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The Oculomotor Nerve: Microanatomical and Endoscopic Study

OBJECTIVE: This study was performed to assess the anatomy of the oculomotor nerve and to describe its course from the brainstem to the orbit. A new anatomically and surgically oriented classification of the nerve has been provided to illustrate its topographic and neurovascular relationships.

METHODS: Fifty-nine human cadaveric heads (118 specimens) were used for the anatomical dissection. Forty-four of these were embalmed in a 10% formalin solution for 3 weeks, and 15 were fresh frozen injected with colored latex. The nerve was exposed along its pathway via frontotemporal, frontotemporo-orbitozygomatic, and subtemporal transtentorial approaches. These approaches were performed to expose each segment of the nerve. An endoscopic endonasal transsphenoidal approach was performed on 9 heads to visualize and compare the neurovascular relationships of the same areas from an inferomedial perspective. Measurements of each segment of the nerve were taken in all specimens during the dissecting process.

RESULTS: The nerve was divided into 5 segments: cisternal, petroclinoid, cavernous, fissural, and orbital. The simultaneous use of a microscopic transcranial and an endoscopic endonasal route allows a better understanding of the spatial relationship of the nerve.

CONCLUSION: The knowledge of the dural, bony, and neurovascular relationships of the oculomotor nerve may help to prevent common complications during both microsurgical and endoscopic approaches to the cavernous sinus, interpeduncular, middle cranial fossa, and orbital regions. We discuss the possible significance of the observed anatomical data and propose classification of the different segments of the nerve.

KEY WORDS: Cavernous sinus, Cranial nerves, Endoscopic endonasal transsphenoidal approach, Oculomotor nerve, Orbit

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During the past few years, advances in the field of surgical anatomy have allowed considerable progress in surgical techniques and have improved the excision of deep skull base lesions. Knowledge of the detailed anatomy and pathway of the oculomotor nerve is critical for the management of lesions located at the level of the middle cranial fossa, clival, cavernous, and orbital regions. Several authors have previously illustrated the relationship of the oculomotor nerve within the cavernous sinus.[1-15] Other anatomical studies have described the pathway of the nerve and its neurovascular relationships within the interpeduncular cistern[16-20] and the superior orbital fissure and orbit.[21-24] However, to our knowledge, there has been no exhaustive and detailed study of the entire course of the oculomotor nerve in the existing literature. In the present study, we have performed a microsurgical and endoscopic dissection of the oculomotor nerve following its entire course from the midbrain to the orbit. An endoscopic endonasal transsphenoidal approach to the interpeduncular cistern and the cavernous sinus has been combined with a microsurgical dissection to better delineate, from anterior and inferior perspectives, the neurovascular relationships of the nerve through its extradural course. The endoscopic point of view might be useful to improve the depiction and understanding of the spatial relationships of the nerve.

ABBREVIATIONS: ICA, internal carotid artery; **LPSM**, levator palpebrae superioris muscle; **PCA**, posterior cerebral artery; **SCA**, superior cerebellar artery; **SRM**, superior rectus muscle

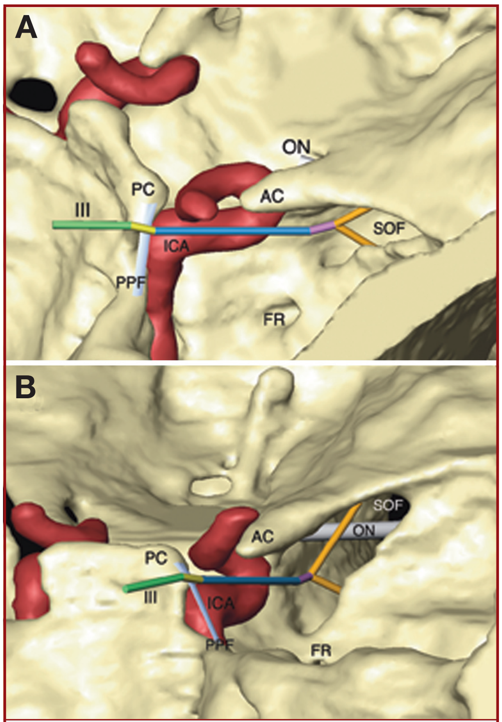

FIGURE 1. *Angio-computed tomography–based 3-dimensional reconstruction of the entire pathway of the oculomotor nerve as seen from a posterolateral (***A***) and posterior (***B***) perspective. The 3-dimensional models of the different segments and related structures have been reconstructed according to the specific radiologic landmarks. AC indicates anterior clinoid; FR, foramen rotundum; ICA, internal carotid artery; III, oculomotor nerve; ON, optic nerve; PC, posterior clinoid; PPF, posterior petroclinoid fold; SOF, superior orbital fissure.*

This study is the last of a series of recently published anatomical studies written by our group that concern other regions of the skull base[1,25-27] In these studies, we have observed the neurovasculature over the skull base as it appears when explored through the endonasal route, compared with a more familiar view of the transcranial approaches. The purpose of this work is to compare the transcranial microsurgical view of the nerve with the endoscopic one to investigate neurovascular relationships and to separately measure each segment through both routes. Surgical approaches to the clivus, the petroclival region, the cavernous sinus, and the orbit through either a transcranial or an endonasal route demand special and detailed anatomical knowledge to avoid injuries to the nerves and surrounding vascular structures. Furthermore, a new surgically and clinically related classification of both intradural and extradural compartments through which the nerve courses is proposed.

MATERIALS AND METHODS

Fifty-nine human cadaveric heads provided 118 specimens that were dissected under operative microscopy at the School of Medicine of Hannover's Laboratory of Neurosurgical Research (Germany) from 1997 to 2001, and at the Laboratory of Surgical Neuroanatomy of the University of Barcelona (Spain) in 2008. Frontotemporal, frontotemporo-orbitozygomatic, and subtemporal transtentorial approaches followed by extradural drilling of the lesser wing of the sphenoid, total unroofing of the optic canal, and anterior clinoidectomy were performed to expose the entire nerve from its origin to the extrinsic ocular muscles. Thereafter, the brain was totally removed to clearly expose the entire skull base and to complete the dissection of the sphenopetroclival area and the walls of the cavernous sinus. After the opening of the superior orbital fissure and common tendon of Zinn, the nerve was entirely exposed and measured. Operating microscopes (Zeiss OPMI 16 and Contraves; Carl Zeiss, Oberkochen, Germany) were used for all dissections and measurements.

An endoscopic endonasal transsphenoidal approach to the interpeduncular cistern and the cavernous sinus was performed to endoscopically explore both the intradural and the extradural course of the nerve. The endoscopic dissection was performed at the Laboratory of Surgical Neuroanatomy of the University of Barcelona (Spain). Endoscopic dissections were performed using rigid endoscopes (Karl Storz GmbH and Co, Tuttlingen, Germany) that were 4 mm in diameter and 18 cm in length, with 0-, 30-, and 45-degree lenses, according to the different steps of the anatomical dissection. A 3-dimensional model of the skull and the most important structures related with the oculomotor nerve pathway was reconstructed from a computed tomographic angiography scan of a healthy volunteer using dedicated software (Amira; Visage Imaging, Inc., Richmond, Australia). The 3-dimensional model of the different segments and related structures was reconstructed according to the specific radiologic landmarks.

TABLE 1. Oculomotor Nerve Segments and Measurements[a]

Segment	Right	Left	Diameter
Cisternal	15.8 (2.2)	14.6 (2.9)	2.5 (0.5)
Petroclinoid	5.2 (0.4)	4.9 (1.3)	2.3 (0.6)
Cavernous	15.4 (0.7)	14.9 (1.5)	2.4 (0.3)
Fissural	6.9 (0.6)	5.9 (1.2)	2.5 (0.4)
Orbital (single trunk)	1.5 (0.1)	2.2 (0.1)	2.4 (0.4)
Root exit zone			3.26 (0.7)
Dural entry foramen			2.8 (0.4)
Endoscopic measurement of the cavernous segment			
With ICA dislocation	8.5 (1.7)	10.9 (1.2)	2.4 (0.6)
Without ICA dislocation	3.12 (0.4)	4.37 (0.6)	2.4 (0.6)

[a] ICA, internal carotid artery. Data are presented in millimeters.

RESULTS

The oculomotor nerve was divided into 5 segments. Two segments were intradural (cisternal and petroclinoid), and 3 were extradural (cavernous, fissural, and orbital) (Figure 1 and Table 1).

The transcranial approaches allowed us to explore either the intradural or the extradural course of the nerve (Figure 2), whereas the endonasal route was found to be particularly effective in exposing the cisternal (Figure 3) and cavernous segments (Figure 4). The endoscopic approach provided an overview of the course of

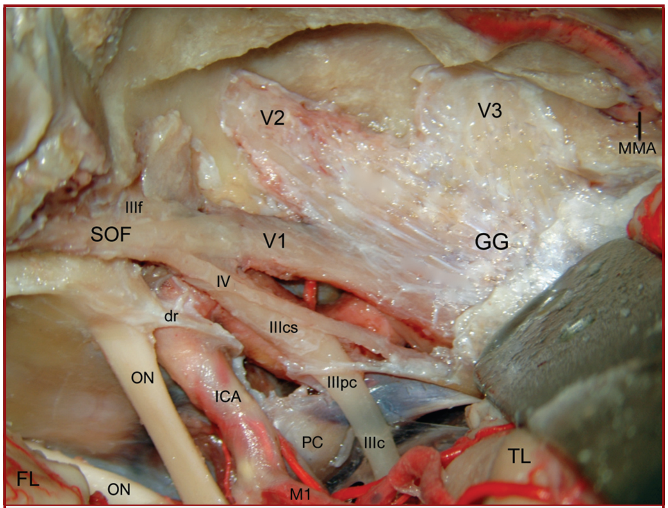

FIGURE 2. *Microsurgical microscopic view of the entire intracranial pathway of the oculomotor nerve. The right cavernous sinus has been dissected, the anterior clinoid process has been drilled out, and the temporal lobe has been retracted to expose the oculomotor nerve segments and its neurovascular relationships. dr indicates distal ring; FL, frontal lobe; GG, gasserian ganglion; ICA, internal carotid artery; IIIc, cisternal segment of the oculomotor nerve; IIIcs, cavernous sinus segment of the oculomotor nerve; IIIf, fissural segment of the oculomotor nerve; IIIpc, petroclinoid segment of the oculomotor nerve; IV, trochlear nerve; M1, first tract of the middle cerebral artery; MMA, middle meningeal artery; PC, posterior clinoid; SOF, superior orbital fissure; TL, temporal lobe; V1, ophthalmic nerve; V2, maxillary nerve; V3, mandibular nerve.*

the oculomotor nerve in its proximal part, from the inferior and medial point of view, which is complementary to the posterior, superior, and lateral views provided by the transcranial approaches to expose its distal part. Endoscopically, the intracavernous segment of the nerve was smaller than the transcranial view (Figure 4). Through the endonasal route, the optic nerve was visible in its course above the optic strut of the anterior clinoid process and through the optic foramen, and the oculomotor nerve below the optic strut to reach the annulus of Zinn. To expose the cavernous part of the third cranial nerve, it was required to medially shift the internal carotid artery (ICA) (Figure 4C). It was possible to visualize the oculomotor and trochlear nerves up to the superior orbital fissure. Then, the trochlear nerve crosses the superolateral aspect of the oculomotor nerve, which is located inferiorly and converges toward the superior orbital fissure. Both endoscopic and microsurgical points of view have allowed us to create a 3-dimensional perspective of the course of the nerve as well as its neurovascular relationships in each segment.

Cisternal Segment

After a frontotemporo-orbitozygomatic approach was completed, the cisternal segment was completely exposed. We found that the oculomotor nerve leaves the midbrain medially to the cerebral peduncles in the lateral part of the interpeduncular fossa, and continues its course anterolaterally and superiorly to run above the posterior petroclinoid fold, which represents the anterior limit of this segment (Figure 3, A and C).

Endoscopically, it was possible to enter the interpeduncular cistern and to highlight its vascular relationships. This part of the nerve was in close relationship, even in contact, with the ventral surface of the posterior cerebral artery (PCA) superiorly and with the superior cerebellar artery (SCA) and its perforating branches inferiorly (Figure 3, B and D). This segment of the nerve is surrounded by many branches arising from the posterior cerebral and the superior cerebellar arteries. The basilar artery was found to be located caudally and medially to the initial part of the nerve. The diameter of the root exit zone of the nerve was 3.26 (0.7) mm in our series (Table 1). The roots combine together to form a unique trunk that enters into the interpeduncular cistern and reaches out toward the posterior petroclinoid fold. This cistern continues anteriorly with a small subarachnoid space which is called the *oculomotor cistern*. The length of this segment from the root exit zone to the posterior petroclinoid fold was 15.8 (2.23) mm on the right side and 14.68 (2.9) mm on the left side, and the main diameter was 2.5 (0.5) mm (Table 1).

Petroclinoid Segment

The petroclinoid segment was found to be located in between the cisternal segment and the cavernous segment. Therefore, it is proximal to the oculomotor cistern, which is a small cerebrospinal fluid–filled dural and arachnoidal cuff that invaginates into the lateral wall of the cavernous sinus surrounding the third nerve itself. This segment of the oculomotor nerve is limited posteriorly by the posterior petroclinoid fold and anteriorly by the dural porus of the lateral wall of the cavernous sinus (Figure 5). The oculomotor triangle represents the floor of the petroclinoid segment. This triangle is delimited medially by the interclinoid ligament, laterally by the anterior petroclinoid fold, and posteriorly by the posterior petroclinoid fold (Figure 5B). Endoscopically, this segment is scarcely recognizable even if the parasellar portion of the ICA is displaced medially. Indeed, the posterior petroclinoid fold completely obstructs the inferomedial angle of view. Furthermore, this segment of the nerve is exposed to damage during the posterior clinoid drilling procedure to have more room for entering the posterior fossa and clival areas. In some selected cases, this segment can be effectively accessed through endonasal routes. This requires a posterior clinoidectomy after a pituitary transposition.[20] This would be of value for certain situations in which tumors grow medial to this segment along the edge of the posterior clinoid, most notably during chordoma surgery, specific types of petroclival meningiomas, and some retroinfundibular craniopharyngiomas.[28] In these cases, an endonasal route with a pituitary transposition followed by a posterior clinoidectomy and release of the petroclinoid fold provides exceptional access that is unparalleled for this otherwise hidden segment. The length of this segment from the posterior petroclinoid fold until its dural porus was found to be 5.2 (0.4) mm on the right side and 4.9 (1.3) mm on the left side, and the main diameter was 2.3 (0.6) mm (Table 1).

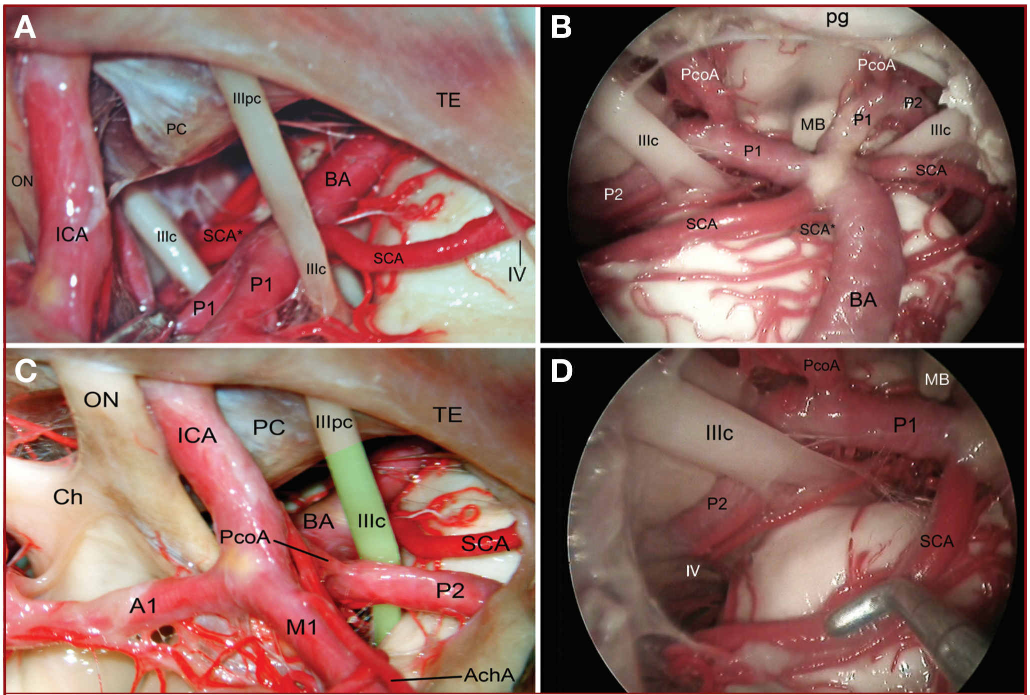

FIGURE 3. *Photographs showing comparison of the cisternal segment of the oculomotor nerve between the microsurgical transcranial view (***A*** and ***C****) and the endonasal endoscopic view (***B*** and ***D****).* **A***, the limits of this segment are represented by the root exit zone posteriorly and the posterior petroclinoid fold anteriorly.* **C***, the main structures related to this segment are the superior cerebellar artery and the posterior cerebral artery. The green part of the nerve shows the entire length of the segment and its limits.* **B***, endoscopic view of the medial and inferior aspect of the cisternal segment and its neurovascular relationship.* **D***, the endoscope has been moved inferiorly and posteriorly to expose the exit of the nerve within the interpeduncular cistern. A1 indicates precommunicating tract of the anterior cerebral artery; AchA, anterior choroidal artery; BA, basilar artery; ICA, internal carotid artery; IIIc, cisternal segment of the oculomotor nerve; IIIpc, petroclinoid segment of the oculomotor nerve; IV, trochlear nerve; M1, first tract of the middle cerebral artery; MB, mammillary body; ON, optic nerve; P1, precommunicating tract of the posterior cerebral artery; P2, postcommunicating tract of the posterior cerebellar artery; PC, posterior clinoid; PcoA, posterior communicating artery; SCA, superior cerebellar artery; SCA*, duplication of the superior cerebellar artery; TE, tentorium edge.*

Inside the oculomotor triangle, the meningeal (superficial) and periosteal (deep) layer of the cavernous sinus could be easily divided and dissected. At the level of the oculomotor foramen, the periosteal layer contributed to the dural sheaths surrounding the nerves through their course on the lateral wall of the cavernous sinus. These 2 layers of dura, easily dissectible, cover the roof. The deeper layer was thinner and contributed to creating the proximal ring around the ICA, whereas the superficial layer contributed to form the distal ring. Removing both dural layers allowed us to visualize the horizontal portion of the intracavernous ICA, the medial wall of the cavernous sinus, and the medial venous space of the cavernous sinus (Figures 2 and 4A).

After piercing the cavernous sinus, the nerve reached out of the lateral wall below the anterior clinoid process. The cranial nerves that course within the 2 dural layers of the lateral wall of the cavernous sinus are the oculomotor, the trochlear, and the ophthalmic branch of the trigeminal nerve (Figure 2). The oculomotor nerve passes laterally to the anterior clinoid process, and medially it is adjacent to the trochlear nerve, running in the upper part of the lateral wall. The oculomotor and the trochlear nerves are surrounded, at this level, by a meningeal sheath. The trochlear nerve enters the lateral wall of the cavernous sinus posterolaterally to the oculomotor nerve and below and medial to the free edge of the tentorium.

In the lateral wall of the cavernous sinus, the oculomotor nerve courses laterally and anteriorly to the dorsum sellae and above the meningohypophyseal trunk of the intracavernous segment of the ICA. In this region, the ICA depicts its anterior loop and is directed medial and superior to the roof of the cavernous sinus.

Endoscopically, the cavernous sinus has been well described by several authors.[1,29-33] The endonasal approach provided adequate exposure of the cavernous segment of the oculomotor nerve. The wider route to reach this segment is represented by the area confined laterally to the parasellar portion of the ICA. Once this artery has been gently medialized with the aid of a microdissector, the oculomotor nerve is exposed below the optic strut and

Cavernous Segment

The superior wall of the cavernous sinus is a trapezoidal area limited laterally by the anterior petroclinoid fold, medially by the diaphragma sellae, anteriorly by the carotid canal, and posteriorly by the posterior petroclinoid fold. A line parallel to the interclinoid ligament divides this area into 2 triangles: the carotid triangle anteromedially and the previously described oculomotor triangle posterolaterally (Figures 4A and 5B). The oculomotor nerve was found to enter the cavernous sinus within the oculomotor triangle, piercing the roof of the cavernous sinus near the center of the oculomotor triangle between 3 and 5 mm posterior to the initial supraclinoid segment of the ICA. The dural entry foramen was larger than the nerve (2.8 [0.4] mm; Table 1). The oculomotor cistern accompanied the oculomotor nerve into the wall of the cavernous sinus to the area just below or anterior to the lower edge of the tip of the anterior clinoid process. The cistern must be opened to mobilize the nerve for dealing with pathology in this area and for posterior clinoidectomy.

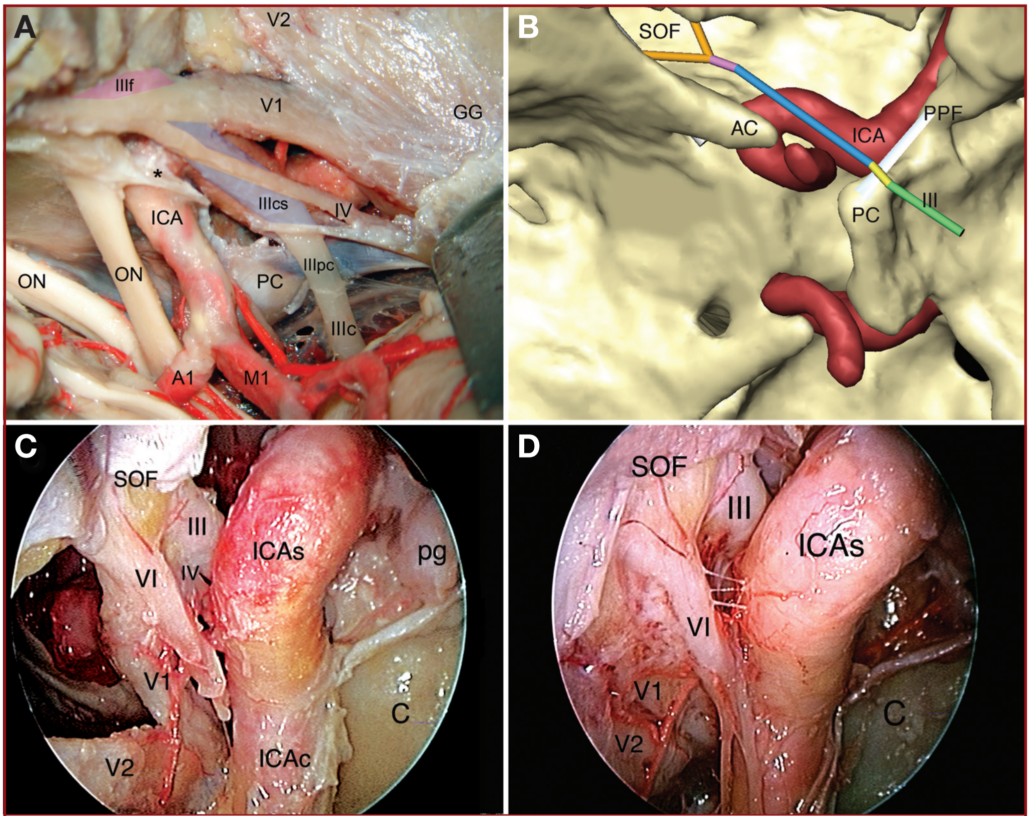

FIGURE 4. *Comparison between the cavernous sinus and fissural segments according to the microsurgical transcranial view (**A**), an angio-computed tomography–based 3-dimensional reconstruction (**B**), and the endonasal endoscopic view (**C** and **D**). **A** and **B**, the right cavernous sinus has been dissected, and the anterior clinoid process has been drilled out to expose the neurovascular structures related to this segment. The dural entry point of the oculomotor nerve and the posterior aspect of the superior orbital fissure represent, respectively, the posterior and anterior limits of the cavernous sinus segment (blue area), and the tract between the posterior aspect of the superior orbital fissure and the orbital cavity correspond to the fissural segment (purple area). **C** and **D**, the endoscopic view enables the exposure of the inferomedial aspect of the cavernous segment after a gentle medialization of the internal carotid artery. In this exposure, the oculomotor nerve can be seen as the superior limit of the superior triangular area. A1 indicates precommunicating tract of the anterior cerebral artery; AC, anterior clinoid; Ch, optic chiasm; ICA, internal carotid artery; ICAc, paraclival segment of the internal carotid artery; ICAs, parasellar segment of the internal carotid artery; IIIc, cisternal segment of the oculomotor nerve; IIIcs, cavernous sinus segment of the oculomotor nerve; IIIf, fissural segment of the oculomotor nerve; IIIpc, petroclinoid segment of the oculomotor nerve; IV, trochlear nerve; GG, gasserian ganglion; M1, first tract of the middle cerebral artery; ON, optic nerve; PC, posterior clinoid; pg, pituitary gland; PPF, posterior petroclinoid fold; SOF, superior orbital fissure; V1, ophthalmic nerve; V2, maxillary nerve; VI, abducens nerve. * Distal ring.*

through the superior orbital fissure. It should be noted that this segment can also be effectively accessed through an extension of the endoscopic anterolateral approach to the Meckel cave as recently described by the Pittsburgh group.[34] The length of this segment inside the lateral wall of the cavernous sinus was found to be 8.5 (1.75) mm on the right side and 10.9 (1.2) mm on the left side with ICA dislocation, and 3.12 (0.4) mm on the right side and 4.37 (0.6) mm on the left side without ICA dislocation (Figure 4, C and D; Table 1). The trochlear nerve is the thinnest nerve within the lateral wall of the cavernous sinus. This nerve and the ophthalmic branch of the trigeminal nerve converge toward the superior orbital fissure laterally to the abducent nerve (Figure 6A).

The length of this segment was found to be 15.4 (0.7) mm on the right side and 14.9 (1.5) mm on the left side, and its main diameter was 2.4 (0.3) mm (Table 1).

Fissural Segment

We found that the superior orbital fissure was limited superiorly by the inferior rim of the lesser wing of the sphenoid bone and inferiorly by the lateral apical border of the orbital surface of the greater wing of the sphenoid (Figure 6D). Usually the oculomotor nerve splits into its superior and inferior divisions before accessing the orbit.

At the level of the fissure, the dura covering the middle cranial fossa and the cavernous sinus blended into the periorbita, the orbital apex, and the common tendinous ring, which surrounded the optic foramen and the adjacent part of the fissure (Figure 6, A and B). The 2 tendons of the lateral rectus muscle divided the superior orbital fissure into 2 parts. The superior part contains the trochlear, the lacrimal, and the frontal nerves and the superior orbital veins, whereas the superior and the inferior branches of the oculomotor nerve together with the nasociliary and abducent nerves were found in its inferior part.

From the endoscopic view, this segment was completely hidden by the lateral aspect of the optocarotid recess, which covers the nerve entering the superior orbital fissure (Figure 4, C and D).

The length of this segment was found to be 6.9 (0.6) mm on the right side and 5.9 (1.2) mm on the left side, and its main diameter was 2.5 (0.4) mm (Table 1).

Orbital Segment

In 22 cases (18.6%), we found a single trunk of the nerve before it split into superior and inferior divisions (Figure 6C). The length of this segment was found to be 1.5 (1) mm on the right side and

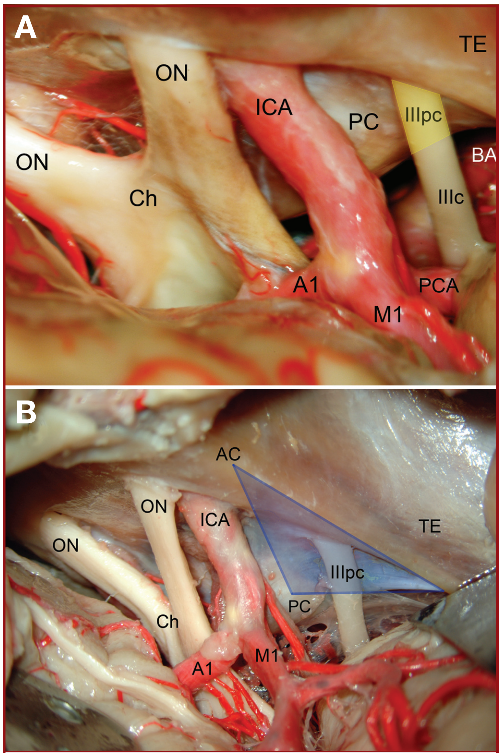

FIGURE 5. *Microscopic view of the petroclinoid segment of the oculomotor nerve (**A**) inside the oculomotor triangle (**B**). This segment has been exposed to show its course and relationship with the oculomotor triangle (**B**) (blue area) and its dural porus where the nerve pierces the roof of the cavernous sinus (**A**). A1 indicates precommunicating tract of the anterior cerebral artery; AC, anterior clinoid; BA, basilar artery; Ch, optic chiasm; ICA, internal carotid artery; IIIc, cisternal segment of the oculomotor nerve; IIIpc, petroclinoid segment of the oculomotor nerve; M1, first tract of the middle cerebral artery; ON, optic nerve; PC, posterior clinoid; PCA, posterior cerebral artery; TE, tentorium edge.*

2.2 (1) mm on the left side, and the main diameter was 2.4 (0.3) mm (Table 1).

Superior Division

The superior division passed through the superior orbital fissure superomedially to the nasociliary nerve, and reached the orbit just above the ophthalmic artery and below the origin of the superior rectus muscle (SRM).

Before ending on the inferior surface (global surface) of the levator palpebrae superioris muscle (LPSM), this branch innervated the SRM and then continued its course medially. On the global surface of this muscle, the superior division left a mean of 5 fibers, 4 of them innervating this muscle and the last one innervating the LPSM. The area embracing the oculomotor nerve from the medial side of the SRM to the inferior surface of the LPSM is a key surgical landmark when taking the transcranial route to the orbit (Figure 6).

Inferior Division

The inferior division of the oculomotor nerve passed the orbital fissure inferiorly and reached the orbit just before the first branching of the medial rectus muscle (MRM). This branch split into a mean of 5 fascicles (3-7) before penetrating the global side of the MRM. After innervating the MRM branch, the inferior division innervated the inferior rectus by reaching the global surface of the muscle and splitting into 7 branches.

The oculomotor root of the ciliary ganglion arose from the inferior division a mean of 5 mm distal to the inferior muscle branch. From the ciliary ganglion arose a mean of 7 ciliary nerves that reached the cornea and the globe. Finally, the inferior division drifted inferolaterally and pierced the inferior oblique muscle (Figure 6C).

Blood Supply

A key point for the safe execution of any operative procedure and for preservation of blood supply to the nerve using either microsurgical or endoscopic techniques is the knowledge of relevant vascular anatomy.[35] The inferolateral trunk of the horizontal portion of the ICA split into 4 branches: marginal tentorial, orbital, maxillary, and mandibular. These branches are involved in the blood supply of the cranial nerves running within the cavernous sinus toward the orbit. Specifically, the inferolateral trunk sends many branches to the oculomotor nerve. The cisternal segment of the nerve is supplied by the tentorial branch[22,32,36]; the cavernous segment is supplied by the orbital branch that nourishes the abducent nerve as well. The other segments of the nerve are supplied by the second proximal branch of the inferolateral trunk directed to the superior orbital fissure.

DISCUSSION

In the previous decades, many authors have described the anatomy of the oculomotor nerve within the cavernous sinus or the orbital region. However, to our knowledge no one has systematically analyzed the entire course of this nerve from the ventral surface of the midbrain to the orbit. Marinković and Gibo[18] and Gönül et al[24] have divided its course into 4 segments—cisternal, supracavernous, intracavernous, and orbital—describing only the cisternal segment and its neurovascular relationships. Natori and Rhoton[23] have examined the cavernous, the fissural, and the orbital segments without purposing any classification of the nerve. Rhoton et al have separately considered its course within the cistern,[37] cavernous sinus,[6,7] and the orbit.[22] Umansky et al[38] have reported its course within the superior wall of the cavernous sinus.

In our anatomical study, a classification of the oculomotor nerve into 5 segments has been proposed because of the need to find a structured and illustrative anatomical pattern that is surgically and clinically oriented, and considers the entire course in which the nerve travels as well as the surrounding neurovascular struc-

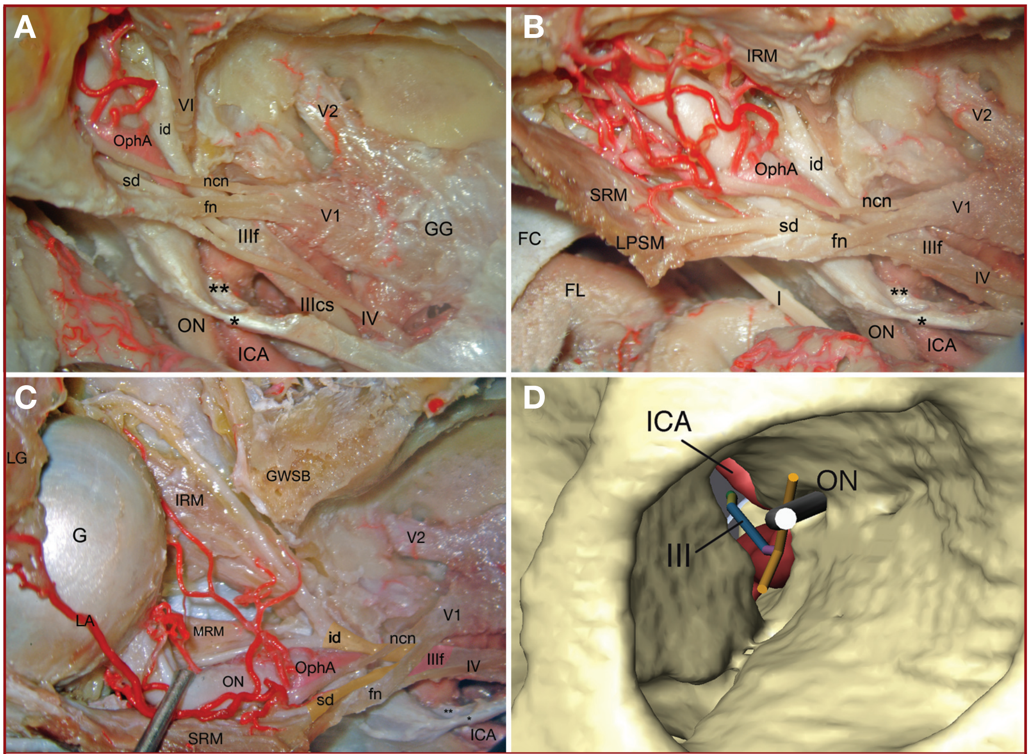

FIGURE 6. *Superolateral view of the fissural and orbital segments of the right oculomotor nerve. The cavernous sinus, superior orbital fissure, and orbit have been dissected, and the rim of the lesser wing of the sphenoid bone and anterior clinoid have been drilled out.* **A**, *microscopic exposure of the superior orbital fissure after disinsertion of the lateral rectus muscle.* **B**, *magnified microscopic view of the superior division of the oculomotor nerve piercing the globar surface of the superior rectus muscle.* **C**, *microscopic panoramic view of the intraconal structures. The optic nerve has been retracted superiorly to expose the distal branches of the oculomotor nerve inside the orbit. The superior and inferior main divisions of the orbital segment have been colored orange, and the fissural segment has been colored purple.* **D**, *3-dimensional angio-computed tomography–based model of the orbital and fissural segments of the oculomotor nerve viewed from an anterior perspective inside the orbit. FC indicates falx cerebri; FL, frontal lobe; fn, frontal nerve; G, globe; GG, gasserian ganglion; GWSB, greater wing of the sphenoid bone; I, olfactory tract; ICA, internal carotid artery; id, inferior division of the orbital segment of the oculomotor nerve; IIIcs, cavernous sinus segment of the oculomotor nerve; IIIf, fissural segment of the oculomotor nerve; IRM, inferior rectus muscle; IV, trochlear nerve; LA, lacrimal artery; LG, lacrimal gland; LPSM, levator palpebrae superius muscle; MRM, medial rectus muscle; ncn, nasociliary nerve; ON, optic nerve; OphA, ophthalmic artery; sd, superior division of the orbital segment of the oculomotor nerve; SRM, superior rectus muscle; V1, ophthalmic nerve; V2, maxillary nerve; VI, abducens nerve. * Distal ring. ** Proximal ring.*

tures. Obviously, this anatomical study should not be considered an attempt to minimize the importance of previous anatomical works that have inspired and helped us to develop our study. Further, this series should not be interpreted as the best classification compared with them. In our opinion, the opportunity to perform and compare both microscopic and endonasal endoscopic observations gave us 2 different perspectives that justified the division of the nerve into 5 portions. Regarding the choice of an endonasal or transcranial route, some points have to be highlighted. The endoscopic endonasal approach is particularly useful for midline lesions enclosed between the cisternal or petroclinoid segments of the oculomotor nerve. Indeed, in such cases, the endonasal route allowed wide exposure of the lesion without any neurovascular manipulation. Considering the distal part of the nerve, especially the cavernous, fissural, and orbital segments, the endonasal route can be used to decompress the third cranial nerve when the lesion has a midline origin and a paramedian extension. The main disadvantages of the endoscopic endonasal approach are related to the fact that it is a midline approach and cannot be used to manage lesions located laterally to the oculomotor nerve. Another important concept regarding the cisternal and the petroclinoid segments concerns the difficulty of endoscopically managing eventual injuries to the main vascular structures.

The cisternal segment has been described by several authors. Our anatomical and clinical observations, even when they agree with the pertinent literature, have motivated us to change the anterior limit on this segment which is considered the posterior petroclinoid fold.

The petroclinoid segment is not properly considered in previous works as a separate segment. In our opinion, it should be described as a separate entity for 2 main reasons. First, from an anatomical perspective, the nerve is in close relation with the posterior clinoid and the posterior and anterior petroclinoid folds. Second, from a clinical point of view, the nerve may be especially susceptible to damage from lesions invading the superior lateral and medial walls of the cavernous sinus or during severe head trauma.[39,40] During its course within the interpeduncular cistern, the oculomotor nerve is in close proximity with the P1 segment of the posterior cerebral artery. Therefore, it is often displaced by aneurysms arising in this segment of the vessel. The cisternal and petroclinoid segments of the nerve are in relationship with the posterior communicating artery, which can be attached to the posterior clinoid; aneurysms developing along the artery in correspondence of these segments can compress and stretch the nerve with subsequent palsy. The aneurysm may also rupture into the nerve. In such cases, the dissection of the fundus has to be extremely delicate. Indeed, lesions invading the cavernous sinus from the parasellar region and the sphenopetroclival venous gulf, above the Gruber ligament, are most likely to cause third cranial nerve dysfunction before the involvement of the other cranial nerves within the cavernous sinus. This is probably because of the close proximity of the nerve to the unyielding interclinoid ligament above and the petroclinoid dural folds below it.[41,42] Another important clinical aspect to be underlined is related to brain injury. The nerve may be especially susceptible to damage when the brainstem shifts downward at the moment of head injury.[39,40,43,44] The mechanisms of damage could be ascribed to the partial tearing of the parasympathetic fibers contused against the posterior clinoid or the interclinoid ligament. Furthermore, this segment of the nerve is exposed to damage during the posterior clinoid drilling procedure to have more room for entering the posterior fossa and clival areas.

The cavernous segment has been discussed in the literature by many authors.[1-15] Through the endoscopic approach, it can be clearly visualized below the optic strut until the superior orbital fissure is exposed. During an endoscopic endonasal approach for pituitary macroadenomas, which invade the cavernous sinus via the medial wall, tumor resection can be achieved by careful inspection of this area through a laterally displaced ICA. Indeed, the lesion can be dissected laterally from the medial walls of the cavernous sinuses and internal carotid arteries under direct endoscopic visualization.

The entry dural porus represents 1 of the 2 main fixation points of the nerve and is surrounded by slight connective tissue to the border of its porus. The other important fixation point is represented by the superior orbital fissure. These areas of attachment to the skull base may explain the high vulnerability of the nerve during pathologic conditions.

The fissural segment has not been previously considered as a separate anatomical entity, whereas the intraorbital segment has been reported in several anatomical works.[22-24,45] In our study, both segments have been mentioned in consideration of the different ways of approaching the superior orbital fissure and the intraorbital portion of the oculomotor nerve. Through the endonasal endoscopic approach, by drilling the lateral aspect of the opto-carotid recess, the fissural segment can be scarcely exposed in close relation with the annulus of Zinn. This exposure is, of course, not possible for the intraorbital portion of the nerve.

CONCLUSIONS

A new 5-segment classification of the oculomotor nerve is proposed. This classification, which considers the entire intracranial and extracranial course of the nerve along with its topographical relationships with surrounding structures, is anatomically valid and surgically oriented when considering both the microscopic and endonasal endoscopic approaches. All of these elements must be taken into consideration when analyzing the risk of injury to the cranial nerves. It must be stressed, however, that through the endoscopic route it was possible only to expose the proximal part of the nerve (cisternal, petroclinoid, and cavernous sinus segments). On the other hand, from an inferomedial perspective, the cavernous sinus segment of the nerve lies more laterally as compared with the same tract of the abducens nerve.[25] Indeed, the abducens nerve, which runs freely within the cavernous sinus space and is in close relationship with the intracavernous segment of the internal carotid artery, is more susceptible to surgical injury during a standard endoscopic endonasal approach to the sellar region. However, the oculomotor nerve, as well as other nerves running in the lateral wall of the cavernous sinus, is more likely to be damaged during an extended endoscopic endonasal approach to the lateral compartment of the cavernous sinus.

Finally, the present study could be useful to explain, segment by segment, the pathogenic mechanism of nerve injuries due to lesions involving the nerve and its intracranial and extracranial course. To avoid injuring the third nerve, knowledge of the proposed new classification could be beneficial to neurosurgeons who are approaching the petroclival area, the cavernous sinus, and the orbit.

Disclosure

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

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COMMENT

This excellent anatomical study is the result of a joint effort of a well-known group of researchers from different institutions. The authors performed a meticulous and detailed study of the entire course of the oculomotor nerve using microsurgical skull base approaches as well as endoscopic visualization. They divided the nerve length into 5 segments: cisternal, petroclinoid, cavernous, fissural, and orbital. They used a large number of anatomical specimens and illustrated their findings with figures of superb quality that are clear and didactic.

The increase use of the extended endoscopic transsphenoidal approach to the sellar, suprasellar, parasellar, and clival areas requires a deep knowledge of the pertinent anatomy. By comparing the different views given by the microscopic and endoscopic approaches, these anatomical observations will result in important surgical applications.

The description of the course of the oculomotor nerve in its cavernous segment is in accord with our own findings.[1,2] In conclusion, this article is an important contribution to the understanding of the anatomy of the skull base, and the authors should be congratulated for their work.

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