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REVIEW

Revisiting anatomical structures of the superior orbital fissure using with interactive 3D-PDF model

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ABSTRACT

The superior orbital fissure is an important cleft that connects the orbit with the middle cranial fossa. The upper border of this fissure is formed by the lesser wing of the sphenoid bone, anterior clinoid process, and optic strut. The lower border is formed by the greater wing of the sphenoid bone. The oculomotor, trochlear, ophthalmic, abducens nerves and orbital veins pass through this small slit. The aim of this study was to review anatomical structures of the superior orbital fissure, through a 3D-PDF model that simplifies the understanding of complex anatomy of this region. According to the literature, any major artery does not pass through it, but it is closely related to the internal carotid artery. There are numerous intracranial-extracranial anastomoses around it. While extracranial branches originate from the maxillary artery, intracranial branches arise from the inferolateral trunk or the ophthalmic artery. Nerves and vascular structures related with this fissure can be damaged due to post-traumatic sphenoid fractures, infectious diseases, aneurysms, carotid-cavernous fistulas, and neoplasms. Surgeries involving the superior orbital fissure are quite complex as there are many important anatomical structures in this region. The radiological anatomy of this fissure in normal and pathological conditions is still an under-studied subject in the literature. There is a need for more detailed studies related to the superior orbital fissure enriching with anatomic models and including pathological conditions. The 3D-PDF model of the superior orbital fissure is an innovative tool to enhance the knowledge of the anatomical structures related with this region. Better understanding of this critical region is necessary to perform safe and successful surgical procedures.

Keywords: Anatomic models, cranial nerves, orbit, superior orbital fissure, 3D-PDF model.

INTRODUCTION

The superior orbital fissure (SOF) is a small but functionally important area that gives passage the oculomotor, trochlear, ophthalmic, abducens nerves and orbital veins. Nerves and vascular structures in this fissure can be damaged due to post-traumatic sphenoid fractures, infectious diseases, orbital pseudotumor, Tolosa-Hunt syndrome, aneurysms, carotid-cavernous fistulas, cavernous sinus thrombosis, pituitary adenoma and neoplastic lesions such as meningioma and craniopharyngioma [1,2]. Knowing the detailed anatomy of this region through an interactive 3D-PDF model is crucial for the diagnosis and treatment of pathologies involving orbit and sellar region.

The aim of this study was to review anatomical structures of the SOF, through a 3D-PDF model that simplifies the understanding of complex anatomy of this region.

Image processing and 3D-PDF development

The anonymised images of cranial computed tomography (CT) and magnetic resonance imaging (MRI) of patients were used. Informed consent was obtained from the individual participant included in this study. The study complied with the Declaration of Helsinki principles. Mimics Innovation Suite 24.0 software programme (Materialise, Leuven, Belgium) was used for 3D planning and modelling processes. Dicom format of cranial CT and MRI data taken from the different sequences were added to Mimics software as a study file. Areas were determined by masking process which was undertaken using Hounsfield Unit (HU) values on cranial CT scan and Grey Value (GV) values on MRI images. By using the segment module of Mimics software, the relevant structures were segmented by following the anatomical border relationship. Separately segmented models were superimposed using the Align Global Registration module in Mimics software, and the overlapping process was performed by ensuring the full harmony of the anatomical boundaries. 3D surface-rendered models of different anatomical structures were created in Mimics software. These 3D models were transferred to the design module 3-matic 16.0 (Materialise, Leuven, Belgium) in Mimics for the detailed modeling phase. We reconstructed anatomical structures such as optic nerve, optic chiasm, oculomotor nerve, trochlear nerve, branches of the ophthalmic nerve, abducens nerve, cavernous sinus, internal carotid artery, extraocular muscles, and ophthalmic veins. Digital data in 3-matic module were exported in 3D-PDF format (Online resource). This model allows for zoom, rotation and selective visualization of the structures (Supplementary Figure 1).

Bony Frame of the Superior Orbital Fissure

The SOF is an important cleft that connects the orbit with the middle cranial fossa. Behind the SOF is the cavernous sinus, and in front of it is the apex of the orbit. The SOF is a triangle wider on the medial, and narrower on the lateral. It extends downward from lateral to medial. The upper edge of the SOF is formed by the lower surface of the lesser wing, the anterior clinoid process, and the optic strut. The anterior clinoid process starts from the medial of the lesser wing and extends posteriorly, and is located at the junction of the medial and lateral parts of the SOF. The optic strut forms the upper medial wall of the fissure and separates the SOF from the optic canal. The upper part of the medial edge of the SOF is formed by the lateral edge of the optic strut, and the lower part by the body of the sphenoid. The anterior part of the carotid groove is located behind the medial edge of the SOF. The lower border of the SOF is formed by the greater wing of the sphenoid bone, and is located at the base of the middle cranial fossa. Its lower edge is separated from the foramen rotundum by a small piece of bone, which is called the maxillary strut [3-6].

Divisions of the Superior Orbital Fissure

Common tendinous ring (annulus of Zinn-CTR) is a ring that encloses the optic canal and the middle part of the SOF. Rectus muscles start from the margins of the CTR and extends to the anterior part of the orbit, attaching to the eyeball. The SOF is divided into 3 parts through the CTR: From its upper part; lacrimal, frontal, trochlear nerves and superior ophthalmic vein pass. Lacrimal nerve is located in the most lateral part of the upper part of the fissure, while frontal nerve is located more medial to the upper part. Trochlear nerve passes through the superomedial edge of the frontal nerve. Superior ophthalmic vein passes through the lower part of the lacrimal and frontal nerves and reaches the cavernous sinus. From the middle section; superior and inferior branches of the oculomotor nerve, nasociliary nerve, abducens nerve and sensory and sympathetic nerve fibers coming to the ciliary ganglion pass. From the lower boundary of middle section; inferior rectus muscle begins. The lower part of the SOF is located below the CTR and through it inferior ophthalmic vein passes. Orbital smooth muscles are found in the lower border of the lower part [3-6].

Cranial nerves passing through the Superior Orbital Fissure

Oculomotor nerve; carries somatomotor and parasympathetic fibers. Somatomotor fibers innervate the extraocular muscles except for the lateral rectus and superior oblique muscles. The parasympathetic fibers innervate the ciliary and sphincter pupillae muscles. It leaves the brainstem through the interpeduncular fossa and pierces the dura mater and enters the cavernous sinus. It runs superiorly on the lateral wall of the cavernous sinus. The oculomotor nerve receives sensory branches from the ophthalmic nerve and postganglionic sympathetic fibers from the internal carotid plexus, when it is inside the cavernous sinus. As soon as it exits the cavernous sinus, it divides into two branches, superior and inferior. These two branches pass through the middle part of the SOF and enter the orbital cavity.

Trochlear nerve; is a somatomotor nerve that innervates only the superior oblique muscle. After leaving the brainstem posteriorly, it moves forward and penetrates the dura mater and enters the cavernous sinus. On the lateral wall of the cavernous sinus, it runs under the oculomotor nerve. The trochlear nerve receives sensory branches from the ophthalmic nerve and postganglionic sympathetic fibers from the internal carotid plexus, when it is inside the cavernous sinus. After exiting the cavernous sinus, it crosses the oculomotor nerve, passes the upper part of the SOF, and enters the orbital cavity. After entering the orbit, it extends medially and innervates the superior oblique muscle.

Ophthalmic nerve; is a branch of the trigeminal nerve and contains only sensory fibers. This nerve receives general sensation from the eyeball, conjunctiva, lacrimal gland, paranasal sinuses, nasal mucosa, upper eyelids, forehead and anterior part of the scalp. It leaves from the upper-inner part of the trigeminal ganglion and pierces the dura mater and enters the cavernous sinus. It runs on the lateral wall of the cavernous sinus, below the trochlear and oculomotor nerves. Ophthalmic nerve leaves the cavernous sinus and gives off the recurrent meningeal branch at the level of the SOF and then divides into lacrimal, frontal and nasociliary branches. Lacrimal and frontal nerves pass through the upper part of the SOF and the nasociliary nerve passes through the middle part of it and all three branches enter the orbit.

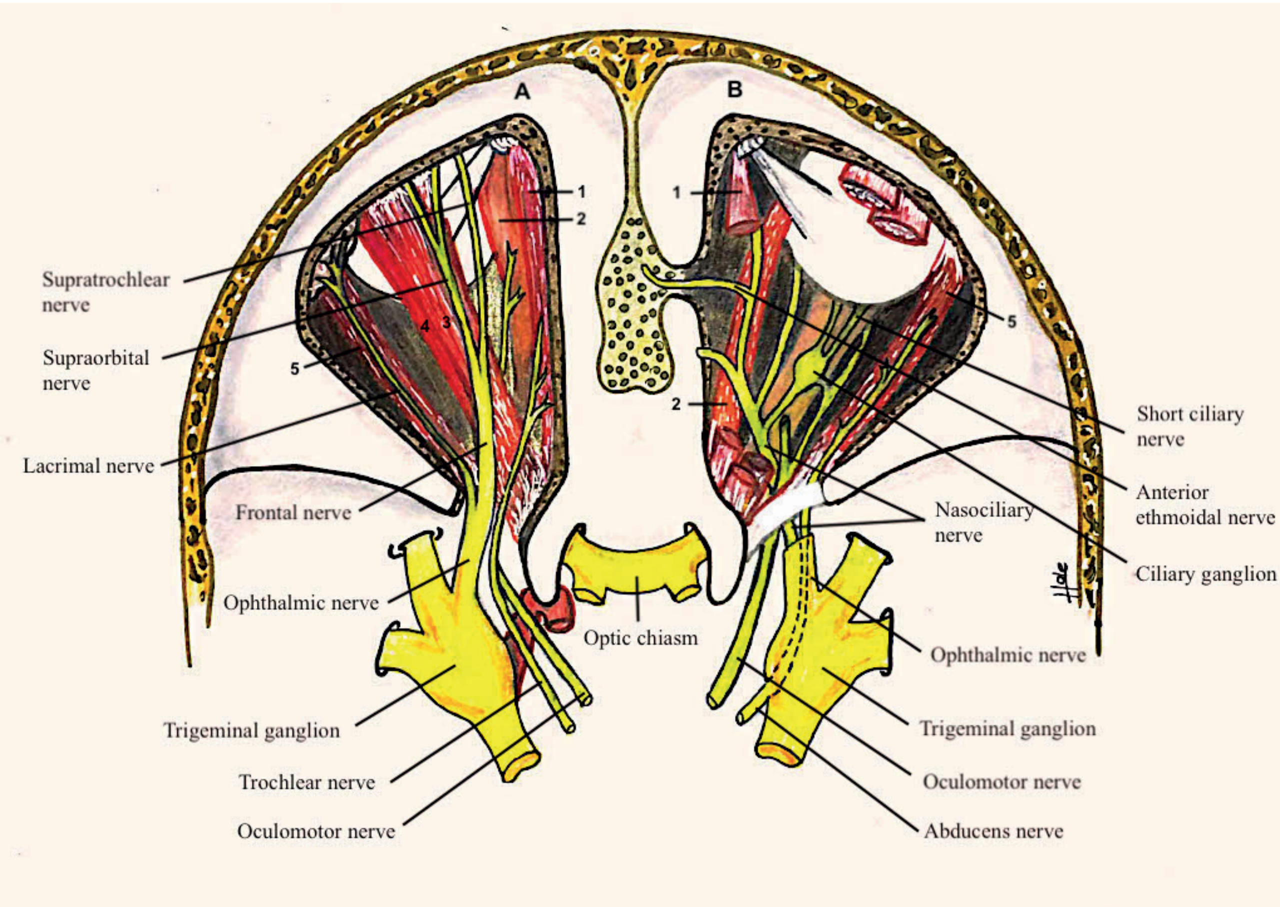

Figure 1. The illustration demonstrates the structures passing through the upper part of the superior orbital fissure (**a**). The illustration demonstrates the structures passing through the middle part of the superior orbital fissure (**b**). (**1:** Superior oblique muscle. **2:** Medial rectus muscle. **3:** Levator palpebrae superioris muscle. **4:** Superior rectus muscle. **5:** Lateral rectus muscle)

Abducens nerve; is a somatomotor nerve that innervates only the lateral rectus muscle. After leaving the brainstem from the bulbopontine groove, it moves forward and penetrates the cavernous sinus by piercing the dura mater. When inside the cavernous sinus, it runs medial to the ophthalmic nerve and lateral to the internal carotid artery. The abducens nerve receives sensory branches from the ophthalmic nerve and postganglionic sympathetic fibers from the internal carotid plexus, when it is inside the cavernous sinus. After exiting the cavernous sinus, it passes through the middle part of the SOF and enters the orbit and innervates the lateral rectus muscle. When passing through the SOF, it courses below the nasociliary nerve and extends laterally (Figure 1) (Supplementary Figure 2)[3-8].

One of the studies evaluating the neural contents of SOF was conducted by Natori and Rhoton [7] in 1995. In this study, 30 SOF dissections were performed on 15 cadavers and the relationships between the nerves and venous structures in the SOF were described in detail. They also measured the distances of these structures to the upper and medial edge of the SOF. As a result of the measurement; the distances to the upper edge and medial edge of the SOF are 1.4 and 3.2 mm for the superior branch of the oculomotor nerve, 3.5 and 3.2 mm for the inferior branch, 2.8 and 4.4 mm for the nasociliary nerve, 4.8 and 5.8 mm for the abducens nerve, 0.6 and 10.9 mm for the superior ophthalmic vein, respectively. The distance of the frontal nerve to the medial edge of the SOF is 6.3 mm, of the trochlear nerve was found to be 4.8 mm. Another study was performed by Shi et al. [8] in 2007. In this study, 36 SOF dissections were performed with the fronto-orbital craniotomy approach and the diameters of the cranial nerves in the fissure and their distances to the fissure margins were measured. As a result of the measurements made; diameter of the superior branch of the oculomotor nerve 1.16 ± 0.21 mm, diameter of inferior branch 1.74 ± 0.26 mm, trochlear nerve diameter 0.85 ± 0.19 mm, lacrimal nerve diameter 0.71 ± 0.26 mm, frontal nerve diameter 1.65 ± 0.43 mm, nasociliary nerve diameter 0.79 ± 0.16 mm and the diameter of abducens nerve was found to be 1.08 ± 0.17 mm. Gövsa et al. [2] examined 57 dry sphenoid bones, 102 skull bases and 58 formalin-fixed cadavers in 1999 to evaluate the SOF anatomy. They examined the shape of the SOF and measured the edge lengths of the fissure. The length of the upper edge of the SOF is 17.3 mm on the right, 16.9 mm on the left. They measured the length of the lower border of the SOF 20.8 mm on the right and 20.1 mm on the left, and the length of the medial edge of the SOF was found 9.5 mm on the right and 9.0 mm on the left.

Arterial anatomy in and around the superior orbital fissure

Any major artery does not pass through the SOF, but it is closely related to the internal carotid artery as shown in the 3D-PDF model (Online resource). The anterior curve of the cavernous segment of the internal carotid artery lies behind the medial edge of the SOF. The internal carotid artery projects along the posterior margin of the optic strut. It then turns upward along the medial edge of the anterior clinoid process and enters the subarachnoid space (Supplementary Figure 3).

Arterial blood supply to the margins of the SOF is via small branches of many arteries. These arteries are; anterior branch of the middle meningeal, recurrent meningeal branch of the ophthalmic, meningeal branches of the internal carotid, tentorial branch of the meningohypophyseal trunk, anterior branch of the inferolateral trunk and the terminal branches of the maxillary artery [7]. The recurrent meningeal branch, which passes lateral side of the upper part of the SOF, is a small branch and often arises from the lacrimal artery. After this artery passes the SOF, it anastomoses with the orbital branches of the middle meningeal artery in the middle cranial fossa [5,9,10]. The inferolateral trunk is one of the important branches of the cavernous segment of the internal carotid artery. It provides blood supply to the oculomotor, trochlear, trigeminal and abducens nerves during their course in the SOF and cavernous sinus. While it is difficult to see angiographically in healthy individuals, it becomes more visible in pathologies such as vascular malformations or tumors. Three branches are defined as anterior, superior, and posterior. Special attention should be given to the inferolateral trunk in skull base surgeries and endovascular interventional treatments, as it provides blood supply to the cranial nerves [11,12].

In 2015, a separate artery passing through the SOF was defined by Kiyosue et al. [13] and this artery was named the "Artery of the SOF". It arises from the maxillary artery either singly or from a common trunk with the artery of the foramen rotundum. It rises upward towards the apex of the orbit and turns posteriorly to enter the cavernous sinus. Within the cavernous sinus, it anastomoses with the anteromedial branch of the inferolateral trunk. It is found more prominent in internal carotid artery stenoses/occlusions and parasellar hypervascular lesions [13].

In addition to these small arteries passing through the SOF, there are numerous intracranial-extracranial anastomoses around it. While extracranial branches originate from the maxillary artery, intracranial branches arise from the inferolateral trunk or the ophthalmic artery. Widespread anastomoses were found in this region between the middle meningeal branch of the maxillary artery and the ophthalmic artery, between the middle meningeal and the cavernous branches of the inferolateral trunk, between the accessory meningeal and the artery of the foramen ovale, between the vidian artery and the petrous internal carotid artery and between the artery of the foramen rotundum and the inferolateral trunk [14]. Surgical and radiological identification of the anastomoses in this region and the evaluating of the arteries passing through the SOF are important to minimize the complications that may occur.

Venous structures passing through the superior orbital fissure

The superior and inferior ophthalmic veins leave the orbit through the SOF to drain into the cavernous sinus. The anatomy of the superior and inferior ophthalmic veins is highly variable and differs from person to person. Therefore, there is a controversial on their number, pattern, and nomenclature in the literature [15]. The facial and intracranial veins connect with each other through the superior and inferior ophthalmic veins. **Superior ophthalmic vein;** has a similar course to the ophthalmic artery. It lies between the optic nerve and superior rectus muscle. It extends posteriorly from the superolateral edge of the extraocular muscle cone and passes through the upper portion of the SOF. The medial palpebral, superior vortex, anterior ethmoidal, lacrimal, central retinal, muscular, and the inferior ophthalmic veins drain into this vein. The central retinal vein sometimes drain directly into the cavernous sinus. The superior ophthalmic vein drains into the cavernous sinus approximately 2.8 mm above the inferior margin of the SOF. **Inferior ophthalmic vein;** drains the inferomedial side of the orbit and extends posteriorly within the extraocular muscle cone. It leaves the extraocular muscle cone by passing between the lateral and inferior rectus muscles. It communicates with the pterygoid venous plexus through a branch that passes through the inferior orbital fissure. It courses below the CTR and leaves the orbit by passing through the lower part of the SOF. It drains into the antero-inferior portion of the cavernous sinus. It often joins with the superior ophthalmic vein before draining into the cavernous sinus.

The sylvian veins drain into the cavernous sinus after coursing along the intracranial portion of the lateral border of the SOF. In cases where the SOF is surgically reached, these sylvian veins should also be considered [5,7].

The relationship between the SOF and dura mater

The dura mater surrounding the middle cranial fossa and cavernous sinus passes through the SOF and mixes with the orbital periosteum and CTR in the orbit [7]. Fukuda et al. [16] mentioned the importance of a dura mater that extends from the frontotemporal basal dura to the orbital periosteum and called "**meningo-orbital band**". It is located on the lateral edge of the upper part of the SOF and can be seen during the pterional craniotomy. This band prevents surgical access to deep structures during the pterional craniotomy. Fukuda et al. [16] advised cutting this band in patients planned for extradural anterior clinoidectomy. They performed the detachment of the meningo-orbital band in 4 stages: 1. Partial removal of the lateral wall of the SOF, 2. Incising the lateral periosteal dura of the SOF, 3. Detachment of the meningeal dura of the temporal lobe from the inner cavernous membrane, 4. Removal of the meningo-orbital band from the orbital periosteum. Testing the safety of meningo-orbital band detachment steps in future studies will be an important contribution to the surgical practice.

Radiological Anatomy of the Superior Orbital Fissure

The studies related with the SOF were done mostly on cadavers. Radiological studies examined SOF have often been performed on computed tomography

(CT) images. La Marra et al. [17] examined the CT images of 84 patients aged 25-90 years in their study. They measured the area of the SOF and the distance of the SOF from the substantia nigra. They found the SOF area 69.2 ± 15.8 mm2 in men and 56.8 ± 11.9 mm2 in women. They measured the distance of SOF from the substantia nigra as 38.4 ± 7.6 mm in men and 36.5 ± 6.1 mm in women. Park et al. [18] also analyzed CT images of 142 patients and measured the width of the SOF. They found the width of the SOF 3.79 ± 0.93 mm in men and 3.65 ± 1.26 mm in women. The radiological anatomy of SOF in normal and pathological conditions is still an under-studied subject in the literature. There is a need for more detailed studies related to SOF enriching with anatomic models and including pathological conditions.

CONCLUSION

The SOF is a complex cleft that gives passage the oculomotor, trochlear, ophthalmic, abducens nerves and orbital veins. The radiological anatomy of the SOF in normal and pathological conditions is still an under-studied subject in the literature. There is a need for more detailed studies related to SOF enriching with anatomic models and including pathological conditions. The 3D-PDF model of the SOF is an innovative tool to enhance the knowledge of the anatomical structures related with this region. Better understanding of this critical region is necessary to perform safe and successful surgical procedures.

Online Resource

The 3D-PDF model demonstrates the neurovascular contents passing through the superior orbital fissure and structures locating closely to the fissure. The 3D-PDF model allows for zoom, rotation, and selective visualization of the structures.

Available at: https://actamedica.org/index.php/actamedica/article/view/907/668

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Author contribution

Study conception and design: HAA, ŞH and İT; data collection: HAA, OT and İT; analysis and interpretation of results: HAA, ŞH and İT; draft manuscript preparation: HAA and İT. All authors reviewed the results and approved the final version of the manuscript.

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Conflict of interest

The authors declare that there is no conflict of interest.

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