Vinko V. Dolenc

Anatomy and Surgery of the Cavernous Sinus

Foreword by Mahmut G. Yaşargil

Springer-Verlag Wien New York

Vinko V. Dolenc, M.D., Ph.D.
Professor and Chairman
University Department of Neurosurgery
University Medical Center
Ljubljana, Slovenia, Yugoslavia

Softcover reprint of the hardcover 1st edition 1989

With 182 Figures (126 in color)

ISBN-13: 978-3-7091-7442-5 e-ISBN-13: 978-3-7091-6942-1
DOI: 10.1007/978-3-7091-6942-1

Foreword

The decision of Harvey Cushing to leave general surgery and concentrate on the infant field of central nervous system surgery was in retrospect a landmark in the history of neurosurgery. His concentrated work, and also that of his colleague Walter Dandy, originated with the desires of both pioneers to understand surgical anatomy and neurophysiology. The fundamental knowledge and surgical techniques that they provided became the standard of excellence for several generations of neurosurgeons; so much so that the general belief was that the surgical techniques could not be improved upon.

Twenty-five to thirty years ago microtechniques began to appear in a few surgical research centers, they were then gradually applied to clinical neurosurgery and have contributed to a new level of understanding in surgical anatomy and neurophysiology. We are now fortunate to have a new standard of morbidity and mortality in the surgical treatment of intrathecal aneurysms, angiomas, and tumors. It has been said that microneurosurgery was reaching its limits, especially when treating lesions in and around the cavernous sinus and skull base; those lesions notorious for involvement of the dural and extradural compartments, with a tendency to infiltrate adjacent nerves and blood vessels. The dangers of uncontrollable hemorrhage from the basal sinuses and post-operative CSF rhinorrhea appeared unsurmountable. The lateral aspects of the petro-clival region have been of interest to a few pioneering ENT surgeons and neurosurgeons but the cavernous sinus in most respects has remained the final unconquered summit.

There have been some admirable approaches and results in surgery of the cavernous sinus, but broad clinical experience and precise surgical anatomic descriptions were missing; Professor Dolenc now presents such a pioneering work on the microanatomy and surgical compartments of this complex region. In addition, he provides new insight into the hemodynamic control of the petrous and intracavernous segments of the carotid artery, hemostatic control of the venous sinuses, and techniques for avoiding CSF rhinorrhea. The clinical sections convincingly demonstrate the effectiveness of this approach and characterize some of the remaining unsolved problems. There is no doubt that this type of microsurgical anatomy study is a new step in the 100 year history of neurosurgery. Finally, this work reconfirms the necessity for future generations of neurosurgeons to work in the microsurgery laboratory; not only for understanding the surgical anatomy, but to acquire the considerable technical skills necessary to perform surgical approaches of this complexity.

Zürich, August 10, 1989 *M. G. Yaşargil*

Acknowledgments

I should like to extend my thanks to Ms Jasna Ostanek for all the time and care that she devoted to the editorial work throughout the preparation of the text. I am grateful to Thomas Wascher, M.D., for his valuable contribution to the initial text. Special thanks are due to Mr Bojan P. Moll, to John Kagi, M.D., and to Dianne Jones, M.D., for reading the text.

I am particulary grateful to Ms Jolanda Kofol, professional medical photographer, and to Mr Bogo Zrimšek, professional medical illustrator, for preparing the figures.

The indispensable help of medical student David Čokl and Borut Prestor, M.D., in the preparation of fresh cadaver specimens for microanatomical dissections, is gratefully acknowledged.

Vinko V. Dolenc

Contents

Abbreviations

Cranial nerves

ON	Optic nerve
III	Oculomotor nerve
IV	Trochlear nerve
V	Trigeminal nerve
GG	Gasserian ganglion
V1	Ophthalmic division
V2	Maxillary division
V3	Mandibular division
Vm	Motor branch of the trigeminal nerve
VI	Abducens nerve

Internal carotid artery

ICA	Internal carotid artery
(AL)	Anterior loop
(ML)	Medial loop
(LL)	Lateral loop
(PL)	Posterior loop

Other structures

A	Aneurysm
ACA	Anterior cerebral artery
ACoA	Anterior communicating artery
ACP	Anterior clinoid process
ACT	Anterior clinoid tip
AICS	Anterior intercavernous sinus
APB	Apex of the petrous bone
BA	Basilar artery
BS	Bony sinus
BSt	Brain stem
CA	Capsular artery(-ies)
CON	Canal of the optic nerve
CV	Cerebral vein
DA	Dawson's artery(-ies)
DP(ON)	Dura propria (optic nerve)
DR	Distal ring
ES	Ethmoid sinus
FL	Frontal lobe
FLa	Foramen lacerum
FO	Foramen ovale
FR	Foramen rotundum
FS	Frontal sinus
FSp	Foramen spinosum
FT	Fatty tissue
GPN	Greater (superficial) petrosal nerve
ILT	Inferolateral trunk
IVW	Inner venous wall
LM	Lilieqvist membrane
LPN	Lesser (superficial) petrosal nerve
LR	Lateral ring
LW	Lateral wall
MCA	Middle cerebral artery
MCF	Middle cranial fossa
MHT	Meningohypophyseal trunk
MM	Mucous membrane
MMA	Middle meningeal artery
OA	Ophthalmic artery
OT	Optic tract
OV	Ophthalmic vein
OVW	Outer venous wall
PB	Pituitary body
PCL	Petroclival ligament
PCoA	Posterior communicating artery
PCP	Posterior clinoid process
PICS	Posterior intercavernous sinus
PR	Proximal ring
PS	Pituitary stalk
PV	Petrosal vein
SCA	Superior cerebellar artery
SF	Sylvian fissure
SN(N)	Sympathetic nerve(s)
SOF	Superior orbital fissure
SPS	Superior petrosal sinus
SW	Sphenoid wall

TA	Tentorial artery
TL	Temporal lobe
TM	Temporal muscle
TTM	Tensor tympani muscle

Introduction

The anatomy of the cavernous sinus is extremely interesting but owing to its tridimensional character rather complex and difficult to understand. There is considerable difference between studying these anatomical relationships with the naked eye and studying them under the microscope. Surgically valid descriptions of the cavernous sinus anatomy have begun to appear only since magnification has become available. And again, examining a fresh cadaver specimen of the parasellar region with arterial and venous injection is vastly different to examination without injection.

Formalin-fixed preparations are almost useless for studying surgical anatomy since the relations between the individual structures may be significantly changed, distorted or even obliterated. It is only a fresh cadaver specimen with proper arterial and venous injection which can offer tridimensional relationships almost identical to those found in a living cavernous sinus. Yet this is still a far cry from a cavernous sinus with all its intricate venous and arterial pulsations in living human beings. However, by studying the anatomy of a fresh cavernous sinus specimen with good arterial and venous injection one can glean useful basic information on the anatomy of the cavernous sinus – information which is a sine qua non for one confronted in the operating theatre with another completely distorted anatomy of a diseased cavernous sinus.

A descriptive system utilizing the simplest geometric figure, the triangle, has been devised to facilitate orientation in the intricate maze of anatomical structures abounding in the parasellar region. The idea was to divide the said region into three subregions and ten surgical triangles defined by constant anatomical landmarks. Approaches through these triangles allow access to lesions in the cavernous sinus with minimum risk. The pertinent microsurgical anatomy, the system of nomenclature, and the possible application of surgical approaches to cavernous sinus lesions are presented. The author sincerely hopes that his modest contribution will be of value to all those who are willing to study the anatomy of the cavernous sinus and are ready to apply their knowledge of the subject derived herefrom.

1.1 Anatomy of the cavernous sinus

The macroscopic and microscopic anatomy of the parasellar skull base region has been increasingly investigated in recent years. As a result, the intracavernous anatomy of the nerves III through VI, the internal carotid artery (ICA) with its branches, and the related osseous structures and adjacent dural folds are well described [3, 12, 21, 23, 25, 33–37, 41, 42, 47, 51].

The surgical anatomy of the parasellar and adjacent skull base regions can be systematically divided into three subregions composed of ten triangles: (A) Parasellar subregion: (1) anteromedial triangle, (2) paramedial triangle, (3) oculomotor trigone, and (4) Parkinson's triangle; (B) Middle cranial fossa subregion: (1) anterolateral triangle, (2) lateral triangle, (3) posterolateral (Glasscock's) triangle, and (4) posteromedial (Kawase's triangle); and (C) Paraclival subregion: (1) inferomedial triangle and (2) inferolateral (trigeminal) triangle: (i) osseous portion and (ii) tentorial portion.

The margins of each triangle are based on the constant anatomical relationships of the osseous, dural, vascular, and neural structures located within the parasellar, middle cranial fossa and paraclival subregions. The purpose of this description of surgical triangles on the osseous borders and on the dural walls of the cavernous sinus (CS) is to define the boundaries of the CS and the windows in its walls through which different vascular and tumorous lesions in the CS can be reached and removed without damage to the vascular and/or neural structures of the CS.

Materials and methods

Parasellar regions from cadaveric skull base bone blocks (each consisting of the sphenoid bone, sella, CSs, medial portions of the petrous bones, clivus, and related structures) were examined using opton OPMI1 and opton OPMI6-CPC microscopes under 5–40 power. Specimens were obtained only from cadavers without historical or autopsy evidence of intracranial disease. Cranial nerves were divided as close to their exit from the brain stem as possible, with care taken to preserve dural folds, to retain accurate in situ anatomical relationships. After ligation of both supraclinoid ICAs and both posterior communicating arteries (PCoA), cannulation of the two proximal petrous ICAs was performed to allow colored acrylic injection of both carotid systems in each specimen. Colored acrylic injection of the venous compartments of the CS was performed through the superior and inferior petrosal sinuses. Photographs at appropriate stages of dissection were taken using a Canon A-1 35 mm camera.

Anatomical relationships

Osseous and dural structures

The most important bony landmarks on the medial aspect are the anterior clinoid process (ACP), the posterior clinoid process (PCP), and the lateral border of the clivus. On the dorsal aspect of the CS the most prominent structure is the anterior surface of the petrous bone whereas on the lateral aspect of the CS the most important landmarks are the superior orbital fissure (SOF), foramen rotundum, foramen ovale, and foramen spinosum.

The tentorium is attached to the petrous apex, to the PCP and ACP. These form a triangular field of dura referred to as the oculomotor trigone, at the lateral border of which the IIIrd and the IVth nerves enter the lateral wall of the CS. The margins of the oculomotor trigone include: (a) the anterior petroclinoid fold extending from the petrous apex to the ACP; (b) the posterior petroclinoid fold extending from the petrous apex to the PCP; and (c) the interclinoid fold extending between the ACP and the PCP [33]. Umansky and Nathan have previously reported that the lateral wall of the CS is consistently formed of two layers: the superficial, dense layer formed by the dura mater, and an inner reticular layer between which run the IIIrd, IVth and V1 nerves [51]. These authors also reported that in 40% of their specimens the thin inner layer was incomplete, and often absent between the IIIrd nerve and V1, leaving a triangular opening onto the cavity of the CS. Medial to Meckel's cave, a layer of firm, fibrous connective tissue lies over the ICA, firmly fixing the ICA to the skull base. The well-formed anterior border of this fibrous bridge delineates the fixed portion of the ICA, which runs over the foramen lacerum from its mobile intracavernous portion. Peripheral to the Gasserian ganglion (GG) and along the lateral wall of the CS, the superficial dural layer can be separated from the inner reticular layer without entering the sinus. At the most anterior aspect of the CS, the two layers of dura separate to envelop the ACP and a part of the anterior loop of the ICA. The inner reticular layer runs inferior to the ACP and surrounds the anterior loop of the ICA forming its proximal ring which thus becomes the roof of the anterior CS, below and lateral to which are found the blood-filled venous trabeculated spaces medial to the ICA. The superficial dural layer continues over the superior surface of the ACP, tightly enveloping the ICA to form a separate ring referred to as the distal or dural ring. (According to this terminology, the adjectives "proximal" and "distal" describe the paraclinoid rings with respect to their location along the anterior loop of the ICA). It should be noted that a paraclinoid segment of the anterior loop of the ICA between the proximal and distal rings is extracavernous in location. The inner reticular layer continues medially, extending over the pituitary body, and inferiorly along the medial wall of the CS. The holes within the inner reticular layer provide for the passage of the intercavernous venous channels from the left to the right CS.

Oculomotor nerve

After exiting from the interpeduncular fossa, the IIIrd nerve runs in an anterolateral and slightly inferior direction in the anterior incisural space between the posterior cerebral artery and the superior cerebellar artery to enter the roof of the CS lateral to the PCP. At this point, the nerve acquires its own sheath of dura in the lateral portion of the anterior petroclinoid fold and continues anteriorly within the lateral wall of the CS.

Trochlear nerve

The IVth nerve exits from the dorsal surface of the midbrain just below the inferior colliculus at the level of the superior medullary velum. In the cerebello-mesencephalic fissure the nerve curves anteriorly around the lateral aspect of both the tectum and tegmentum in the quadrigeminal and ambiens cisterns, then continues in the antero-latero-inferior direction to enter the inferior surface of the tentorial edge lateral to the cerebral peduncle. It then runs anteriorly for several millimeters in a groove on the inferior surface of the tentorium before becoming completely encased in the dural canal. After entering the tentorium, the IVth nerve continues anteriorly, following the margin of the anterior petroclinoid fold to enter the lateral wall of the CS where running inferior and lateral to the IIIrd nerve it is embedded between two dural layers.

Trigeminal nerve

After arising from the lateral pons, the motor and sensory roots of the Vth nerve run in an anterior and lateral direction through the middle incisural space of the posterior cranial fossa superior to the petrous apex to enter the subarachnoid and dural outpouching known as Meckel's cave. Several millimeters superior and posterior to the entry of the Vth nerve into Meckel's cave is the dural entry point of the petrosal vein into the SPS. Ventro-medial to Meckel's cave at the petrous apex is the lateral loop of the ICA, which runs over the foramen lacerum. A previous study indicated that the bone separating the dura of Meckel's cave and the ICA was absent in 68 % of specimens [12]. In these cases, the GG was separated from the ICA by a layer of fibrous connective tissue. The greater superficial petrosal nerve (composed of pre-ganglionic parasympathetic fibers), after exiting from its hiatus in the anterior side of the petrous bone, runs anteriorly and epidurally over the floor of the middle cranial fossa to join the Vth nerve. As the fascicles of the Vth nerve lose their arachnoid covering, they coalesce to form the GG which gives off V1, V2, and V3. V3 continues inferiorly, laterally, and slightly anteriorly to leave the middle cranial fossa via the foramen ovale several millimeters lateral to the foramen lacerum. V2 runs anteriorly and slightly inferiorly between the two dural layers to leave the middle cranial fossa through the foramen rotundum. Here, V2 forms the inferolateral margin of the CS. Before entering the SOF, V1 runs anteriorly between two dural layers of the lateral wall of the CS where it is located inferolateral to the IVth nerve and superomedial to V2.

Abducens nerve

The VIth nerve extends anterosuperiorly through the prepontine cistern after leaving the anterior pontomedullary sulcus. The nerve pierces the dura overlying the basilar venous plexus of the clivus. The fascicles of the VIth nerve are sometimes divided, forming several individual nerve bundles at the entry point into the clival dura. The length of the nerve within Dorello's canal is somewhat variable, depending on its dural entry point. After entering Dorello's canal, the VIth nerve continues superiorly and slightly medially in close apposition to the bone, forming the cortex of the distal clivus. It then runs anteriorly and slightly medially beneath the fibrous petroclinoid ligament, close to the base of the PCP, to enter the venous spaces of the CS, lateral to both the proximal segment of the medial loop of the ICA and the horizontal portion of the ICA, and medial to V1. A small spicule of bone is commonly found along the apex of the petrous bone at the lateral end of the petroclinoid ligament, with the nerve coursing immediately medial to this bony prominence and lateral to the ICA to enter the CS; it continues laterally as it courses anteriorly within the venous trabeculae of the CS. In some cases the petroclinoid ligament is completely calcified, forming a foramen through which the nerve enters the CS.

Internal carotid artery

After running through the bony carotid canal and over the foramen lacerum, ventro-medial to Meckel's cave, the ICA in its sheath of sympathetic fibers courses beneath the previously described fibrous connective tissue bridge to enter the posterior portion of the CS, lateral to the base of the PCP. Usually, the cavernous ICA has three major groups of branches [12, 42], the largest, most proximal and most constant of these branches being the meningo-hypophyseal trunk (MHT), which extends medially from the medial loop of the cavernous ICA, to divide into the tentorial artery, the dorso-meningeal artery, and the inferior hypophyseal artery. A few millimeters distally, the artery of the inferior CS (also called the infero-lateral trunk (ILT) or the lateral main stem artery) arises from the inferolateral aspect of the horizontal segment of the ICA. After coursing superior to the VIth nerve, it gives off branches to the lateral dural wall of the CS and to the adjacent cranial nerves.

The horizontal segment of the intracavernous ICA then runs medially and superiorly to form a U-turn referred to as the anterior loop. In 30 % of specimens the distal horizontal segment of the ICA has been found to give rise to McConnor's capsullar arteries, making them the least consistent branches of the cavernous ICA [12, 41]. The inferior and anterior capsullar branches have been described as supplying the floor and the roof of the sella, respectively. In approximately 8 % of cases the ophthalmic artery arises from the intracavernous (extradural) ICA [12]. As described previously, the inner layer of the dura forms the proximal dural ring providing the barrier separating the intracavernous ICA from its extracavernous paraclinoid portion. Four to six millimeters distally, the dura surrounds the ICA to form the distal dural ring separating the paraclinoid portion of the anterior loop from the intradural supraclinoid ICA. The supraclinoid ICA enters the subarachnoid space lateral to the optic nerve (ON) and medial to the ACP.

Intracavernous relationships

The cranial nerves III, IV, and V1 continue anteriorly between the superficial and the reticular dural layers forming the lateral wall of the CS to enter the SOF. Throughout the posterior portion of the CS these nerves maintain a constant relationship to each other with regard to the superior – inferior orientation, although the course of the IVth nerve, inferior to the IIIrd nerve and superior to V1, has been shown in a previous study to be somewhat more variable anteriorly within the lateral wall of the CS [23]. However, 5–7 mm posterior to the bony margin of the SOF, the IVth nerve runs superiorly along the lateral aspects of the IIIrd nerve, crossing over the IIIrd at this point; it continues anteriorly, now superior and slightly lateral to the IIIrd nerve, to enter the SOF.

The IVth nerve runs inferior to the petroclinoid ligament and then enters the posterior CS maintaining its direction throughout the lateral wall of the CS lateral to the cavernous ICA and adjacent to the medial aspect of V1. Sympathetic fibers, running with the ICA, coalesce into discrete fiber bundles, which leave the ICA to join the VIth nerve for several millimeters before crossing over to join V1, with which they run peripherally to provide sympathetic innervation in the corresponding trigeminal territory. As the VIth nerve continues anteriorly, it assumes a slightly more inferior location within the CS in relation to V1, so that, at the level of the SOF, the VIth nerve is both medial and inferior to V1.

In addition to the VIth nerve, sympathetic fibers, venous trabecular channels, and the intracavernous ICA, variable amounts of fatty connective tissue are also found throughout the CS. Other potential venous tributaries include the superior and inferior ophthalmic veins, the superior and inferior petrosal sinuses, the sphenoparietal sinus, cortical veins, veins of the pterygoid plexus, via the foramen ovale, and the basilar venous plexus.

The relationships of the intracavernous structures, predominantly of the ICA and venous compartments to the bony sinuses and to the sella, will be discussed in detail.

1.2 The surgical triangles of the cavernous sinus

The constant anatomical relationships of the dural, osseous, neural and vascular structures of the parasellar skull base region permit the organization of the relevant anatomy into a series of ten triangular windows, each with its particular surgical significance in skull base lesions. One of these triangles has been further subdivided into osseous and tentorial portions. These ten triangles have been grouped into three subregions (the parasellar, the middle cranial fossa, and the paraclival one). Conceptually, the two-dimensional triangles can be expanded into three-dimensional spatial figures to form a series of ten tetrahedrons, each containing specific dural, osseous and neuro-vascular structures. For the sake of simplicity and consistency, however, the term »triangle« will be retained throughout this book to include the three-dimensional extension of each triangle with its specific contents.

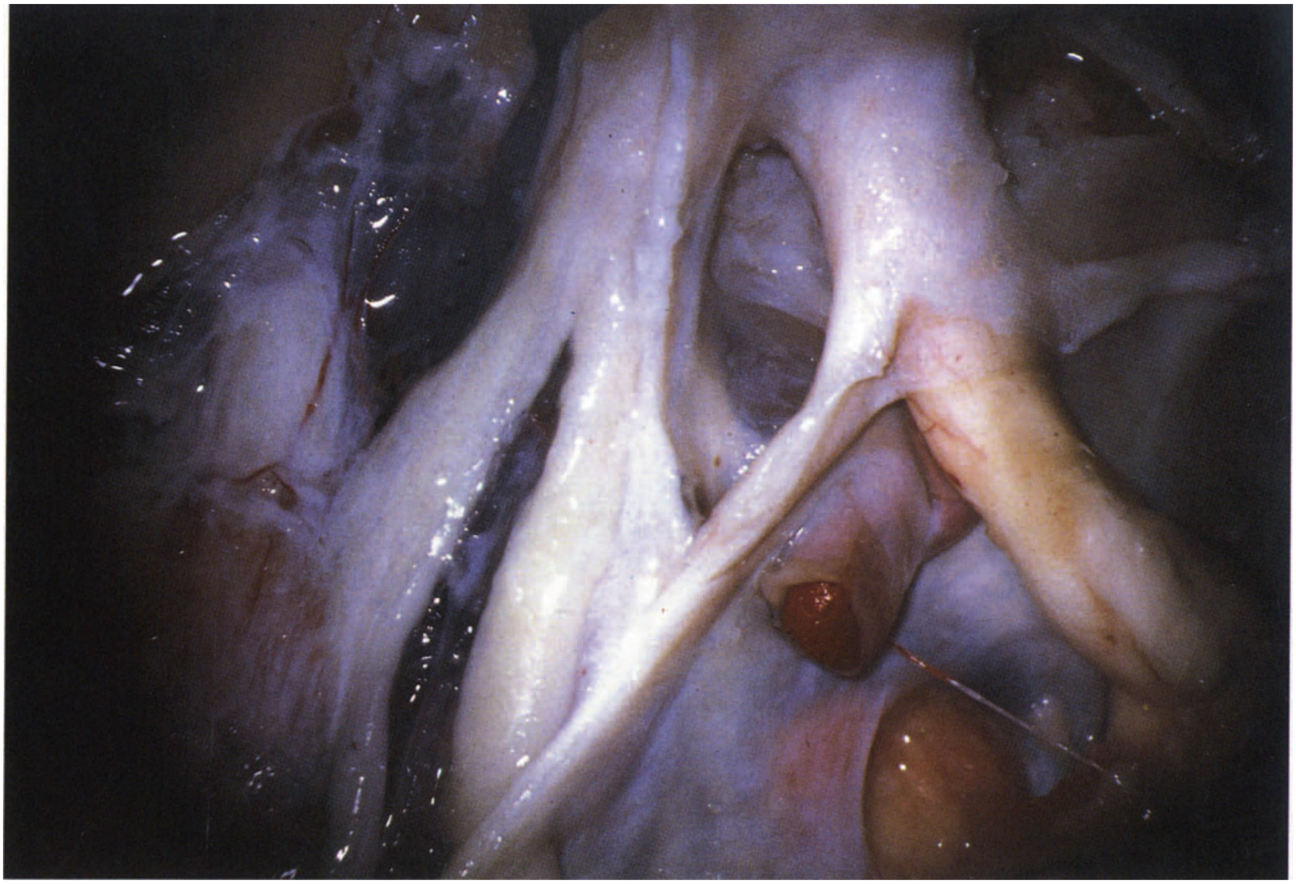
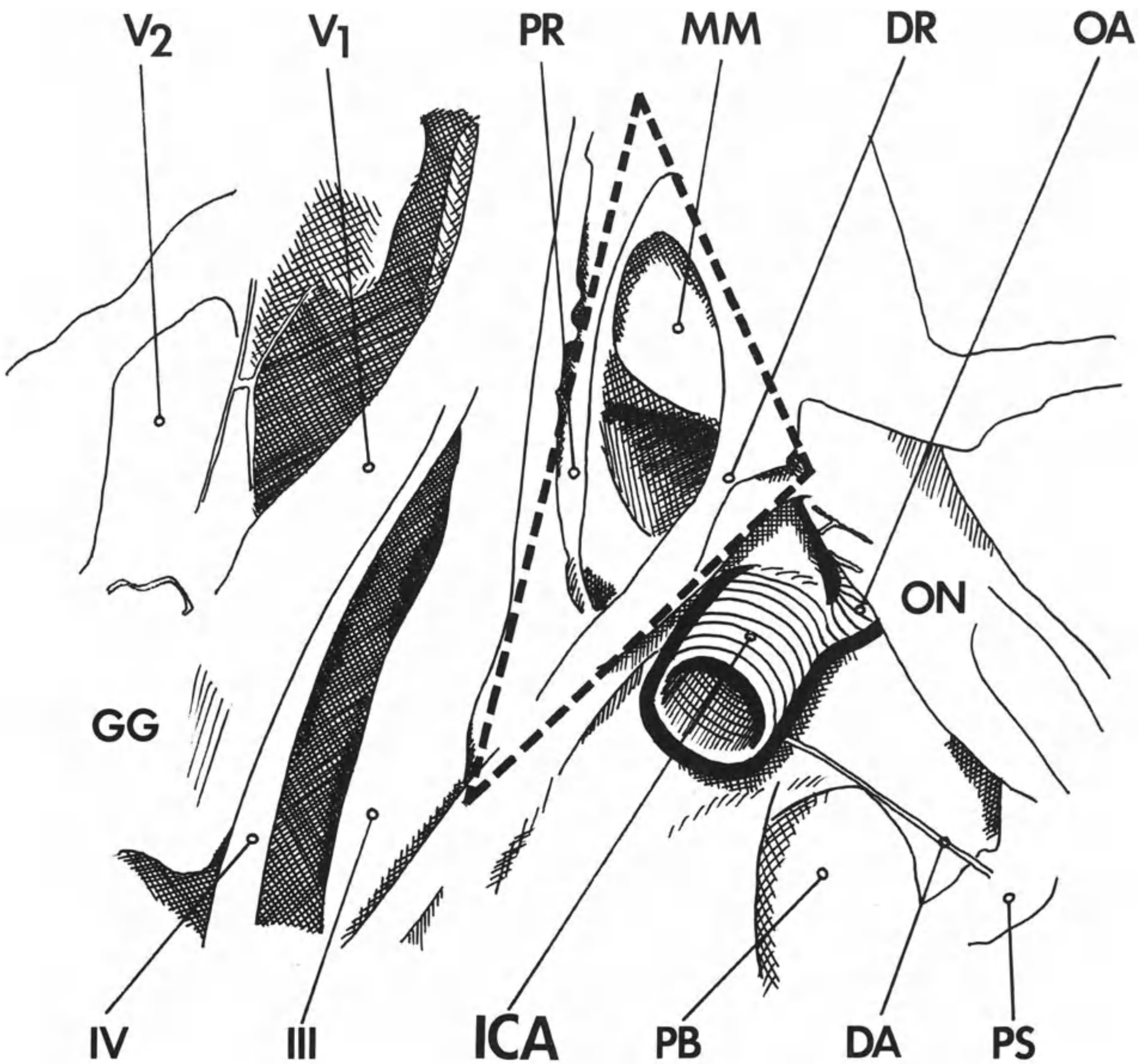


Fig. 1. A fresh cadaver specimen with red acrylic injected into the arteries and blue transparent acrylic injected into the venous compartments. The ACP and the outer dural layer of the lateral wall of the CS have been removed. The anteromedial triangle is bordered medially by the ON covered with the dura propria, laterally by the IIIrd nerve covered with the fibrous tissue of the proximal ring, and by the dura extending from the entry point of the IIIrd nerve to the ON. On the floor of the anteromedial triangle the anterior loop of the ICA, covered by venous blood and by a thin fibrous layer, is seen. Anterior to the anterior loop of the ICA is the mucous membrane of the sphenoid sinus. Posterior to the anterior loop of the ICA, fibrous tissue is seen between the dura and the IIIrd nerve

Parasellar subregion



Anteromedial triangle

The sides of this triangle include: the lateral aspects of the ON confined within the optic canal (medial border); the medial aspects of the IIIrd nerve within the sheath of dura entering the SOF (lateral border); and the dura extending between the dural entry point of the IIIrd nerve and the ON (posterior border), which forms the dural ring around the paraclinoid ICA [8, 9] (Fig 1). Exposure of the anteromedial triangle requires complete extradural removal of the ACP. Impor-

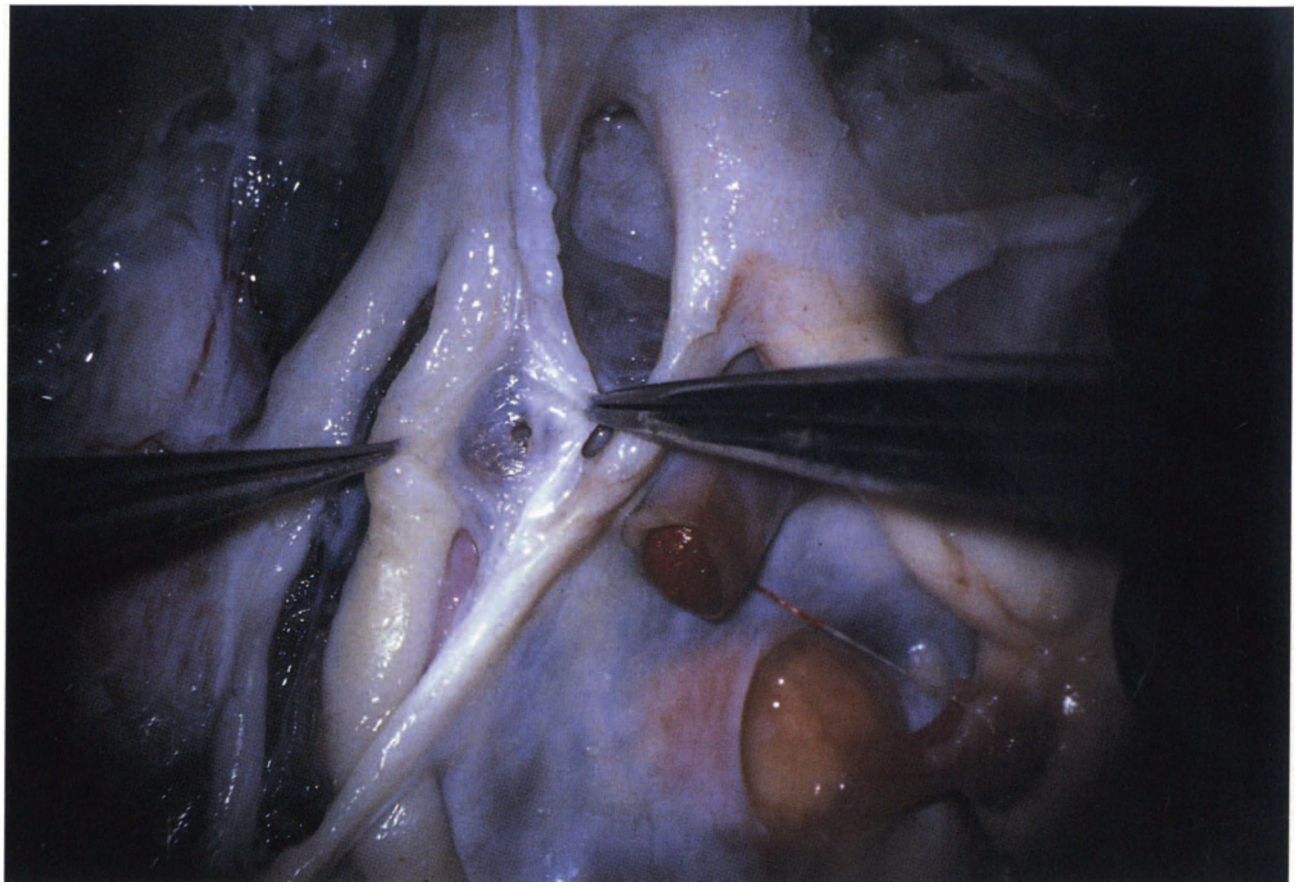
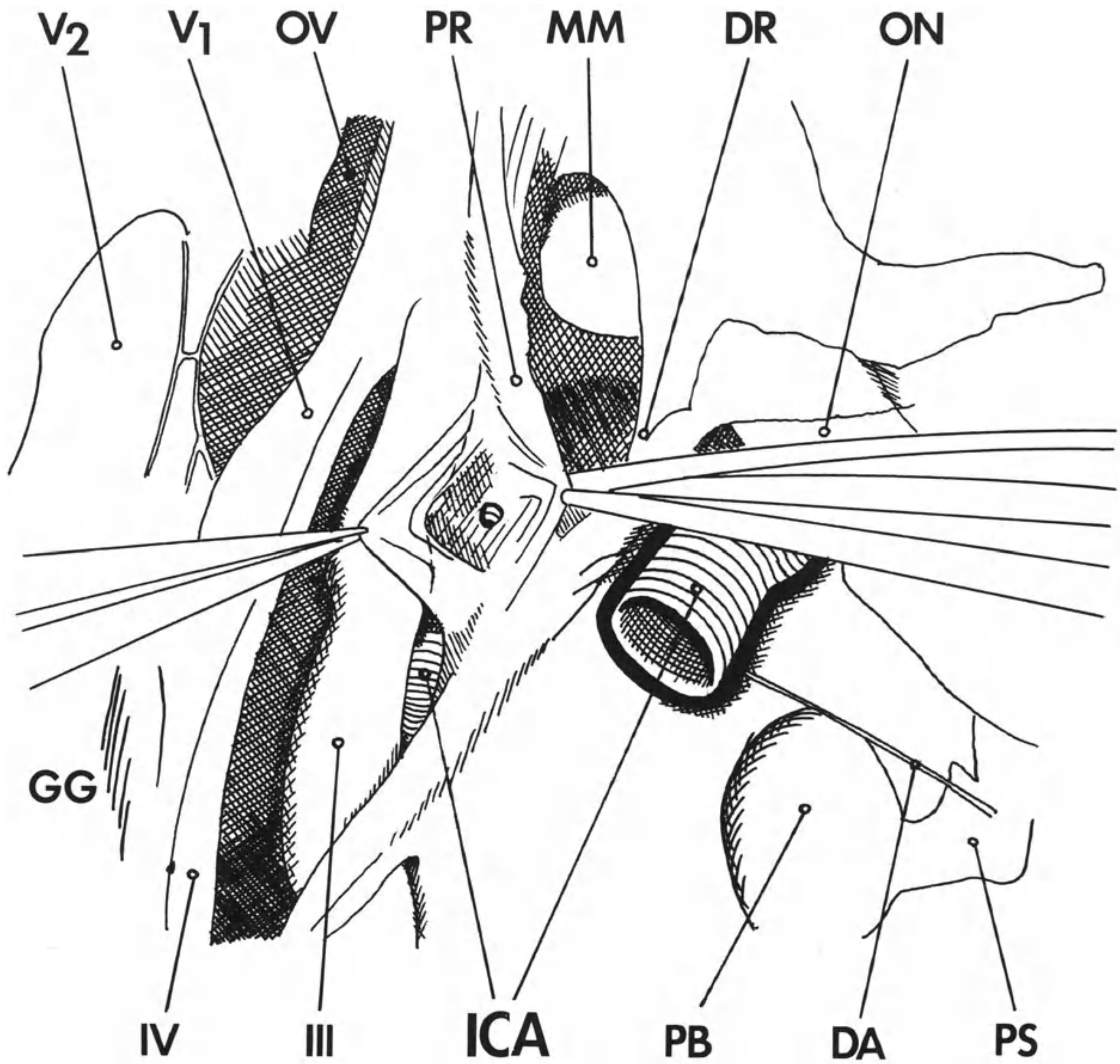


Fig. 2. The same specimen as in Fig. 1. Step-wise dissection of the fibrous tissue on the medial aspect of the IIIrd nerve has been performed. It can be clearly seen that the fibrous tissue layer running from the dura along the medial aspect of the IIIrd nerve is strong and that it divides the extracavernous from the intracavernous area of the anteromedial triangle

tant structures within the anteromedial triangle include: (i) the distal horizontal segment of the intracavernous ICA, the anterior loop of the ICA, (ii) the venous trabecular channels of the anteromedial portion of the CS, and (iii) a thin layer of fibrous connective tissue continuous with that surrounding the anterior loop of the ICA thus forming the proximal dural ring of the paraclinoid ICA. The anterome-



dial triangle therefore includes the extradural space occupied by the ACP as well as the anteromedial portion of the CS. These two adjacent regions are separated by the connective tissue of the proximal dural ring extending toward the PCP along the lateral aspect of the sella.

The anteromedial triangle of the **left** CS is shown in Figs. 1–5.