artery (ACP) and the oculomotor nerve (III), the neurovascular structures traversing the APC: trigeminal nerve root (RT), acoustic-facial bundle (PAF), anterior inferior cerebellar artery (AICA), mixed nerves (NM: IX, X, and XI), hypoglossal nerve (GH), posterior inferior cerebellar artery (PICA), vertebral artery (AV), and the trigeminal porus (PT). **C.** Sectioning of the cerebellar peduncles reveals the two roots of the trigeminal nerve: the sensory root (RS) and the motor root (RM).

The trigeminal root is located in the upper portion of the cerebellopontine angle. It extends over a length ranging from 8 to 15 mm, with an average of 12.3 mm (13.10 ± 1.12 mm according to Sindou and Brinzeu [8]), and courses upward, forward, and laterally to reach the superior border of the petrous part of the temporal bone. It is cylindrical near the pons and becomes increasingly flattened in its anterior segment [6].

The distance between the right and left trigeminal nerves is approximately 4 cm. The trigeminal root is related to the neurovascular structures of the cerebellopontine angle cistern: superiorly and medially to the superior cerebellar artery; inferiorly and laterally to the acousticofacial bundle, the anterior inferior cerebellar artery (AICA), and the internal auditory artery (labyrinthine artery). The posterior surface of the root is in contact with the superior petrosal vein [7].

Trigeminal (Gasserian) Ganglion

Figure 2 shows that the trigeminal root, becoming flattened in a horizontal plane, crosses the superior border of the petrous bone within a bony depression known as the trigeminal notch. This notch is located at the medial third of the petrous ridge.

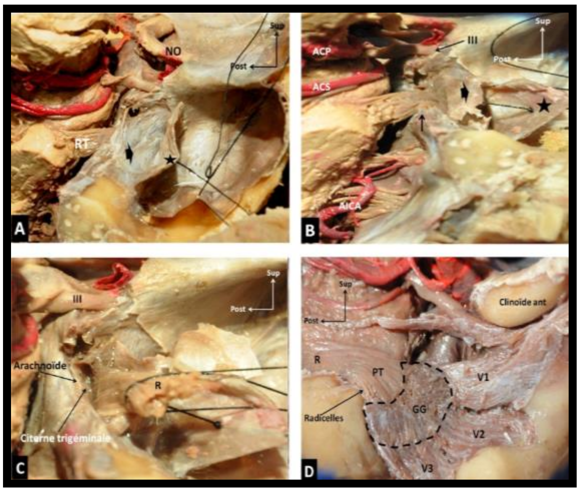

Figure 2: Illustration of the dissection of the fibrous compartment of the Gasserian (trigeminal) ganglion. **A.** Separation of the dura mater of the middle cranial fossa (asterisk) from the dural roof of Meckel's cave (arrowhead). **B.** Grüber's notch (arrow). **C.** Anterior reflection of the sectioned trigeminal root reveals the trigeminal cistern and the arachnoid extension from the posterior cranial fossa (FCP) into the middle cranial fossa. D. Removal of the dural roof of Meckel's cave exposes the triangular plexus (PT) formed by rootlets, the Gasserian ganglion (GG), and its three divisions: ophthalmic (V1), maxillary (V2), and mandibular (V3).

The trigeminal notch is lined by the dura mater of the posterior cranial fossa, and the passage of the tentorial attachment (the free edge of the tentorium cerebelli) over this bony depression forms a canal that extends into the middle cranial fossa. Indeed, the dura mater of the posterior cranial fossa, drawn by the embryonic formation of the trigeminal ganglion, invaginates into the middle cranial fossa, forming a glove-finger-like diverticulum called the trigeminal cave (Meckel's cave). This cavity is itself lined superiorly by the dura mater of the middle cranial fossa and rests on a bony depression on the anterosuperior surface of the petrous part of the temporal bone: the trigeminal fossa.

The already flattened root enters the posterior part of the cave (the trigeminal porus) and takes on the shape of a triangular plate known as the triangular plexus, a cluster of rootlets originating from the posterior border of the trigeminal ganglion.

Inside the fibrous compartment, a swelling called the trigeminal ganglion, which is closely adherent to the dural roof of the trigeminal cave, appears semi-lunar in shape, crescent-like, with a transverse major axis, convex anteriorly and concave posteriorly. It measures 15 mm in width, 5 mm in length, and 3 mm in thickness. The ganglion gives rise anteriorly to three branches: the ophthalmic nerve (V1), the maxillary nerve (V2), and the mandibular nerve (V3).

The motor root, initially relatively conjoined with the sensory root in its cisternal portion, separates at this point and crosses anteriorly and laterally beneath the body of the ganglion. Becoming lateral and accompanying V3, it exits the cranial cavity through the foramen ovale, where it merges with the mandibular branch, making V3 a mixed nerve.

The descriptive anatomical exploration of the various structures highlighted in Figure 3, along with the analysis of data provided in specialized studies [7,10-13], confirms that the trigeminal ganglion has highly diverse anatomical relationships, particularly with:

the cavernous sinus, the internal carotid artery in its intracavernous portion, the trochlear nerve, the oculomotor nerve, and the trochlear nerve on the medial side;

the middle meningeal artery, which supplies vascularization to the ganglion on the lateral side;

the superficial and deep petrosal nerves, as well as the internal carotid artery in its intrapetrous portion, from which it is separated by a thin bony lamina on the inferior side;

the inferomedial border of the temporal lobe on the superior side.

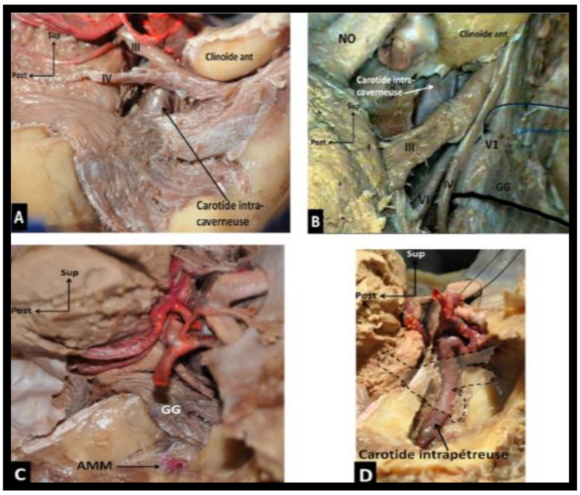

Figure 3: Anatomical relationships of the Gasserian (trigeminal) ganglion. **A** and **B**: Medial relationships. **C:** Lateral relationships. D: Inferior relationships (the GG is represented by a transparent illustration). (AMM: Middle meningeal artery; ON: Optic nerve).

Functional Anatomical Observations (Systematization)

The trigeminal nerve is a mixed nerve. It has a significant sensorimotor component. The arrangement of the various anatomical structures allows for the simulation of different sensory and motor relationships (Figure 4), reflecting its functional anatomy.

The sensory component of the trigeminal nerve includes [14]:

Cutaneous sensation of the face, except for the angle of the mandible.

Sensation from mucous membranes (conjunctiva, oral cavity, nasal cavity and facial sinuses, cornea, and part of the meninges).

Osteoarticular and proprioceptive sensation from the temporomandibular joint and the masticatory muscles.

Apart from the fibers that carry proprioceptive sensation—which travel via the motor root and whose first-order cell body is located in the mesencephalic nucleus— it is within the Gasserian ganglion that the first-order cell body of the fibers responsible for exteroceptive (pain and temperature) and epicritic (fine touch and vibration) sensation is located.

The dendrites of these first-order neurons reach the ganglion through the three branches. Their axonal processes travel toward the brainstem nuclei via the triangular plexus and the sensory root, where they synapse with second-order neurons in the respective nuclei.

There is a somatotopy of sensory fibers at various segments:

Within the Gasserian ganglion, there is a retrogasserian somatotopic organization: mandibular efferents are located inferolaterally, ophthalmic afferents are positioned superomedially, and maxillary afferents occupy an intermediate position. This somatotopy then gives way to a functional organization [1,2].

In the juxtapontine segment of the trigeminal root: thermonociceptive fibers, grouped according to their functional modality, are situated inferolaterally in the pars major and project to the spinal nucleus. Epicritic fibers are located superomedially in the pars intermediaris, between the pars major and the motor root, and project to the main pontine nucleus [4].

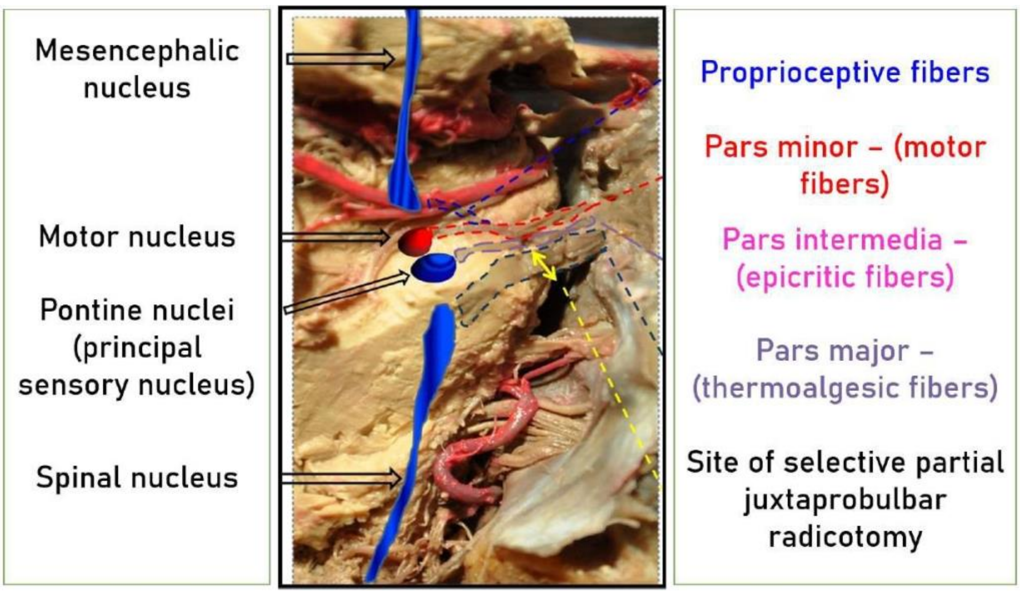

Figure 4: Simulation of the localization of sensory and motor nuclei within the neuraxis, the juxtaprotuberant somatotopy, and their connections.

The central portion of the root, which measures approximately 4.2 mm ± 0.8 mm in length, is considered relatively more "excitable" than the peripheral portion [8]. The motor component of the nerve arises from the pontine motor nucleus [5]. The proprioceptive and myotatic fibers of the nerve, mainly originating from the masticatory muscles, travel retrogradely through the pars minor (motor root) and form the mesencephalic tract, terminating in the mesencephalic nucleus.

Cells of this nucleus send fibers to the motor nucleus (in the pons), playing an informational role in regulating motor neurons [15], whose axons gather to form the motor root [8].

The motor branch of the trigeminal nerve mainly innervates the masticatory muscles: masseter, temporalis, and the internal and external pterygoid muscles [5].

Practical Aspects of the Surgical Management of Trigeminal Neuralgia

The trigeminal root maintains anatomical relationships with vital neurovascular structures [1]. Its complex intracranial course, particularly in terms of surgical landmarks, makes it vulnerable to injury during surgical procedures. There are numerous surgical approaches to access the nerve, but the choice among currently used treatment techniques for neuralgia is largely limited to three main types: microsurgical vascular decompression, considered the reference conservative and curative technique; percutaneous lesioning techniques; and radiosurgical techniques [3,16,17].

Neurovascular decompression: Microsurgical vascular decompression is proposed when a neurovascular conflict is present. This method requires direct access under general anesthesia. The patient is positioned in a contralateral decubitus position with the head slightly elevated and the neck moderately flexed toward the opposite side and rotated 15° toward the contralateral side. This position better exposes the superolateral region of the nape, allowing, after skin and aponeurotic incision and exposure of the mastoid and occipital crest [8], a retromastoid cranial approach approximately 2 cm in diameter. This provides access to the entire trigeminal nerve, from the anterior Meckel's cave to the posterior entry point of the nerve into the brainstem, enabling placement of a prosthetic cushion to keep the nerve away from the offending vessel [16]. According to Sindou [18], the conflict is most often due to a megadolicho-artery of the cerebellum, and rarely to a venous impression (Dandy).

Trans-oval percutaneous techniques: These percutaneous techniques aim to interrupt the transmission of nociceptive signals. Anatomical dangers associated with these procedures include the Stensen's canal, internal maxillary artery and its branches, the Eustachian tube, and most critically, the internal carotid artery at the base of the skull.

 Thermocoagulation by radiofrequency or retrogasserian thermorhizotomy consists of placing a transjugular electrode through the foramen ovale, with its tip positioned behind the trigeminal (Gasserian) ganglion, in the triangular plexus located in Meckel's cave. The procedure is performed under local anesthesia and radiographic guidance to accurately position the electrode tip at the neuralgia site (trigger zone) [16]. The procedure enables selective and long-lasting analgesia in the painful area by applying heat to the sensory axons of the trigeminal nerve, where a good somatotopic arrangement exists according to the origin of fibers: V3, V2, V1 [8,11].

 Percutaneous balloon compression of the Gasserian ganglion is performed via the foramen ovale, using a technique similar to that of thermocoagulation. Under general anesthesia, a trocar with a balloon (typically a "Fogarty catheter") is introduced through the foramen ovale into Meckel's cave. The balloon is gradually inflated with contrast agent under fluoroscopic guidance for approximately one minute to compress the Gasserian ganglion. The shape of the balloon confirms whether the compression was successful [6,16].

 Neurolysis by glycerol injection into the trigeminal cistern involves, with the patient seated and head flexed, and under radiographic control, puncturing Meckel's cave via the transjugular approach as previously described. Under local anesthesia, cerebrospinal fluid is withdrawn, iodinated contrast agent is injected and removed, and finally small doses (<0.5 mL) of glycerol are injected directly into the trigeminal cistern until hypoesthesia of the painful area is achieved [8,16]. This technique relies on the neurotoxic effect of glycerol on the post-gasserian fibers of the trigeminal nerve.

Stereotactic radiosurgery is a minimally invasive and low-morbidity technique [17] that requires placing a stereotactic localization frame but is performed under simple local anesthesia. The target is retrogasserian, at a single isocenter of 4 mm on the cisternal segment of the nerve, where a single-session radiation dose of 80 to 90 Grays is delivered. Doses exceeding 15 Grays at the nerve root entry zone into the brainstem are discouraged [8,16].

CONCLUSION

Precise knowledge of the surgical landmarks of the trigeminal nerve and their relationships with associated neurovascular anatomical structures is essential. The use of cadaveric dissection of the cisternal segment of the trigeminal nerve, aimed at detailing a root portion that is difficult to access in living patients during surgical procedures, represents a valuable alternative practice.

ETHICS STATEMENT

The cadaveric heads studied in this document were obtained from the anatomical collection of the Anatomy Laboratory of the Faculty of Medicine and Pharmacy of Fez, Morocco.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

AUTHOR CONTRIBUTIONS

Oualid Romli collected the data and wrote the manuscript; Meryem Himmiche provided a critical revision of the manuscript; Mohamed El Faiz Chaoui and Mohamed Aggouri coordinated the surgical team responsible for the dissection; and Mohamed Aggouri and Khalid Chakour reviewed and approved the final version for publication. All authors read and approved the final manuscript.

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