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Authors: Hakan Kına, Ayşegül Ayran, İsmet Demirtaş

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Hakan Kına[1], Ayşegül Ayran[2], İsmet Demirtaş[2]

[1]Department of Neurosurgery, Istinye University Medical Park Gaziosmanpasa Hospital, Gaziosmanpaşa, Istanbul, Turkey

[2]Department of Anatomy, School of Medicine, Istinye University, Zeytinburnu, Istanbul, Turkey

Address for correspondence: İsmet Demirtaş, Department of Anatomy, School of Medicine, Istinye University, İstinye Üniversitesi Topkapı Kampüsü, Maltepe Mah., Teyyareci Sami Sk., No.3 Zeytinburnu, İstanbul, Turkey 34010, tel: +90 850 283 60 00, e-mail: ismetdemirtas21@gmail.com

Assistant Professor Hakan Kına – Orcid No: 0000-0002-9741-7720

Research Assistant Ayşegül Ayran - Orcid No: 0000-0002-6789-1296

Assistant Professor İsmet Demirtaş - Orcid No: 0000-0001-5789-6985

ABSTRACT

Background: The endoscopic endonasal approach is common in the treatment of pathologies in and around the cavernous sinus. This cadaveric study aims to examine the anatomy of the cavernous sinus to guide endoscopic studies and determine points to consider during surgical approaches.

Materials and methods: For this study, a total of seven cadavers, four male and three female, were injected with colored silicone and dissections were performed under the microscope. The characteristics of the surgical corridors encountered during the

transsphenoidal, transsellar and transcavernous approaches were examined and their images were recorded.
Results: The stages and limitations of surgical approaches to the cavernous sinus in cadavers are presented. The anatomical features of the triangles defined in the cavernous sinus and the structures they contain are explained. The surgical field formed by clinoidal and anteromedial triangles was determined could be used effectively to reach cavernous sinus pathologies during endoscopic endonasal interventions. It was also observed that supratrochlear and infratrochlear triangles are dangerous for such surgical interventions.
Conclusions: The detailed anatomical features revealed on the cadaver related to the cavernous sinus in our study are valuable in terms of preventing complications that may occur during surgical interventions.
Key words: cadaver, endoscopic endonasal, transcavernous approach, transsphenoidal surgery, cranial nerves, internal carotid artery

INTRODUCTION

The cavernous sinus (CS) has a complex anatomical structure and contains many important neurovascular structures. In addition to the venous vascular network, the internal carotid artery (ICA) and abducens nerve pass through the CS, which has four walls surrounded by the dura mater. Its lateral wall, from top to bottom, contains oculomotor, trochlear, ophthalmic and maxillary nerves [2]. Its medial wall is adjacent to the sella turcica and the sphenoidal sinus [30]. All these structures are at risk of being damaged during surgical procedures involving the CS and surrounding areas [19, 28].

CS was considered a "no man's land" for many years until Parkinson (1965) performed a microsurgical approach to this area in 1965 and explained its surgical anatomy [24]. Repeated surgical interventions over the years have demonstrated that the CS and its surroundings are surgically accessible. However, it has been reported that transcranial methods cause damage to important neurovascular structures. Since this method has a high morbidity rate, it has been avoided by surgeons over time [9].

Various endoscopic endonasal methods have been described in the last 30 years and these methods have begun to replace the open surgical approach [14]. The development of transsphenoidal and transmaxillary endoscopic techniques has made safe access to many parts of the CS possible. The identification of different surgical corridors in the studies [6, 8, 18, 27, 32] provided endoscopic access to CS and its surroundings.

Widespread application of the transcavernous approach by surgeons has facilitated access to tumors located in and around the CS [20, 32]. While midline interventions were frequently performed in previous years, the application of extended endoscopic endonasal approaches allowed surgical access to the lateral portions of the CS [21]. The triangular fields formed between the anatomical structures on the CS contributed to the understanding of the anatomical neighborhoods observed in the endoscopic interventions [1]. However, neurovascular structures within these defined areas should be examined from different perspectives in order to safely perform minimally invasive surgical interventions.

This study explains in detail the anatomy of the CS and the complex neurovascular structures encountered during endoscopic endonasal surgical interventions, thus minimizing the risk of complications that may occur during minimally invasive surgical procedures.

MATERIALS AND METHODS

This research was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of Prof. Dr. Mazhar Osman Mental Health and Neurological Diseases Training and Research Hospital (Date: 06.09.2016 / Ethics approval number: 571).

A total of seven adult cadavers, four male and three female are dissected and prepared for further examination. The cadavers of adults over the age of 18 who had not undergone previous craniofacial surgery were included in the study. Disruption of the integrity of the skull base anatomy and severe damage to the bone and mucosal tissue were determined as exclusion criteria. The study was carried out in the Microneurosurgery and Neuroanatomy Laboratory of Cerrahpaşa Medical Faculty between October and December 2016.

All cadavers were injected with silicone dye and preserved in 75% alcohol. During the preparation phase, the cadavers were positioned supine. A microscope unit was placed in front of the surgeon. After a surgical drill and aspirator were placed, the procedure was initiated. Dissections were performed using a microsurgery kit with a microscope (Zeiss OPMI Pico, Oberkochen, Germany) at 4x and 40x magnification. The high-speed surgical drill (Medtronic, USA) and an angled drill bit were used for the drilling process. The skull base images of the cadavers were obtained using a macro lens camera (Canon EOS 650 D, Tokyo, Japan).

The heads of the cadavers were fixed on the table using a 15-degree flexion position. The skin and subcutaneous tissue up to the orbicularis oculi muscle superiorly, the maxillary sinus inferiorly, and the malar eminence inferiorly and laterally were passed. The nasal septum was preserved, and the ala of the nose was removed. Then, the anterior wall of the maxillary sinus was drilled superiorly to the level of the maxillary nerve. The maxillary sinus mucosa and medial wall were removed, preserving the inferior nasal concha. The nasal septum was removed. The parts of the nasal conchae, except for the bone attachment areas, were excised to permit wider surgical exploration. The posterior wall of the maxillary sinus was removed with a drill and the pterygopalatine fossa was reached. An anterior sphenoidotomy was performed. The sinus mucosa and sphenoid septum were removed. Surgical margins were determined by imaging the base of the sella, sphenoidal plane, clivus, opticocarotid recess, optic protuberance and carotid protuberance. After the pterygoid process resection, the surgical anatomy of the sphenoidal sinus lateral wall, Meckel's cave, CS, ICA, and the pathways to the petrous apex were examined.

RESULTS

After the alae of the nose of the cadavers were removed, the medial nasal septum and the lateral middle and inferior nasal concha were detected. During endoscopic endonasal surgery, it's critical to stay oriented so as not to gravitate towards the anterior cranial fossa. One of the important anatomical structures for orientation is the choana; following choana localization, the inferior, middle, superior and, if present, supreme nasal concha should be defined.

Lateral to the middle nasal concha, the uncinate process anteriorly and ethmoidal bulla posteriorly were exposed. Maxillary hiatus was observed in the middle or posterior 1/3 parts of the ethmoidal bulla. The choana was seen postero-inferior to the nasal cavity, posterior to the inferior nasal concha, and medial to the vomer.

One of the structures encountered in the first stage of surgery is the nasal septum, which consists of cartilage anteriorly and bone posteriorly. Most surgical approaches require a posterior nasal septectomy [23]. The spheno-ethmoidal recess, where the sphenoidal sinus is opened, is one of the structures used to locate the sinus during surgery. If the sphenoethmoidal recess is followed superiorly to the choana, the opening of the sphenoidal sinus is reached [29].

Transsphenoidal approach

Without resection of the nasal septum, the middle and superior nasal concha was retracted laterally, and bilateral openings of sphenoidal sinuses were found. The opening of the sphenoidal sinus was detected just infero-medial to the superior nasal concha. As a result of the measurements, the opening of the sphenoidal sinus was determined approximately 15 mm superior to the choana or in the middle of the distance between the nasal septum and the superior nasal concha.

Conchae were resected bilaterally, and after the nasal septum mucosa was scraped subperiosteally, total nasal septectomy was performed. Both openings of sphenoidal sinuses were joined (Fig. 1). Intersphenoid septums were resected. During dissection of the inferolateral part of the sphenoidal sinus, care should be taken not to damage the vidian nerve and the sphenopalatine artery. The sphenopalatine artery was located in the inferolateral corner of the sphenoidal sinus and approximately 1 cm anterior to the posterior border of the middle nasal concha. The sphenoidal sinus was enlarged until the sphenoidal plane and anterior skull base in the superior, the sella in the postero-superior, the clival recess in the postero-inferior, and both paraclival carotid protuberances in the lateral appeared (Fig. 2). The opening of sphenoidal sinuses was seen just above and medial to the insertion site of the superior nasal concha in four of seven cadavers.

Transsellar approach

The sellar fossa was enlarged with a 3 mm drill and the sellar dura was exposed (Fig. 3). Maximum care should be taken not to damage the CS and pituitary gland during drilling. In standard approaches to the sellar region, it is sufficient to limit dural exposure between the anterior intercavernous sinus superiorly and the inferior intercavernous sinus inferiorly. The sellar dura was opened in a rectangular shape, preserving the cavernous portion of the ICA, and the pituitary gland was exposed (Fig. 4). The neurohypophysis was revealed by retracting the pituitary gland superiorly. In addition, the pituitary gland was retracted medially, exposing the medial wall of the CS and the inferior hypophyseal artery. Then, the pituitary gland was resected and the sellar diaphragm was exposed.

Transcavernous approach

First of all, the conchae were resected to enlarge the surgical area. The medial and posterior walls of the maxillary sinus were removed. Sphenoidotomy was performed using the opening of the sphenoidal sinus as a landmark. Since the dura mater is thin and the nerves are just below this layer, particular care should be taken not to injure the abducens nerve at this stage. A periosteal incision was then made over the superior orbital fissure and the cavernous portion of the ICA (Fig. 5). After reaching the CS, the oculomotor, ophthalmic, and maxillary nerves were observed on the lateral wall. The abducens nerve and trigeminal ganglion were located on the medial wall. The trochlear nerve was not clearly seen from this angle.

The structures forming the borders of the triangles should be considered during the surgery and their course should be examined. The clinoidal triangle, which is defined as the region among the optic nerve, oculomotor nerve and ICA, was determined. Then, the anteromedial triangle located between the line connecting the ophthalmic nerve, maxillary nerve, foramen rotundum and superior orbital fissure was evaluated [4, 13].

When the dura on the CS was opened, the ophthalmic nerve was seen superiorly and the abducens nerve was observed just anteriorly to it. The maxillary nerve was traced backward from the foramen rotundum. It was observed that the V1 and V2 divisions of the trigeminal nerve merged in the trigeminal ganglion. After removing the bone and periosteum over the superior orbital fissure, the oculomotor nerve was exposed. The oculomotor, ophthalmic and abducens nerves entering the superior orbital fissure were seen. The trochlear nerve located posteriorly was observed after exclusion of the ophthalmic nerve.

The optic protuberance was drilled and traced up to the common tendinous ring, and the optic nerve was exposed. The supratrochlear triangle between the oculomotor nerve and the trochlear nerve was identified. Then, the infratrochlear triangle between the trochlear nerve and V1 division of the trigeminal nerve was exposed [13]. However, because it requires cranial nerve manipulation this was not evaluated as a surgical corridor that could be used with endoscopic endonasal methods (Fig. 6).

In order to expose the posterior part of the CS, the superior nasal concha and posterior part of the ethmoidal sinus were resected. The uncinate process was resected to expose its lateral wall. The base of the sella was resected towards the carotid prominence up to the pterygoid process, and the inferior of the CS was exposed. After exposure of the Vidian nerve, a triangular region was detected lateral to the ICA. This triangle was formed inferiorly by the vidian nerve. The lateral edge of the triangle is formed by the medial plate of the pterygoid process, and the medial edge by the ICA. After the dura covering the triangle was opened, oculomotor, abducens and maxillary nerves were exposed. The described CS sections were examined in detail with ICA exclusion.

DISCUSSION

While the first endoscopic studies generally addressed pituitary adenomas, over the years the surgical field has been expanded from anterior to posterior. Endoscopic surgery's success encouraged surgeons to use it in approaching lateral and posterior skull base lesions as well. To reach these regions, it was necessary to apply extended endoscopic endonasal methods [3].

Surgery to the CS region is challenging because of the important neurovascular structures in the sinus. The CS is generally divided into 4 compartments that include medial, lateral, anteroinferior, and postero-superior. Transsphenoidal [12], transmaxillary [5], and transethmoidal [7] approaches have been described to safely reach different parts of the CS and adjacent structures. While endoscopic midline transsphenoidal surgery is sufficient to reach the medial part of the CS, extended approaches are often needed to reach the lateral part.

The primary pathologies of CS are meningiomas, neurogenic tumors and hemangiomas. These pathologies mostly tend to locate in the lateral part of the CS.

Secondary tumors are pituitary adenomas, chordomas, chondrosarcomas, perineural spread of head and neck malignancies, and hematogenous spread of distant lesions. The localization of these pathologies can vary widely. Pituitary adenomas mostly involve the medial and postero-superior compartments, while chordomas and chondrosarcomas involve the antero-inferior compartment. The endonasal route is safer than other invasive procedures used to reach CS-invading lesions because of the intervention through the medial wall of the CS, which is devoid of cranial nerves [22].

There are some points to be considered during the endoscopic endonasal approach to CS. The meningeal wall of the CS has three weak points where tumors can invade more easily. These are the venous plexus around the superior orbital fissure, the medial wall adjacent to the pituitary gland, and the meningeal sheaths of the cranial nerves, where the dural layer is either very thin or absent [16]. Although there are two layers, meningeal and endosteal, on the lateral and superior walls of the CS, there is one layer on the medial wall [30]. In some cases, this layer is also absent or missing [10, 11]. Depending on the ICA localization, there are venous compartments of different shapes and sizes within the CS. These are called the superior, inferior, lateral, and medial compartments. While the venous space medial to the ICA is 48% dominant, the lateral venous space is 22% dominant [25]. In some cases, the pituitary gland may cover the intercavernous portion of the ICA with a protrusion [26].

Although the majority of nonfunctional pituitary adenomas are not aggressive or invasive, their spread into the CS can be explained by these features [31]. Due to the decompression of the sinuses after excision of the lesion, abundant venous bleeding may occur. These bleedings can be stopped by using suitable hemostatic materials. In addition, the risk of venous bleeding in endoscopic endonasal approaches is not different from the microscopic method [15]. Being away from the ICA and not damaging the cranial nerves below the dura is vital in removing the dura on the CS during the opening phase. The location of the tumor and the direction in which it displaces the ICA can be used to determine the opening of the dura.

In this study, first of all, the stages of transsphenoidal and transsellar approaches and points to be considered during the surgery were emphasized. Then, the surgical corridors encountered during the transcavernous stage were discussed. After opening the dura with the endoscopic endonasal method, the oculomotor nerve superiorly and the ophthalmic nerve inferiorly were identified. The abducens nerve was observed anterior and medial to the ophthalmic nerve, and the maxillary nerve was observed below it. The methods required for safe surgery were defined using the various sites and intervals in the CS.

Our study examined the clinoidal triangle, one of the smallest surgical fields defined in CS. Medial to the clinoidal triangle is the optic nerve, bounded by the optic canal, and lateral to it is a line drawn between the oculomotor nerve and the superior orbital fissure. The base of this triangle corresponds to the dura layer lying behind the medial and lateral border. The clinoidal triangle is where the oculomotor nerve meets the lateral CS. The oculomotor nerve then enters the superior orbital fissure under the anterior clinoid process and lateral to the ICA. The contents of the clinoidal triangle can be reached after drilling the anterior clinoid process with supraorbital approaches. The morphology of the venous structure in this part of the ICA is highly variable. The anteromedial triangle (Mullan's triangle) is located between the first two branches of the trigeminal nerve. The ophthalmic nerve is located in the medial border of this triangle and the maxillary nerve is located in the lateral border of this triangle. The base of the anteromedial triangle is the line connecting the point where the ophthalmic nerve passes through the superior orbital fissure and the point where the maxillary nerve passes through the foramen rotundum [4, 13]. Although the ICA covers most of the CS, the opening formed by the clinoidal and anteromedial triangle allows access to other structures and pathological formations within the CS. It was stated that these potential sites facilitate endoscopic endonasal access to the middle cranial fossa [17].

On the lateral wall of the CS, a supratrochlear triangle is formed between the oculomotor nerve medially and the trochlear nerve laterally. At the base of this triangle is the dura layer, which lies between the entry points of these two cranial nerves. This triangle is suitable for examining the intracavernous portion of the ICA. However, great care should be taken because of the possibility of bleeding that can be caused by the meningohypophyseal trunk. This vein should be identified as a priority during interventions. The infratrochlear triangle (Parkinson's triangle) was defined by Parkinson in 1965 with the aim of safely reaching the lesions in the CS [24]. The medial border of this triangle is formed by the inferior surface of the trochlear nerve on the lateral wall of the CS from the sinus entrance to its exit. On the lateral border of the infratrochlear triangle is the superior surface of the ophthalmic nerve [4, 13]. Reaching the supratrochlear triangle and the infratrochlear triangle is seen as dangerous because they are narrowed by the cranial nerves. The anterior part of these two triangles is narrow and their posterior part is wide, but the abducens nerve limits the forward passage [17]. Similarly, during this cadaveric study, it was observed that the supratrochlear and infratrochlear triangles were not suitable for endoscopic endonasal approaches.

CONCLUSIONS

In this cadaveric study, the anatomy of the CS and the surgical sites encountered during endoscopic endonasal interventions in this region were examined. The limitations of surgical techniques and the points to be considered were described. Detailed information and recommendations needed to reduce complications that may occur during the treatment of various lesions encountered in CS were presented.

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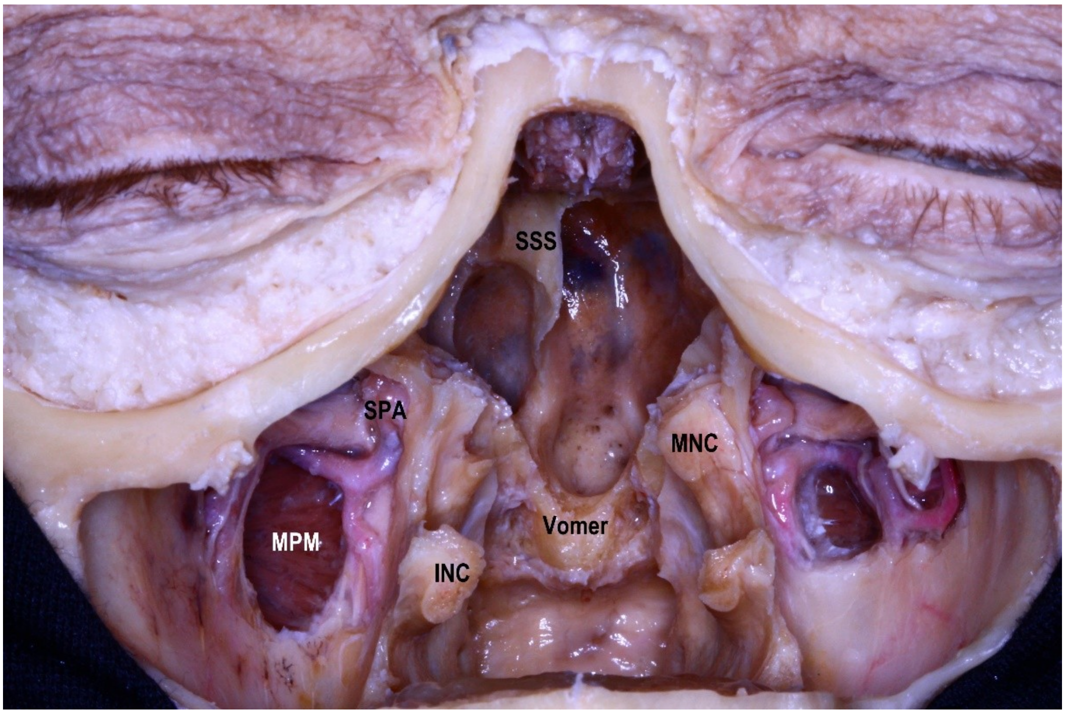

Figure 1. The anterior wall of the sphenoidal sinus was drilled to reach the sinus. Anterior sphenoidotomy was performed by drilling the inferior of the opening of the sphenoidal sinus to reveal the relationship between the opening of the sphenoidal sinus and the sella. It was observed that the opening of the sphenoidal sinus was at the same level as the base of the sella. After the sphenoidal sinus mucosa was removed, a septum directed towards the right carotid protuberance was seen. MNC: middle nasal concha, INC: inferior nasal concha, SSS: septum of sphenoidal sinuses, SPA: sphenopalatine artery, MPM: medial pterygoid muscle.

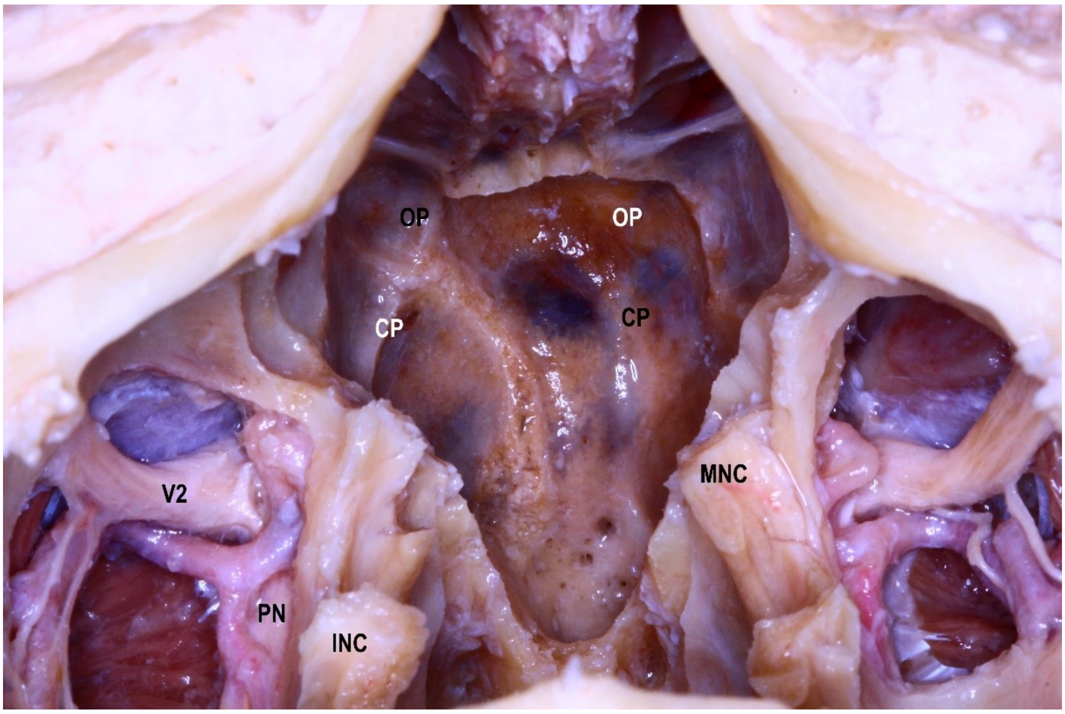

Figure 2. Some important points during the surgery were detected in the sellar type sphenoidal sinus. Carotid protuberance formed by the sellar prominence in the midline in the coronal plane and by the ICA in the antero-lateral of the sella was observed. Anterior to this prominence is the optic prominence. An opticocarotid recess was observed in the pit area between the optic protuberance and the carotid protuberance. MNC: middle nasal concha, INC: inferior nasal concha, OP: optic protuberance, CP: carotid protuberance, PN: palatine nerves, V2: maxillary nerve.

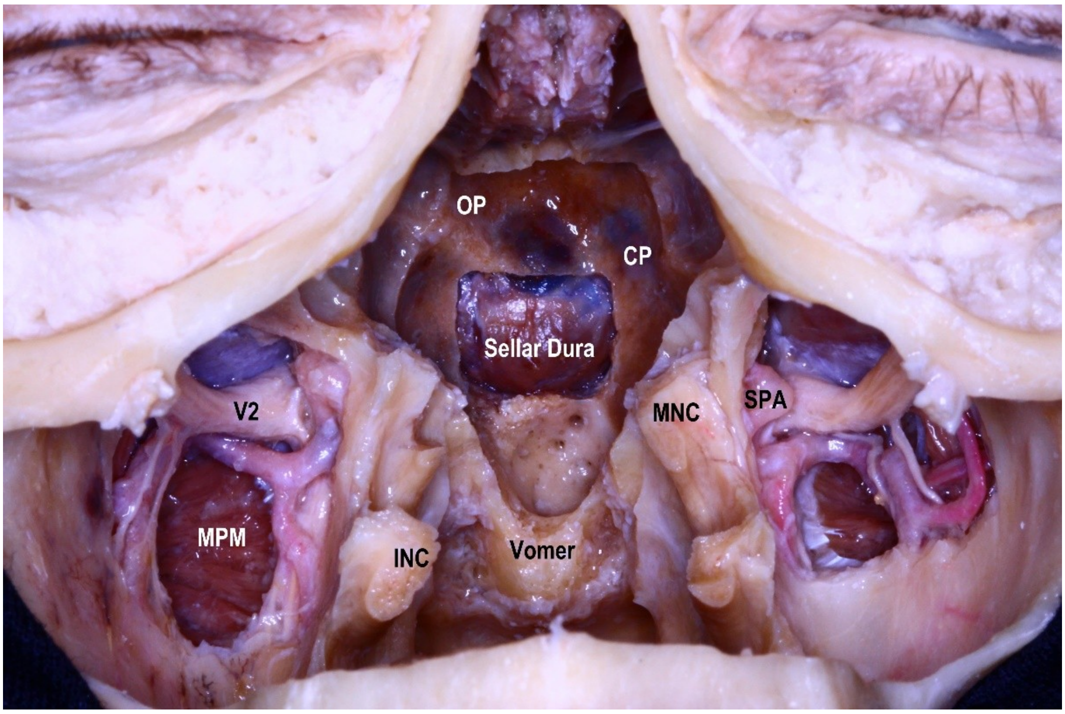

Figure 3. The anterior wall of the rectangular sella turcica was opened at the border of the anterior and inferior intercavernous sinuses. Medial opticocarotid recess (MOR) and lateral opticocarotid recess (LOR) were observed within the sinus. MOR was seen as a pit at the junction of the paraclinoid ICA, which was the optic nerve. LOR was observed lateral to the carotid protuberance and inferior to the optic canal. The clival recess starts from the dorsum sella at the posterior border of the sella turcica and extends to the inferior wall of the sphenoidal sinus. Laterally, it is surrounded by carotid protuberances. MNC: middle nasal concha, INC: inferior nasal concha, OP: optic protuberance, CP: carotid protuberance, V2: maxillary nerve, SPA: sphenopalatine artery, MPM: medial pterygoid muscle.

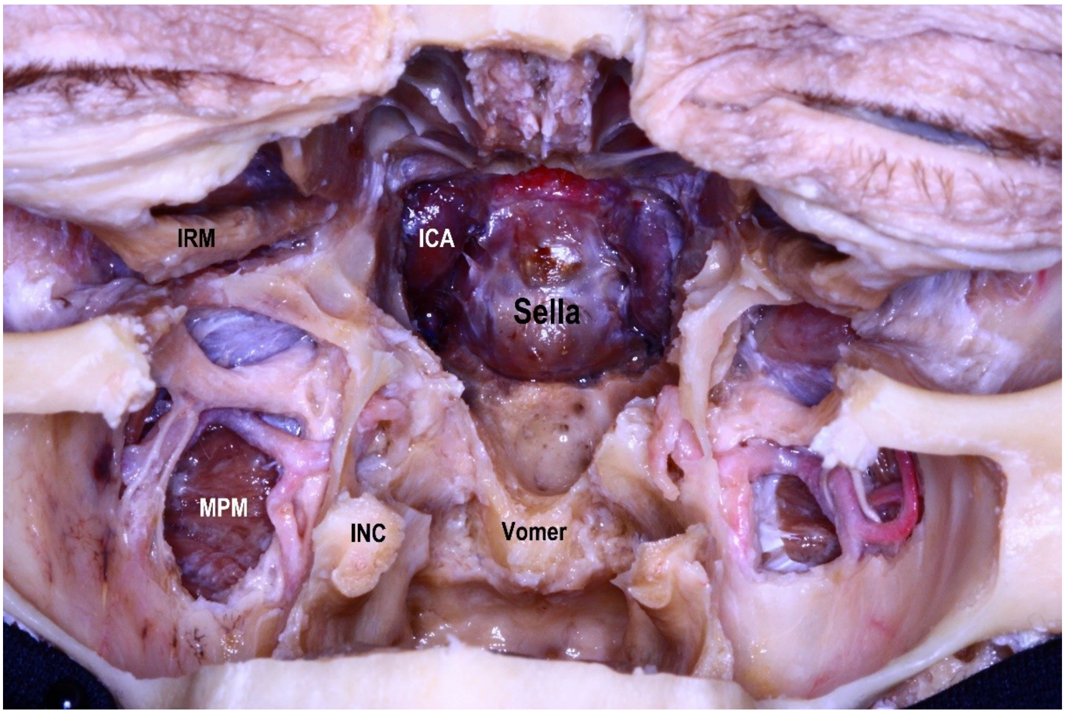

Figure 4. For extensive exploration, the hypophyseal fossa was opened lateral to both cavernous ICAs laterally and posterior to the level of the optic chiasm superiorly. Maximum care should be taken against ICA damage while the lateral border is being excised with the aid of a drill. INC: inferior nasal concha, MPM: medial pterygoid muscle, ICA: internal carotid artery, IRM: inferior rectus muscle.

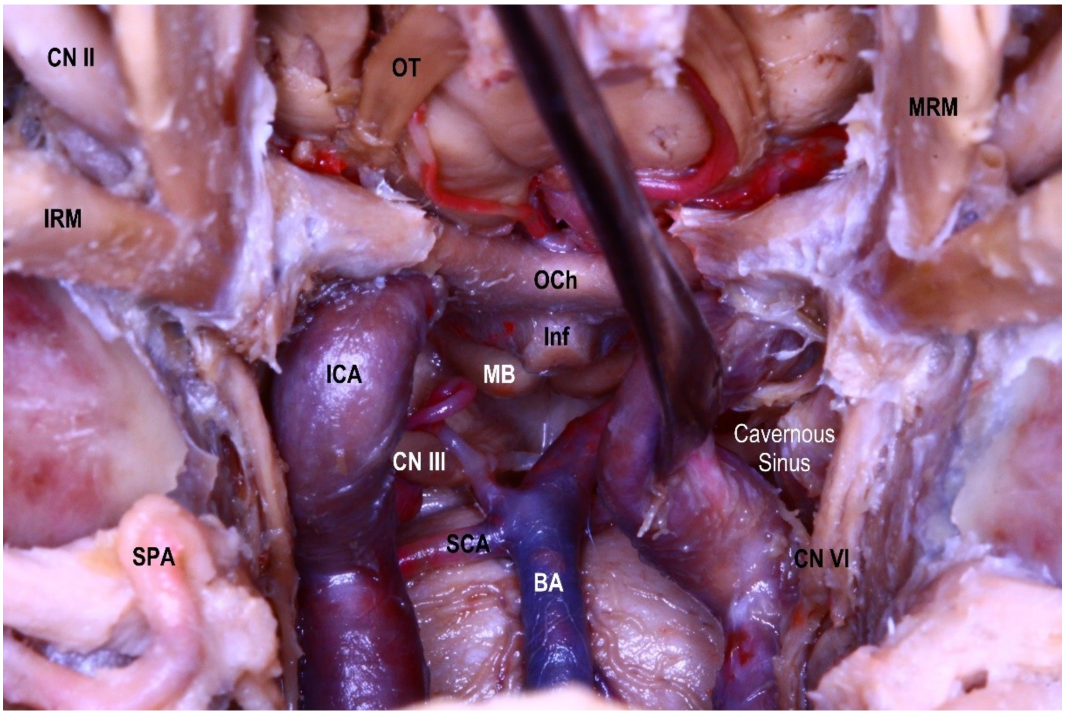

Figure 5. After the periosteum on the CS was removed and the ICA was retracted medially, the inside of the sinus was reached. The oculomotor, ophthalmic and maxillary nerves are located on the lateral wall, while the abducens nerve and trigeminal ganglion are located on the medial wall. The trochlear nerve is not usually seen from this angle. In the region among the optic nerve, oculomotor nerve and ICA, the clinoidal triangle is detected. The anteromedial triangle is examined in the area between the line joining the ophthalmic nerve, maxillary nerve, foramen rotundum and superior orbital fissure. OT: olfactory tract, CN II: optic nerve, CN III: oculomotor nerve, SPA: sphenopalatine artery, BA: basilar artery, SCA: superior cerebellar artery, CN VI: abducens nerve, MB: mammillary body, Inf: infundibulum, MRM: medial rectus muscle, IRM: inferior rectus muscle, ICA: internal carotid artery, OCh: optic chiasm.

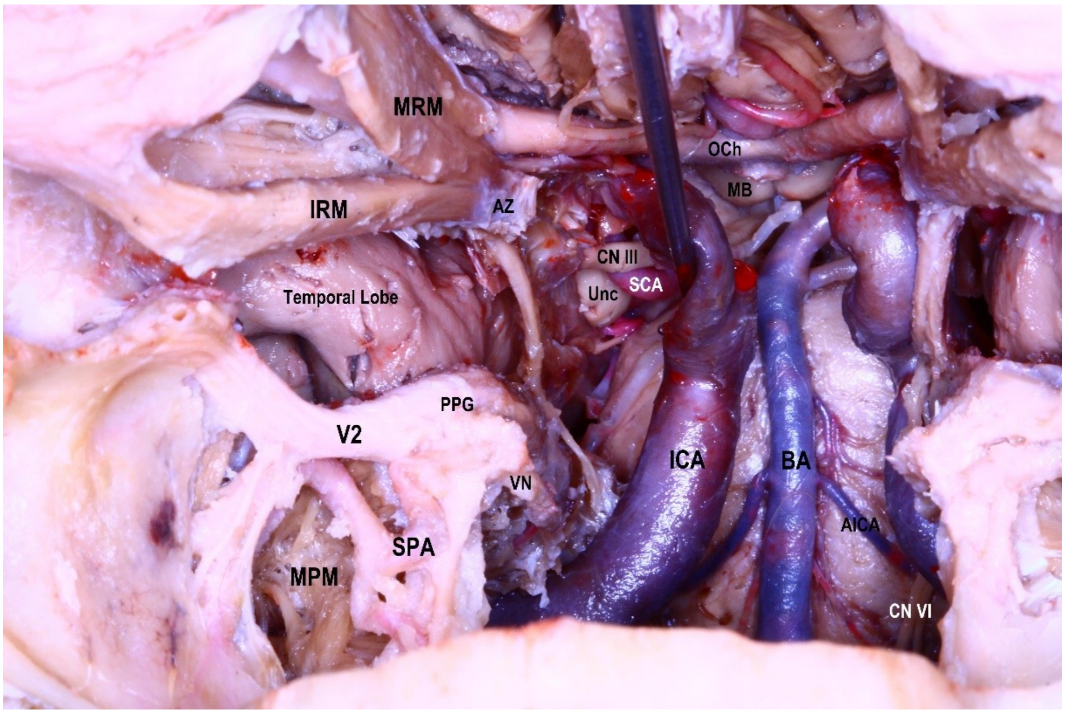

Figure 6. The oculomotor nerve, ophthalmic and abducens nerve in the CS are seen. The trochlear nerve is not seen from the anterior view in the endoscopic endonasal approach. The most superficial region contains the abducens nerve. The ophthalmic nerve is located below the abducens nerve and the trochlear nerve is located posterior to these; therefore, the structure with the least risk of injury in lateral skull base approaches is the trochlear nerve. When the ophthalmic nerve is retracted to the inferior, there is the oculomotor nerve, the trochlear nerve, and the supratrochlear triangle located between the dura layers of these two nerves. When the ophthalmic nerve is pulled up, the infratrochlear triangle becomes visible. CN III: oculomotor nerve, V2: Maxillary nerve, SPA: sphenopalatine artery, BA: basilar artery, SCA: superior cerebellar artery, AICA: anterior inferior cerebellar artery, CN VI: abducens nerve, MB: mammillary body MRM: medial rectus muscle, IRM: inferior rectus muscle, PPG: pterygopalatine ganglion, MPM: medial pterygoid muscle, VN: vidian nerve, Unc: uncus of the temporal lobe, OCh: optic chiasm, ICA: internal carotid artery, AZ: annulus of Zinn.