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Abstract The superior orbital fissure is a critical three-dimensional space connecting the middle cranial fossa and the orbit. From an endoscopic viewpoint, only the medial aspect has a clinical significance. It presents a critical relationship with the lateral sellar compartment, the pterygopalatine fossa and the middle cranial fossa. The connective tissue layers and neural and vascular structures of this region are described. The role of Muller's muscle is confirmed, and the utility of the maxillary and optic strut is outlined. Muller's muscle extends for the whole length of the inferior orbital fissure, passes over the maxillary strut and enters the superior orbital fissure, representing a critical surgical landmark. Dividing the tendon between the medial and inferior rectus muscle allows the identification of the main trunk of the oculomotor nerve, and a little laterally, it is usually possible to visualize the first part of the ophthalmic artery. Based on a better knowledge of anatomy, we trust that this area could be readily addressed in clinical situations requiring an extended approach in proximity of the orbital apex.

Keywords Endoscopy · Expanded endonasal approach · Superior orbital fissure · Orbital surgery

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Introduction

The superior orbital fissure (SOF) is a critical three-dimensional space connecting the middle cranial fossa and the orbit, and it represents the posterior part of the sino-orbito-cranial interface. Anatomically speaking, it is situated laterally to and below the optic canal. The medial edge of the SOF is formed by the body of the sphenoid bone and its junction with the optic strut. The maxillary strut constitutes the inferior border which divides the SOF from the rotundum canal. Given the amazing evolution of endoscopic endonasal techniques and the increasing complexity of the skull base lesions treated, a detailed description of the endoscopic endonasal perspective of this anatomical region and its relationships has become critical. An academic report of the anatomical details is meaningless, and cannot represent the basis for a modern surgical approach which in turn should be functionally and surgically oriented. In this respect, detailed micro-surgical descriptions of the SOF have been presented [1–3] and constitute the basis for traditional external approaches. Endoscopic endonasal perspectives of this region have been generally neglected, and only very recently the critical role of Muller's muscle has been underlined as a safe landmark to reach the superior orbital fissure [4]. Even more recently, the same authors have pointed out the critical "endoscopic-endonasal" anatomy of the inferior orbital fissure (IOF), thus increasing our knowledge of these regions from an endonasal viewpoint [4].

Aim of this study is to describe the anatomical features of the superior orbital fissure and orbital apex regions from an endoscopic endonasal viewpoint, and to accurately present the critical landmarks to orient the surgeon in this very complex sino-orbito-cranial interface.

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Materials and methods

Six double-injected orbits were carefully dissected via endoscopic endonasal approach, mainly focusing on the vascular network and its relationship to the cavernous sinus. Other two orbits were dissected in a medial to lateral direction. Osteologic relationships were evaluated in other three dry orbits, that were carefully prepared and dissected under microscopic vision. Storz® endoscopes (4 mm, 0° and 45°) were used for visualization during transnasal dissection. Recording of data was made using an integrated system. External pictures were taken with a standard digital photocamera (Panasonic®, Lumix, DMC-TZ10). Dissections were performed by three authors (ID, RL, MTZ) at the Dept. Of Neuroanatomy, University of Barcelona. The local Ethical Committee approved the design of the study.

Results

From an osteologic viewpoint, the medial aspect of the SOF is bordered inferiorly by the maxillary strut and superiorly by the optic strut. The inferior aspect of the optic strut represents the superomedial border of the SOF (Fig. 1).

Endoscopic evaluation: After a standard spheno-ethmoidectomy, the lamina papiracea and the medial aspect of the superior orbital fissure are exposed transnasally. Once the bony layers have been carefully removed, the connective tissues appear underneath. The periorbital layer presents a "continuum" with the dura of the lateral sellar compartment, and the fascial system covering the inferior orbital fissure and the pterygopalatine fossa (Fig. 2). After removing the connective layer, deeper structures come into view. Muller's muscle extends for the whole length of the inferior orbital fissure, passes over the maxillary strut and enters the superior orbital fissure (Figs. 3, 5c–d). This muscle presents an intimate relationship with the cavernous sinus. In five out of six dissections, an extraconal vein draining into the anteromedial aspect of the cavernous sinus was easily recognizable once the periorbit had been removed. This vein lies on the medial surface of the common annular tendon. Entering the posterior aspect of the orbit by dividing the tendon of the medial and inferior rectus muscle allows the identification of the two main branches of the oculomotor nerve, and laterally to it, the

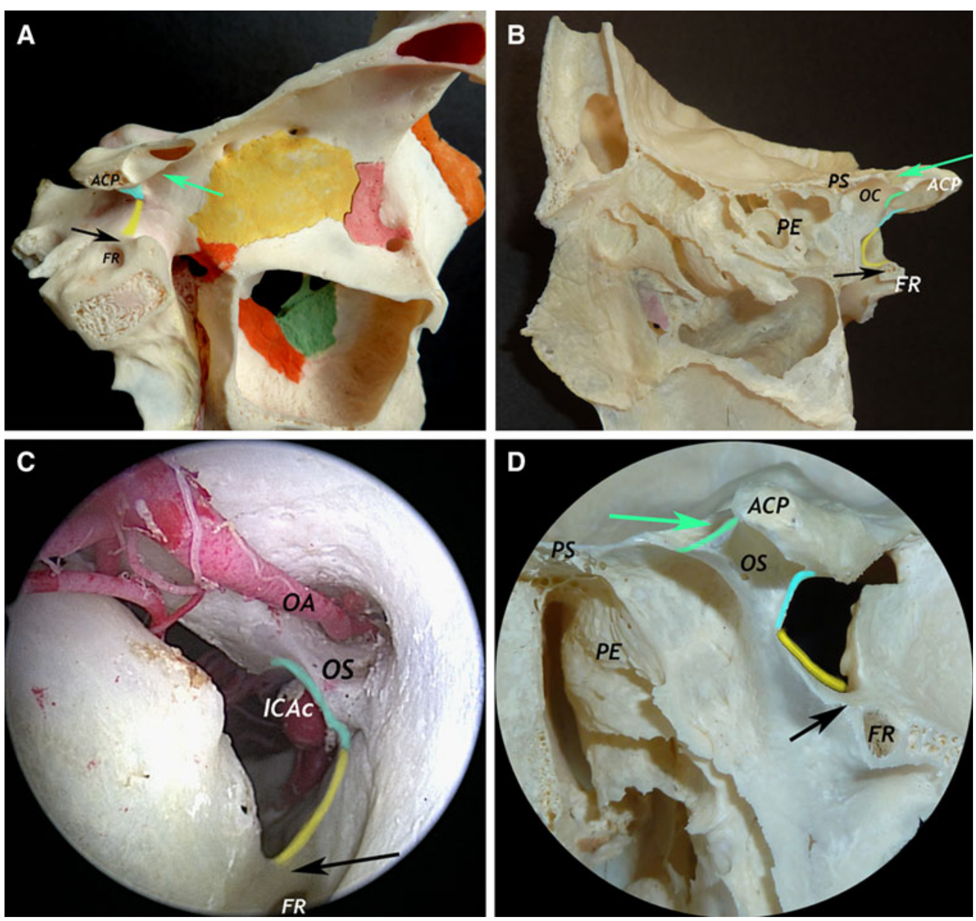

Fig. 1 Osteology of the sino-orbito-cranial interface and superior orbital fissure region (right side). **a** lateral perspective, **b** medial perspective, **c** endoscopic perspective, **d** posterior perspective. *ACP* anterior clinoid process, *FR* foramen rotundum, *ICAc* cavernous portion of the internal carotid artery, *OA* ophthalmic artery, *OC* optic canal, *OS* optic strut, *PE* posterior ethmoid, *PS* planum sphenoidale, *light blue line* indicates the superomedial aspect of superior orbital fissure (in close relationship to optic strut), *yellow line* indicates the medial aspect of the superior orbital fissure, *black arrow* indicates maxillary strut, *green arrow* indicated optic canal, *green line* indicates the superior aspect of the lateral optico-carotic recess

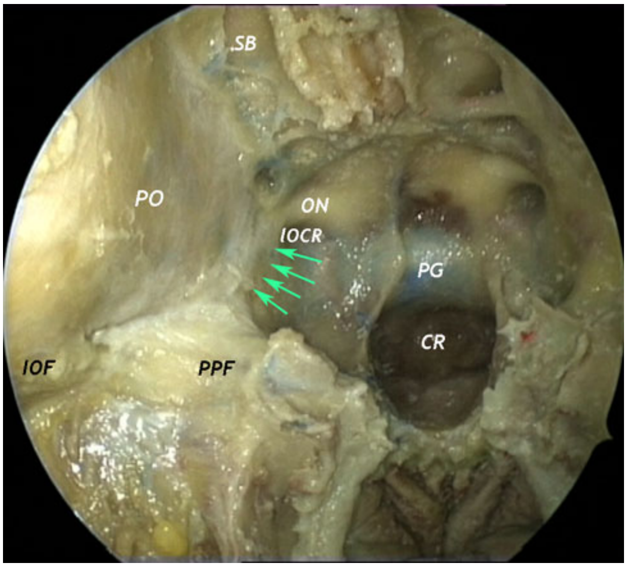

Fig. 2 Endoscopic endonasal view of the right sino-orbito-cranial interface, with particular attention to the superior orbital fissure. The fascial system covering the infratemporal fossa, pterygopalatine fossa, orbital and lateral sellar compartment is well evident. *CR* clival recess, *IOF* inferior orbital fissure, *PPF* pterygopalatine fossa, *PO* periorbit, *SB* skull base, *ON* optic nerve, *lOCR* lateral optico-carotid recess, *PG* pituitary gland, *green arrows* indicate the medial aspect of the superior orbital fissure

first segment of the ophthalmic artery can be appreciated (Fig. 4). Posteriorly, after the removal of the dura of the medial cavernous sinus, the relationship between Muller's muscle, maxillary strut and anterior bend of the internal carotid artery becomes evident. This bend lies immediately posterior to the optic strut (Fig. 3b). The maxillary strut is identified as a really constant bony landmark useful for indicating the superior orbital fissure and the "front door" to the cavernous sinus (Fig. 5). The geometrical relationships between superior orbital fissure, foramen rotundum and vidian canal are critical (Fig. 6), and the role of maxillary and optic struts in defining these relationships fundamental. Extending the dissection laterally, the content of the cavernous sinus and, to some extent, the content of the middle cranial fossa can be explored.

Discussion

Superior orbital fissure (SOF) and its critical relationship is poorly described from an endoscopic endonasal viewpoint, and most of the previous papers have pointed out the microsurgical anatomy of the SOF, thus witnessing the prevalent external interest in this area. Some things have changed with the well written paper by De Battista et al. [4] that has focused the attention on this region and clearly demonstrated the role of Muller's muscle in indicating the inferior portion of the superior orbital fissure and thus one of the roads to the cavernous sinus. A subsequent publication from the same group has increased our knowledge on this topic [5]. So, based on the increasing complexity of the pathologies treated and on the growing interest in endoscopic skull base approaches, new anatomical details are needed. Transnasal endoscopic anatomy of the medial intraconal spaces has already been described [6], and clinical application on this topic has been subsequently published [7]. Currently, a clear and sound description of the endoscopic perspective of the orbital apex and SOF anatomy is lacking. From an endoscopic viewpoint, although the shape of SOF has been shown as extremely variable [8], the medial aspect is less influenced by this variability. It is far more influenced by the degree of pneumatization of the sphenoid sinus and bone. The optic and maxillary struts constitute the superior and inferior borders of the medial aspect of the SOF, respectively. The optic strut divides the SOF from the optic canal, while the maxillary strut divides the SOF from the foramen rotundum. In well pneumatized sphenoid sinuses, the lateral optico-carotid recess (lOCR), that corresponds to the pneumatization of the optic strut, is clearly evident. In these cases, the superior aspect of the lOCR faces the optic canal while the inferior aspect faces the superior aspect of the SOF. In poorly pneumatized sinuses, these landmarks are virtually impossible to identify. Most of the authors admit that only the medial aspect of the SOF is functionally relevant [3], since no major neural and vascular structures pass through the lateral compartment. This highlights the potential role of endoscopic endonasal approaches in comparison with traditional neurosurgical approaches used to address these critical areas. The Pterional approach and subsequent modifications [9] or even transfacial transorbital approaches [10] can be used but require an extensive bony work and do not allow to manage easily and with low morbidity these regions. The golden rule of the Pittsburgh group [11] of "never cross the nerves" is our leading rule; consequently, we have tried to explore alternative solutions for effectively and safely managing the medial aspect of the posterior sino-orbito-cranial interface. Endoscopically speaking, once the bony structures are removed a "comprehensive" connective bag covering the pterygopalatine fossa, infratemporal fossa, orbit (with inferior orbital fissure) and lateral sellar compartment becomes evident (Fig. 2). In this contest, the medial aspect of the SOF can be visualized above V2 (that more posteriorly corresponds to the inferior apex of the lateral sellar compartment bag). Posteriorly to the SOF lies the lateral sellar compartment. Passing through the SOF, and so anteriorly to the lateral sellar compartment, it is possible to identify the lateral sellar compartment junction. This is a transition region between the lateral sellar compartment and the orbit,

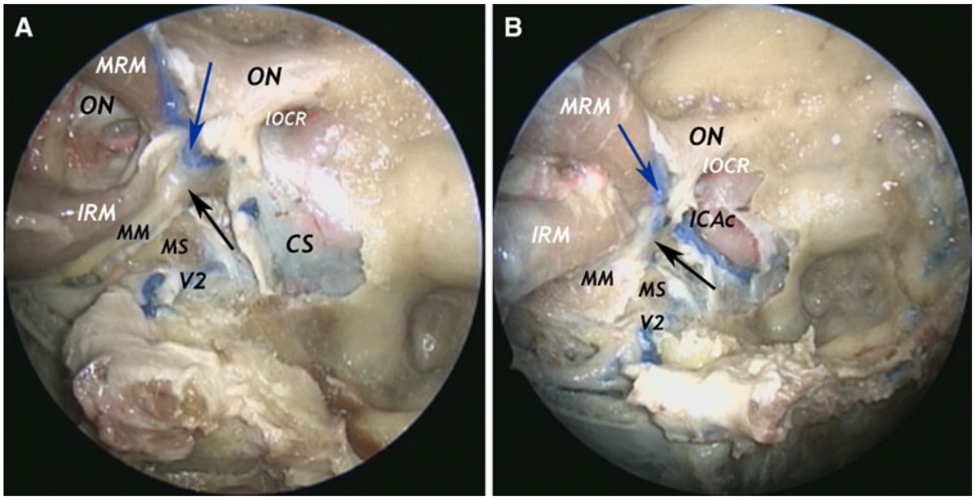

Fig. 3 Endoscopic endonasal views of the superior orbital fissure region and its relationship with lateral sellar compartment/cavernous sinus. *CS* cavernous sinus, *ICAc* cavernous portion of the internal carotid artery, *IRM* inferior rectus muscle, *lOCR* lateral optico-carotid recess, *MM* Muller's muscle, *MRM* medial rectus muscle, *MS* maxillary strut, *ON* optic nerve, *V2* second branch of the trigeminal nerve, *black arrow* indicates the cavernous portion of the Muller's muscle, *blue arrow* indicates the extraconal vein connecting the orbital system with the lateral sellar compartment

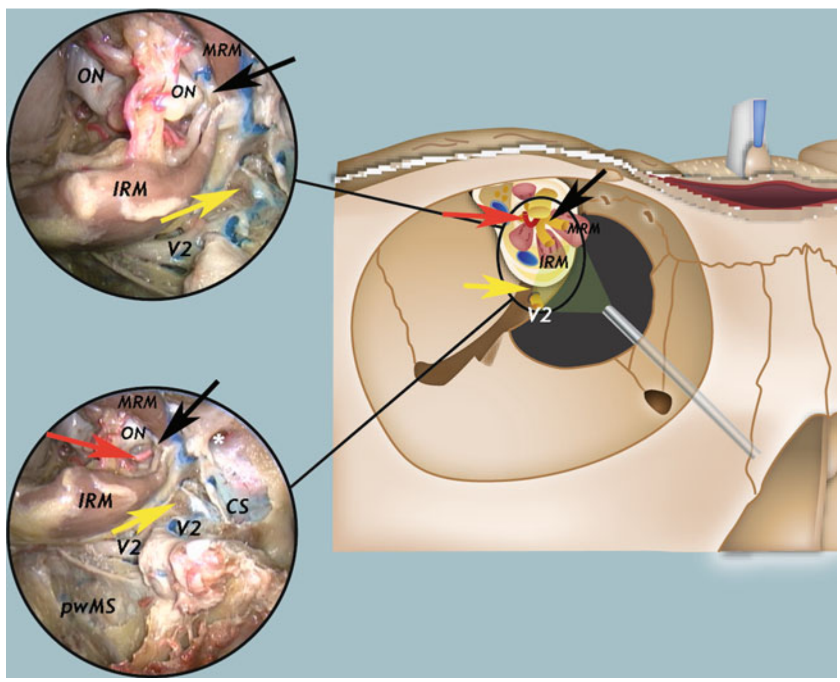

Fig. 4 3D reconstruction and endoscopic endonasal views of the medial aspect of the superior orbital fissure (with particular attention to the neurovascular content of the medial aspect of the SOF). *CS* cavernous sinus, *IRM* inferior rectus muscle, *MRM* medial rectus muscle, *MS* maxillary strut, *ON* optic nerve, *pwMS* posterior wall of the maxillary sinus, *V2* second branch of the trigeminal nerve, *black arrow* indicates the division of the oculomotor nerve, *yellow arrow* indicates the maxillary strut, *red arrow* indicates the ophthalmic artery, *white asterisk* lateral optico-carotid recess

located at the medial, wider, aspect of the SOF [3], in close proximity to the nasal aspect of the SOF. From an endoscopic viewpoint, once the connective tissue has been cleaned away from the bony structures, the geometrical relationship between the SOF, foramen rotundum and vidian canal becomes evident (Fig. 6). The periostium at the level of the orbit and SOF corresponds to the external layer of extradural neural axis compartment [12]. By opening this connective tissue at the level of the medial aspect of the SOF, the region of the orbital apex is exposed. Usually a venous channel, immediately beneath the periostium, appears running toward the medial aspect of the cavernous sinus (Fig. 3). This vein has been described as the medial orbital or ophthalmic vein, and should not be confused with the superior or inferior ophthalmic vein, both of them are intraconally placed. This vein was found in five out of six of our specimens. The common annular tendon lies beneath this vessel. The common tendon forms a cone inserted posteriorly on the infraoptic tubercle and, from an anterior viewpoint, comprises a superomedial and

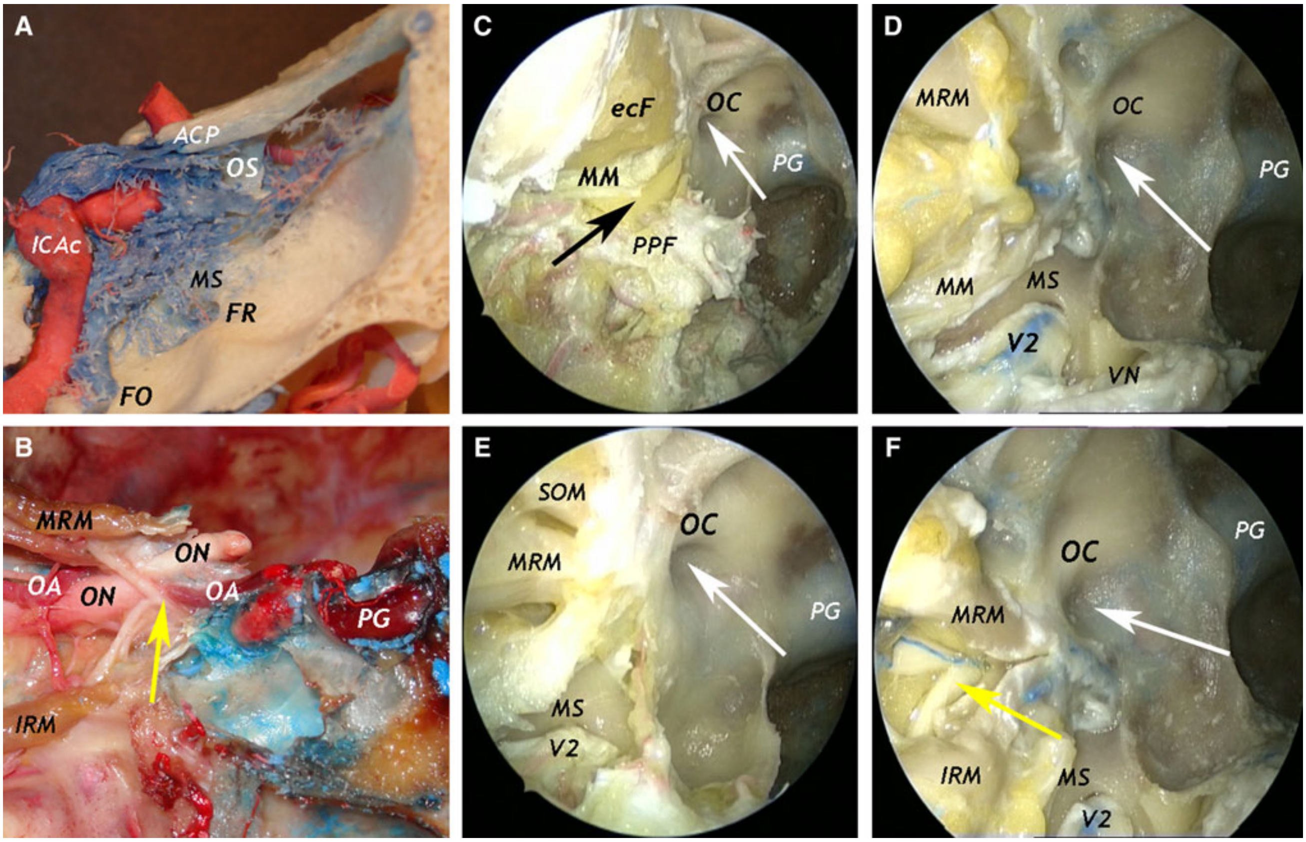

Fig. 5 Composite picture showing medial, lateral and endoscopic views of the superior orbital fissure region. **a** lateral view, **b** medial view, **c**–**f** endoscopic views. *ACP* anterior clinoid process, *ecF* extraconal fat, *FO* foramen ovale, *FR* foramen rotundum, *ICAc* cavernous portion of the internal carotid artery, *IRM* inferior rectus muscle, *MM* Muller's muscle, *MRM* medial rectus muscle, *MS* maxillary strut, *OA* ophthalmic artery, *OC* optic canal, *ON* optic nerve, *OS* optic strut, *PG* pituitary gland, *PPF* pterygopalatine fossa, *SOM* superior oblique muscle,*VN* vidian nerve, *V2* second branch of the trigeminal nerve, *white arrow* indicates the lateral optico-carotid recess, *black arrow* indicates the pterygopalatine fat, *yellow arrow* indicates the oculomotor nerve

superolateral annular foramen [3]. The annular tendon surrounds the optic canal and the upper portion of the medial part of the fissure [1]. Although it has been reported that the annulus of Zinn is fused to the periorbit along the superior and medial orbital wall at the level of the posterior orbit [13], this is not consistent with our findings. Dividing the tendon of the inferior and medial rectus muscle at the level of the posterior orbit and superior orbital fissure region allows identification of the superior and inferior division of the oculomotor nerve (Figs. 4, 5f), and sometimes of the central retinal vein. The superior branch of the oculomotor nerve has been described as the closest nerve to the medial rim of the fissure, and the trochlear nerve as the closest one to the superior rim of the fissure [2]. Endoscopically speaking, the identification of the trochlear nerve at this level is really complex and really hardly applicable in clinical settings. The ophthalmic artery normally enters the optic canal infero-laterally to the optic nerve, and, at this level, is usually laterally placed with respect to the oculomotor division (Fig. 4). The artery usually passes the oculomotor foramen of the annulus of Zinn beneath the optic nerve [14]. In any case, it should be underlined that the location of the ophthalmic artery varies in relation to the stem of the optic nerve. According to Reymond et al. [8], at the level of the posterior part of the orbit, the artery was inferior to the nerve in 34 % of cases while in 66 % of cases it was lateral and superior. Extending the dissection toward the IOF, it is quite easy to appreciate the connection between this last one and the SOF, at least in dry skulls. To be precise, the real exact border between them is more conceptual than practical. The IOF is filled by Muller's muscle, a smooth muscle first described in the nineteenth century [15]. This muscle has been considered part of the fascial system of the orbit and it has been re-described, in a more modern viewpoint, by the Cincinnati group [4]. The muscle is covered by a thin fascial layer that blends intimately with the periostium/periorbita, covering the margins of IOF and separated from the inferior rectus and inferior oblique muscles by adipose tissue [4]. Connective connections with the inferior rectus muscle are described [13]. Posteriorly, fibers of Muller's muscle were associated with the anterior venous

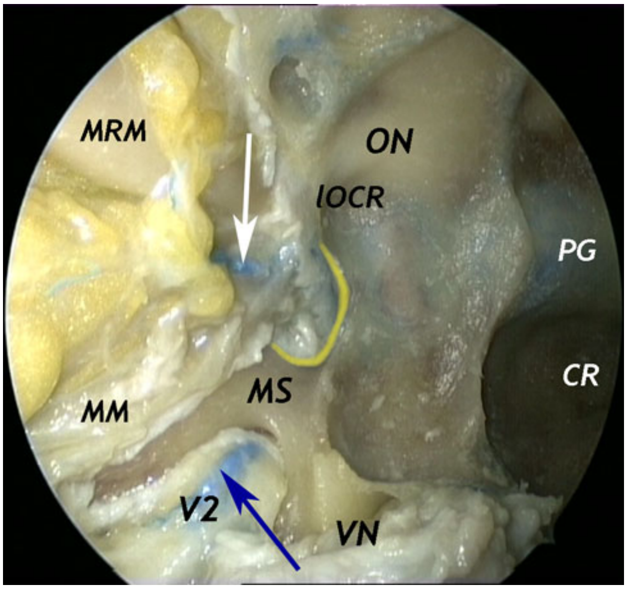

Fig. 6 Endoscopic endonasal view of the superior orbital fissure region, with particular attention to the geometrical relationship between the superior orbital fissure, foramen rotundum and vidian canal. *CR* clival recess, *lOCR* lateral optico-carotid recess, *MM* Muller's muscle, *MRM* medial rectus muscle, *MS* maxillary strut, *ON* optic nerve, *PG* pituitary gland, *VN* vidian nerve, *V2* second branch of the trigeminal nerve, *blue arrow* indicates the foramen rotundum vein, *white arrow* indicates the medial ophthalmic vein, *yellow line* outlines the medial aspect of the superior orbital fissure

confluence of the lateral sellar compartment, and to some extent the muscle itself enters the lateral sellar compartment and can act like an arrow to the inferior portion of the lateral sellar compartment. These muscular fibers are accompanied by orbital branches of the pterygopalatine ganglion and are passed through by the zygomatic nerve (Figs. 3, 4). Functionally speaking, it has been postulated that Muller's muscle may exert influence on the venous system [16]. From a clinical viewpoint, when dealing with such regions, one of the major problems encountered is the management of the neurovascular structures. In most cases no major arteries pass through the SOF even though small branches from the maxillary system can be appreciated, and they connect with the superior orbital fissure branches from the infero-lateral trunk. As previously stated, the lOCR corresponds to the pneumatization of the optic strut. This is really a critical landmark, given the fact that the anterior bend of the cavernous portion of the ICA rests against the posterior surface of the optic strut. This portion of the ICA is included in the venous system of the lateral sellar compartment, that in turn fills the posterior margin of the SOF. The venous system is particularly represented at this level with an intricately complex connection with the pterygoid plexus (via the IOF), the foramen rotundum and ovale plexus (Figs. 5a, 6). The endoscopic endonasal visualization of the superior ophthalmic vein (SOV) at the level of the posterior orbit and SOF region is really a hard task, and needs an extensive dissection above the optic nerve. In fact, anatomically speaking the SOV passes backward within the superolateral part of the extraocular muscle cone [1]. The inferior ophthalmic vein (IOV) represents a slightly different case inasmuch as can be identified more easily through a nasal window. The main trunk of the IOV passes out of the muscle cone and dilates into several broad venous sinuses below the annulus of Zinn [17]. It runs below the annular tendon and through the inferior sector of the SOF. This finding is consistent with some of our observations. Notwithstanding this, it is not difficult to believe, given the extreme changeability of the orbital venous system, that in a variable percentage of patients IOV may not be easy to dissect as a single entity [18]. Certainly of greatest clinical interest, given the endoscopic viewpoint, is the presence of the medial ophthalmic vein (MOV). As previously stated, this vein runs extraconally on the medial surface of the medial rectus muscle and drains into the medial aspect of the cavernous sinus [17]. It is immediately evident under the periorbital layer (Fig. 3). This vessel has been reported in 40 % of normal individuals [17] while other authors have described MOV in 8 out 36 orbits always running medial to the SOV [18]. The central retinal vein is not always found. It is described as having a short course and drains directly into the cavernous sinus. Clinically speaking, this vein is really critical and should absolutely be spared.

Extended endonasal approaches can now involve areas that only a few years ago were not manageable with endoscopic techniques. The description of endoscopic anatomy of the SOF and its lateral (toward the middle cranial fossa) and posterior extension (toward the lateral sellar compartment) is a necessary tribute to the surgeons of tomorrow. In this respect, the aim of this study is to describe these anatomic regions in detail from an endoscopic viewpoint, hoping that this may furnish the basis for future clinical application. Obviously only clinical experience will tell us the real applicability, in terms of morbidity and functional impairment, of such extended approaches. Furthermore, especially in poorly pneumatized sinuses, where traditional endoscopic landmarks are not identifiable, the role of neuronavigation is absolutely mandatory. Notwithstanding this, we maintain that "sine anatomia non sciemus", and for this reason, we call for further and comparative studies on this topic.

Conclusions

Endoscopic endonasal anatomy of the superior orbital fissure and orbital apex is described, as well as the critical relationship with the lateral sellar compartment, the pterygopalatine fossa and the middle cranial fossa. The role of Muller's muscle is confirmed and the utility of the maxillary and optic strut is outlined. Based on our dissections and on the "endoscopic evolution", we really trust that the medial aspect of the superior orbital fissure and the orbital apex will be probably soon addressed in clinical settings. Further studies and possibly pioneer clinical applications are necessary.

Conflict of interest The authors certify that they have no potential conflicts of interest with any entity mentioned in the manuscript and that they receive no financial support for this work.

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