Lateral Supraorbital Approach -
Simple, Clean, and Preserving
Normal Anatomy

Rossana Romani

Academic Dissertation

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Helsinki 2011
To my mother
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Abstract

Objective The anterior skull base region can be reached through different surgical approaches. The most frequently used are the pterional, bifrontal, and orbitozygomatic approaches. No previous reports describe the microsurgical technique when treating olfactory groove meningiomas (OGMs), anterior clinoidal meningiomas (ACMs), and tuberculum sellae meningiomas (TSMs) through the small lateral supraorbital (LSO) approach. The purpose here was to assess the reliability and safety of the LSO for the treatment of vascular and neoplastic lesions of the anterior skull base. The neuroanesthesia method when using this small approach is also presented. When needed, anterior clinoidectomy, intradurally or extradurally, is also possible through the LSO approach.

Patients and Methods Between September 1997 and August 2010, we analyzed the clinical data, radiological findings, surgical treatment, anesthesiological procedure, histology, outcome, and long-term follow-up of 66 OGMs, 73 ACMs, 52 TSMs consecutive patients treated by the senior author (J.H.) through the LSO approach. Anterior clinoidectomy technique through the LSO is presented after reviewing 82 patients who underwent surgery for vascular and neoplastic lesions between June 2007 and January 2011. Altogether 273 patients of a total of 3000 LSO approaches were analyzed, and 15 videos were selected to show the approach and the microsurgical techniques used.

Results Olfactory groove meningiomas: There was no surgical mortality. Six patients (9%) had CSF leakage, four (6%) had wound infections and cotton granulomas, and one (2%) had postoperative hematoma. The median Karnofsky score at discharge was 80 (range, 40-100). Six patients had residual tumors: three were re-operated on after an average of 21 (range, 1-41) months, one was treated with radiosurgery, and two were followed up. During the median follow-up of 45 (range, 2-128) months there were four recurrences (6%) diagnosed on average 32 (range, 17-59) months after surgery.

Anterior clinoidal meningiomas: At three months after discharge, 60 patients (82%) had a good recovery, nine (12%) were moderately disabled, one (1%) presented with severe disability, and three (4%) died due to surgery-related complications. Sixteen
patients (22%) had residual tumors, six of which required re-operation. Of 39 patients, pre-existing visual deficit improved in 11 (28%), worsened in four (5%), and three (4%) had de novo visual deficit. During the median follow-up of 36 (range, 3-146) months tumor recurred in three patients: two were followed up and one was reoperated.

*Tuberculum sellae meningiomas:* At three months postdischarge, 47 patients (90%) had a good recovery, four (8%) were moderately disabled, and one (2%) died 40 days after surgery of unexplained cardiac arrest. Of 42 patients, pre-existing visual deficit improved in 22 (42%), remained the same in 13 (25%), and worsened in seven (13%), and de novo visual deficit occurred in one patient (2%). Seven patients (13%) had minimal residual tumors, two of which required re-operation. During the median follow-up of 59 (range, 1-133) months tumor recurred in one of the patients who had received a second operation.

*Anesthesia:* Surgical conditions with slack brain were good in 154 meningioma patients. Slack brain was achieved by a head position elevated 20 cm above cardiac level in all patients; administering mannitol preoperatively in medium or large meningiomas (60 cases); propofol infusion (46 cases) or volatile anesthetics (107 cases) also in patients with large tumor (37 cases); and controlling intraoperative hemodynamics. The mean systolic blood pressure was 95-110 mmHg during surgery. The median intraoperative blood loss was 200 (range, 0-2000) ml and 9% of patients had red blood cell transfusion. One-hundred and fifty-seven patients (84%) were extubated on the day of the surgery. The median (25th/75th percentiles) time to extubation after surgery was 18 (8/105) min.

*Anterior clinoidectomy:* Eighty-two patients underwent anterior clinoidectomy: 45 patients (55%) were treated for aneurysms, 35 patients (43%) were treated for intraorbital, parasellar, and suprasellar tumors, and two patients (2%) presented with carotid-cavernous fistula. Intradural anterior clinoidectomy was performed in 67 cases (82%); in 15 cases (18%), an extradural approach was used. We performed a tailored anterior clinoidectomy: in five patients (6%), only the medial tip of the anterior clinoid process (ACP) was removed, in eight (10%) the head of the ACP, in 18 (22%) the body of the ACP, and in 51 (62%) the entire ACP. Four patients (5%) had new postoperative visual deficits and 12 (15%) improved their preoperative visual deficits after intradural anterior clinoidectomy. Extradural anterior clinoidectomy and use of ultrasonic bone device (Sonopet) may increase the risk of postoperative visual deficits. There was no mortality in the series.

**Conclusions** The LSO approach can be used safely for OGMs, ACMs, and TSMs of all sizes, with a low mortality and a relatively
low morbidity. Anterior clinoidectomy can be performed through the LSO approach. However, it is required only in selected cases and we prefer the intradural route.
A slack brain is mandatory when performing the small LSO approach and can be achieved by patient positioning, propofol or inhaled anesthetics, preoperative mannitol, and optimizing cerebral perfusion pressure.
With advancements in the neurosurgical field, the skull opening should be simple and as minimally invasive as possible. Surgical results with the simple, clean, and fast LSO approach are comparable with those achieved with more extensive, complex, and time-consuming approaches. We highly recommend the use of LSO for removal of vascular and neoplastic lesions of the anterior skull base.
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<td>ACA</td>
<td>Anterior cerebral artery</td>
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<td>AChA</td>
<td>Anterior choroidal artery</td>
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<td>ASB</td>
<td>Anterior skull base</td>
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<td>AVM</td>
<td>Arterio-venous malformation</td>
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<td>BA</td>
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<td>BC</td>
<td>Before Christ</td>
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<td>CBF</td>
<td>Cerebral blood flow</td>
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<td>CIs</td>
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<td>CPP</td>
<td>Cerebral perfusion pressure</td>
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<td>CSF</td>
<td>Cerebrospinal fluid</td>
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<td>CT(A)</td>
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<td>HES</td>
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<td>ICA</td>
<td>Internal carotid artery</td>
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<td>ICP</td>
<td>Intracranial pressure</td>
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<td>LSO</td>
<td>Lateral supraorbital</td>
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<td>MMA</td>
<td>Middle cerebral artery</td>
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<td>MRA</td>
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<tr>
<td>MRI</td>
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<tr>
<td>NA</td>
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<td>ORs</td>
<td>Odds ratios</td>
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<tr>
<td>PCA</td>
<td>Posterior cerebral artery</td>
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<tr>
<td>PComA</td>
<td>Posterior communicating artery</td>
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<td>PEAs</td>
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<td>SAH</td>
<td>Subarachnoid hemorrhage</td>
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<td>SCA</td>
<td>Superior cerebellar artery</td>
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<tr>
<td>SOF</td>
<td>Superior orbital fissure</td>
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<tr>
<td>SSS</td>
<td>Superior sagittal sinus</td>
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<td>TSMs</td>
<td>Tuberculum sellae meningiomas</td>
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List of Original Publications

This thesis is based on the following publications, referred to in the text by their Roman numerals:


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1 Introduction

The surgical opening of the skull is one of the most fascinating practices in human history. Since the first skull trepanation dates back to the Neolithic period ca. 8000 BC, enormous efforts have been made to refine this surgical procedure (247). Over the centuries, especially during the last one, the procedure has undergone important developments. This progression is due to the parallel evolution of the neuroradiological field, essential for optimal understanding of the anatomy and neurovascular relationship of the lesion, and improvement of neurosurgical techniques with the introduction of the microscope and microsurgical techniques.

According to the location and anatomical features of the intracranial lesion, several surgical approaches have been developed, particularly in the last fifty years. We focused our study on the surgical approach to reach the anterior skull base (ASB). This is the endocranial surface of the skull bordered posteriorly by the sphenoid ridge and joined medially by the chiasmatic sulcus. This region is particularly difficult to reach because of the complex neurovascular structures present.

Several surgical approaches are described to reach the ASB. Those most frequently used are the pterional, frontolateral, bifrontal, and fronto-orbitozygomatic approaches.

The aim of this study was to demonstrate the reliability and safety of the lateral supraorbital (LSO) approach in the treatment of the most frequent neoplastic and vascular lesions of the ASB. More specifically, the microsurgical technique, long-term follow-up, and neuroanesthesia procedures were carefully examined to demonstrate the efficacy of the LSO approach for treating olfactory groove meningiomas (OGMs), anterior clinoidal meningiomas (ACMs), and tuberculum sellae meningiomas (TSMs). The results were then compared with those obtained utilizing pterional, orbitozygomatic, bifrontal approaches that are more invasive and time-consuming approaches. Furthermore, the skull base approach with both extradural or intradural anterior clinoidectomy, for the treatment of vascular and neoplastic lesions, was studied through the LSO approach.

All patients analyzed and described in this study were treated by a single neurosurgeon, the senior author (J.H.), at the Department of Neurosurgery, Helsinki University Central Hospital, Finland.
2 Review of the Literature

History of Craniotomy

Pre-Historic and Classic Eras

Neolithic Era (8000 BC)

The primitive technique to open the skull was trephination, performed in the Neolithic era (8000-5000 BC) in different locations around the world (Africa, South America, and Melanesia, one of the regions of Oceania). The first archeological findings related to perforation of the skull date back to the Neolithic period and were made in France in the Neolithic site of Ensisheim in 1685 (217). The word “trepanation” is derived from the Greek and it means auger (hand tool for boring holes). The word “trephination”, by contrast, refers to an opening made by a circular saw of any type. Skull opening through trepanation was practiced in Europe, Asia, New Zealand, Pacific Islands, and North America. Trephination or trepanation consisted of removing a piece of the skull (frontal, parietal, or occipital bones) from a living patient to expose the dura mater. In the pre-anesthesia and pre-antisepsis era, patient survival improved if the dura mater remained intact when opening the skull. While the operation was performed on men, woman, and children, the patients were most often adult males. Two-thirds of the skulls found and examined reveal various degrees of healing, providing evidence of survival and indicating great skill of the surgeon considering the number of potential complications (e.g. bleedings, infections, edema).

Neolithic trepanation and trephination have been the subject of speculation since the first specimens were discovered in the nineteenth century. Archaeologists speculate that it was performed to allow evil or unwanted spirits to escape. More reasonable is a therapeutic treatment of headaches, fractures, localized cranial deformities, mental changes, infections, or convulsions. Another explanation is a religious one, to acquire the
rondelles (the disks of bone obtained from the cutting of circular holes in the skulls) used as amulets or talismans. The findings of skull fracture suggested also that the procedure was performed to relieve intracranial pressure. Three surgical techniques were used: scraping, drilling, and cutting (Figure 1). The Neolithic Age occurred before the introduction of metallurgy. The holes were made with a sharp-edged flint scraper or knife, deeper and deeper until penetration to the dura mater was accomplished. In ancient Peru, people used knives of bronze or obsidian. The wound was covered with a shell, a gourd, or even a piece of gold or silver. The most common tool used was the bow drill. The bow was made of springy wood and had a leather thong wound around the drill several times. To perform the procedure, the operator positioned the drill tip against the head and bored through the bone. Drilled holes were usually roughly circular. Holes made by a knife were typically more square. A few skulls have had up to five holes, the longest of which measures two inches across (205, 217, 247).

Classic Era

Edwin Smith was an American Egyptologist who bought an ancient papyrus from Mustapha Aga, a consular agent in Luxor in 1862 (223). Smith died in 1906 and his daughter gave the papyrus to the New York Historical Society in 1920. The papyrus was

Figure 1: Schematic drawing showing the different skull trepanation techniques during the Neolithic era (8000 BC). (A) The intersecting incisions to remove a rectangular piece of skull; (B) Boring and cutting; (C) Grooving; (D) Scraping.
translated in 1922 by James H. Breasted, an American Egyptologist, and published in two volumes in 1930. The translation of Edwin Smith's papyrus is the only medical treatise of the Pharaonic era, and it reveals how advanced medical care, especially trauma surgery, was in ancient Egypt. Edwin Smith's papyrus describes for the first time cranial sutures, meninges, the external surface of the brain, and the cerebrospinal fluid (CSF). Forty-eight different pathological cases are presented with details of the examination, diagnosis, treatment, and prognosis. Trauma cases with neurological symptoms are very well described; for example, cervical vertebral dislocation was considered to be the cause of such symptoms as quadriplegia and urinary incontinence. Trepanation is not mentioned in the papyrus (20, 223, 247).

The codification of craniotomy performed for head injury was first done by Hippocrates in 5th century BC. The Corpus Hippocraticum is a systematic review of the head trauma treatment performed by ancient physicians. The book describes guidelines for the treatment of head trauma with symptoms, techniques, and complications. The Corpus Hippocraticum remained valid for 2000 years. Hippocrates advised performing the craniotomy without delay, within the first three days of the trauma in severe contusions. In skull fractures, he advised removal of the embedded fragments without lacerating the meninx (217).

Hippocrates was the first to demonstrate that the specific location of injury of the skull was important. Trauma at bregma was associated with a higher risk of brain injury than a lesion in the temporal region, which in turn was associated with a higher risk of brain injury than a lesion in the occipital region. Simple concepts of head injury location and its prognosis were applied by the Hippocrates school and were valid for many centuries.

Celsus was a counselor to the emperors Tiberius and Caligula. He was not a surgeon or physician, but a patrician intellectual who wrote a series of books entitled: De Re Medicina. Book VIII, Chapter 4 describes an epidural hematoma. Celsus advised operating on the patient on the side of greater pain and placing the trephine where the pain is best localized. This is the first observation of dura innervation and its sensitivity to pressure. Celsus first described how a craniotomy is performed: making a number of holes and then connecting them with a hammer and chisel. Regarding the trephination operation, Celsus considered it the “ultimum refugium”, to be applied only when conservative methods failed.

Galen of Pergamon (AD 129-210) lived under the reign of Marcus Aurelius (reign AD 161-180), one of the most powerful and important emperors of the Roman Empire. Galen was the physician of the gladiators, allowing him to treat traumatic injuries. He
made important contributions to neuroanatomical knowledge and neurosurgical techniques. He was the first to differentiate between pia and dura mater, and he provided descriptions of many anatomical structures, including the corpus callosum, pineal and pituitary glands, cranial nerves (he identified seven), and ventricular systems. Besides neuroanatomical studies, he provided an extensive description of how the trephination is performed without lacerating the dura (85).

**Medieval Period**

During this period the leading medical school was in Salerno, Italy. A prominent leader of this school was Constantinus Africanus (ca. 1015-1087), known as “magister orientis et occidentis”. He was credited for introducing Arabic medicine to all of Europe. In contrast to the pre-historic and classic Greek-Roman period, when the craniotomy was quite frequently performed, in the Middle Ages this was an exceptional procedure for Byzantine, Arabic, and Eastern surgeons. The only procedure performed and only rarely was trephination (217).

**Renaissance and the 18th Century**

During the Renaissance the craniotomy was again performed frequently, especially to treat traumatic head injuries. In the 16th century, the indications and surgical techniques for craniotomy were described in the most important surgical books. These books included “Tractatus de fractura calvae sive crani” written by Giacomo Berengari from Carpi, Italy, “Dix Livres de la Chirugie” by Ambroise Pare’, and “Cirugia Universale” by Giovanni Andrea Dalla Croce. Knowledge of the anatomy of the brain progressively increased, especially in the second half of the 17th century with the studies of Malpighi and Willis (217). During the 18th century the craniotomy procedure was performed only in exceptional cases because of the high incidence of complications such as infections.

**19th Century and the Osteoplastic Craniotomy**

In the second half of the 19th century, with the introduction of general anesthesia, the introduction of asepsis by Lister, and greater knowledge of neuroanatomy and neurophysiology, the craniotomy was not only performed for trauma cases but also to
2 Review of the Literature

treat intracranial expansive lesions. At the end of the 19th century, the first operations of brain tumors are described. Sir William Macewen (1848-1924) in Glasgow pioneered the treatment of the brain abscess and also other lesions. On July 27, 1879, he removed a tumor, a meningioma, from the left olfactory groove. The patient had a good recovery and was able to return to work in a few months (7).

In 1894 and 1895, Chipault A.M.J.N, a French anatomist and assistant of surgery à la Salpêtrière, Paris, published the Chirurgie Opératoire du Systeme Nerveux in two volumes. In the first volume, the history of cranio-cerebral surgery from the pre-historic era was reported. The importance of a small skull opening over the suspected tumor area was emphasized. The osteoplastic craniotomy was described. This method was needed to expose a large area of the brain in order to localize the neurological disease without leaving the patient with a big hole in the skull. Before this, the trepanation technique was the only one performed and the small area of bone removed was not reinserted (145, 245).

The osteoplastic craniotomy was described in the Chipault volume, but it was first applied by Wilhelm Wagner (1848-1900), a chief general surgeon from a small hospital in Königshütte (Germany) interested in cranial and spinal injuries (23, 24, 145, 246). He was a brilliant surgeon who developed, based on cadaveric dissection, a technique of elevating the bone flap attached to the temporal muscle. Wagner met Julies Wolff, who created and published in 1863 an experimental work where the osteoplastic techniques were possible. Julies Wolff (1836-1902) was an orthopedic surgeon who graduated from the University of Berlin and investigated bone remodeling, later inspiring Wagner (248). Wagner was the first to perform the osteoplastic craniotomy on a patient by cutting the bone with a chisel. At the same time, the Gigli saw by Leonardo Gigli from Florence (1863-1908) was introduced and popularized. The Gigli saw was initially used for cutting the symphysis pubis and later for performing the craniotomy (246).

Fedor Krause and the Unilateral Frontal Osteoplastic Craniotomy

Fedor Krause (1857-1937), the chairman of the surgical department of Augusta Hospital in Berlin, was the first surgeon in Germany to treat epilepsy. He also was known for innovative skull openings and surgical approaches. In 1900, he removed a revolver bullet from the region of the clinoid process by performing a frontal osteoplastic craniotomy. Krause was the first to perform a unilateral subfrontal approach without
removal of the orbital rim, recommending this approach to reach pituitary adenomas. Neurosurgeons worldwide remember Krause for his famous infratentorial supracerebellar approach in 1913, but even before this he was credited with first using the unilateral frontal osteoplastic craniotomy. He published his surgical experiences in “Die Chirurgie des Gehirns und Rückenmarks nach eigenen Erfahrungen” (Surgery of the Brain and Spine), in two volumes appearing in 1908 and 1911 and translated into English, French, and Spanish (23).

Sir Victor Horsley: From the Transfrontal Route to the Subtemporal Approach

In 1889, Sir Victor Horsley (1857-1916) performed in London the first pituitary adenoma operation through a transfrontal route, sacrificing the frontal veins draining into the superior sagittal sinus (SSS). The patient presented with a frontal infarction documented at autopsy a few years later. Horsley subsequently abandoned the transfrontal route for the temporal craniotomy, reaching the lateral aspect of the pituitary gland through a subtemporal route. Once during pituitary surgery by a subtemporal route, Horsley was forced to ligate the internal carotid artery (ICA) to gain access to the tumor (132). Cushing spent a short time with Horsley in London and after visiting him stated that: “the refinements of neurological surgery could not be learned from Horsley” (86).

Francesco Durante: The First Olfactory Groove Meningioma Surgery through Unilateral Frontal Osteoplastic Craniotomy

In Rome in 1885, Durante described the first operation of meningioma removal. Durante was born in Messina (Sicily) and educated in Florence, Paris (with Ranvier) and in Berlin (with Virchow) (88). In the surgical report of the operation, Durante wrote the following: “With a chisel and a hammer, layer by layer a portion of the frontal bone, a part of the superior internal margin of the orbit was removed, and an opening about 5 cm² was made. In the base I found the inner table to be destroyed up to the external table. From the inner table in the frontal region I gradually extirpated the tumor with much care. After having removed the greater part I found the point of attachment to the dura mater. It was then easy to remove all of the extensions of the tumor. These included the left cranial base of the anterior fossa and part of the right anterior fossa. I finally arrived at
the anterior clinoid tubercle of the sella turcica. In the region of the lamina cribrosa of the left ethmoid sinus there was a prolongation of the tumor that descended into the ethmoidal cells. After excising the tumor that was emplanted on the dura mater, one could observe that the orbital roof was depressed, but not broken. The left frontal lobe was replaced by a tumor the size of an apple. After hemostasis was established and the soft tissues were closed a drain was inserted from the cranial cavity into the left nasal cavity. The operation lasted about one hour. The loss of blood was not great. The patient withstood the chloroform anesthesia very well. Later she responded and was able to speak. On the third day after the operation she had recovered” (63).

Durante utilized the hypophysectomy method with a pharyngeal approach (64). He was also instrumental in building the Policlinico of Rome (88). The end of the 19th century is the period in which many neurosurgeons performed brain operations with poor results (217).

20th Century and the Macrosurgical Period

Cushing and “The Special Field of Neurological Surgery”

Harvey Cushing (1869-1939) spent one year in Europe (July 1900- August 1901) at the beginning of his career. He was in Berne, Switzerland, for five months with physiologist Hugo Kronecker researching brainstem control of blood pressure during a rise in intracranial pressure (Cushing response). He spent two months in Turin, Italy, with physiologist Angelo Mosso studying the same topic, and finally three months in Liverpool, England, with physiologist Charles S. Sherrington studying the motor cortex mapping of anthropoid apes (86). Returning to USA, Cushing became an Associate Professor of Surgery at John Hopkins University, and in 1905 published in the hospital Bulletin a report entitled “The Special Field of Neurological Surgery”. The report includes the following three sections: The Brain and its Envelopes, The Spinal Cord, and The Peripheral Nerves. In The Brain and its Envelopes, he wrote: “For the first time aseptic processes had permitted surgeons to perform craniotomies with a certain assurance... of operative safety... Not only has the localization of the more approachable parts of the cortex –after a long series of researches culminating in Flechsig’s
anatomical observations and in the experimental researches of Sherrington and his coworkers; -been put on a working basis for us, but also through the enormous strides in operative technique, particularly through Wagner’s osteoplastic method of resection, we are now able to bring under observation extensive portions of the cerebral surface” (43). In the same article, Cushing wrote that a properly trained neurosurgeon must be his own clinical and experimental neuroscientist. Besides general surgical skills, a knowledge of clinical neurology, neuropathology, and experimental neurophysiology is essential not only for proper treatment of the patient but also to achieve progress in the neurosurgical field (43). These statements after almost 100 years remain true. One of Cushing’s great contributions was to utilize the transsphenoidal approach for a pituitary adenoma in 1909 (86, 132). Cushing performed the head opening to reach the ASB through an osteoplastic craniotomy. Regarding meningioma surgery, he wrote in 1922: “There is today nothing in the whole realm of surgery more gratifying than the successful removal of a meningioma with subsequent perfect functional recovery, especially should a correct pathological diagnosis have been previously made” (41).

Cushing was a leader in the development of neurosurgical procedures, and many neurosurgeons from around the world learned from him. In 1910, he wrote another article “The Special Field of Neurological Surgery: five years later” where he reported the following: “Neurological surgery is fascinating and will long continue an important and profitable field for intense cultivation, partly because it has been largely unworked from an operative standpoint, partly because it deals with one of the two most important systems of the body - nervous and circulatory. It is gratifying to see that a number of young men are fitting themselves to specialize in it, with a preparation which makes envious one who has wriggled into the subject and, like the proverbial squid, has left little but a trail of ink behind him” (42).

Ludvig Puusepp and the First School of Surgical Neurology

Ludwig Puusepp (1875-1942) was born in Kiev, Ukraine, on December 3, 1875. He graduated in St. Petersburg, where he undertook his neurological training with neurologist Professor Vladimir Bechterew, who established a special operating room for the surgical treatment of his patients. The neurosurgical results were poor and
Bechterew said: “If today’s neurologists must still request the help of surgeons, then the coming generation will no longer need to do so, for they have sized the scalpel to perform what legitimately belongs to their realm”. These words inspired Puusepp to become a neurologist and surgeon in a new speciality. He performed his first operation in 1899. At that time, Puusepp wrote: “...Today nobody is surprised at the gynecologist performing operations in his own field, the ophthalmologist in his own: only the neurologist is still at the sidelines... if an operation in his field is necessary, the neurologist asks for the assistance of a general surgeon... if nobody asks a surgeon to remove a cataract from as small an organ as the eye, how can we then insist on the surgeon having detailed knowledge of so complicated a structure as the nervous system?”

During the year between 1904 and 1905, Puusepp served as a surgeon in the Russo-Japanese war, operating on traumatic injuries. In 1907, he became an Assistant Professor at the Department of Nervous and Mental Diseases of the St. Petersburg Military Medical Academy. In 1907 in St. Petersburg, a Chair of Surgical Neurology was established, and Puusepp accepted this post in 1910. This resulted in Puusepp being the first Professor of Surgical Neurology worldwide to emerge from a neurological background. After World War I and the October Revolution in 1920, Puusepp moved to his father’s native country (Estonia), where he was appointed Professor of Neurology at Tartu University. Until 1940, Puusepp’s clinic in Tartu was the only center specialized in neurology and neurosurgery. Puusepp had a great influence on the Russian neurosurgical school. In 1917, he wrote the textbook “Principles of Surgical Neurology” in Russian. Puusepp is recognized worldwide as the first neurological surgeon (192).

Otto George Theobald Kiliani and the Bifrontal Osteoplastic Craniotomy

In 1903 in New York, Kiliani operated on a patient with pituitary apoplexy with an acute intratumoral hemorrhage. The lesion was reached through a bifrontal osteoplastic craniotomy and a subfrontal approach (132).

Louis Linn McArthur and Charles Frazier and the First Fronto-Orbital Osteoplastic Craniotomy

In 1908, McArthur, in Chicago, performed the first frontal craniotomy with resection of the orbital rim. The approach to reach the pituitary gland was epidural, with a dura
opening of 0.5 cm proximal to the chiasmatic sulcus (155). Charles Frazier (1870-1936), in Philadelphia, used a frontal extradural approach and later changed to a frontobasal intradural approach with resection of the supraorbital rim and part of the orbital roof, as previously described by McArthur. This approach was used to remove large pituitary adenomas (74).

Walter Dandy and the Frontotemporal Craniotomy

In 1914, based on a cadaveric study, George Heuer (1882-1950) of Baltimore, suggested a new approach to the pituitary region through the sylvian fissure. This approach differed from the approach of Krause or Frazier, and it was first applied to a living patient by Walter Dandy (1886-1946), who was one of Cushing’s residents. Dandy spent his entire career at the Johns Hopkins Hospital in Baltimore and made important contributions to the fields of pathophysiology and neuroradiology. The relationship between Cushing and Dandy was strained, the main cause being Dandy’s talent. Dandy discovered ventriculography and conducted an important study in cerebrospinal fluid physiology. He also made important findings in the treatment of acustic neurinoma and was the first to perform hemispherectomy to eradicate an infiltrating glioma in the nondominant hemisphere (86). He developed craniotomy techniques, performing the frontotemporal approach, a large flap used to treat vascular and neoplastic lesions. Dandy was credited with performing vascular surgery with the principle of selective obliteration of the aneurysm, sparing the parent artery, and in March 1937 he was the first to apply a silver clip to the neck of a posterior communicating artery (PComA) aneurysm (Figure 2) (45). Dott in 1931 used the frontotemporal approach for the surgical treatment of an intracranial aneurysm by wrapping it with a piece of muscle, but this approach became popular with Dandy (73). The frontotemporal approach was used by Dandy at the beginning of his surgical career to reach the pituitary region and later to treat vascular and tumoral lesions.
Figure 2: Schematic drawing showing the osteoplastic frontotemporal craniotomy performed by Dandy to treat a PComA aneurysm in 1937 (45).
The Leadership of Herbert Olivecrona

Herbert Olivecrona (1891-1980) is considered the father of the European School of Neurosurgery and one of the founders of modern neurosurgery. He started his career at the Serafimerlasarettet in Stockholm in 1918. One year later, he went to Baltimore to learn brain tumor surgery with Cushing, and in 1922 he performed his first tumor operation. A few years later, in 1927, he published his early experience in the treatment of brain tumors (Die Chirurgische Behandlung der Gehirntumoren: The Surgical Treatment of Brain Tumors), where he thoroughly analyzed the possible causes of surgical complications. In 1935, he became a Professor of Neurosurgery at the Karolinska Institute. In 1940 the Karolinska Hospital was opened, later becoming the foremost European neurosurgical school hospital (Figures 3 and 4).

Figure 3: Olivecrona performing an operation at the Karolinska Institute (Courtesy of Professor Lars Kihlström from the Department of Neurosurgery of Karolinska Institute).
The contributions of Olivecrona to the development of neurosurgical techniques are several. He emphasized the importance of a precise preoperative diagnosis of intracranial lesions. The surgical technique was performed while taking care to minimize trauma to the surrounding normal brain, and he considered perfect hemostasis mandatory for successful intracranial surgery. In 1930, Olivecrona introduced use of hydrogen peroxide solution to stop bleeding from small vessels in tumor cavities. Olivecrona was a pioneer in vascular neurosurgery and was the first to perform the arterio-venous malformation (AVM) operation (142). In 1935, he published a book entitled “Parasagittal meningiomas (Die parasagittalen Meningeome)”. In 1936, he published his early experience in AVM surgery in the Gefässmissbildungen und Gefässgeschwüste des Gehirns (Vascular Malformations and Vascular Tumors of the Brain) (107). Olivecrona removed OGM through an unilateral frontal approach with a partial lobectomy (174), and in 1946 he already had a total experience of 46 cases (27). Olivecrona also performed the osteoplastic craniotomy, especially to reach lesions of the temporal region (107, 148). In 1951, Olivecrona wrote down his thoughts about the development of neurosurgery. He emphasized advancements in psychiatric neurosurgery by Egas Moniz and also in functional neurosurgery. Moreover, he established the basis for neurosurgical training, predicting subspecialization by
subspecialists, which he referred to as “super-neurosurgeons”. He first posed the question of whether a neurosurgeon trained in a specialized field, such as pediatric neurosurgery, should be allowed to perform vascular or spinal surgeries (176). This question is today a pressing reality.

Olivecrona’s pupils became the founders of European neurosurgery (Figure 5). Early on, he understood the importance of collaboration with the departments of neurology, neuroradiology, and neurophysiology. In his view, this was the key to success, and it remains at the basis of the organizational structure of the Karolinska University Hospital. In this environment, Lars Leksell, a pupil of Olivecrona’s, developed his stereotactic system for functional neurosurgery and radiosurgery, the Leksell Gamma Knife (142).

Figure 5: Olivecrona and his pupils. European directors. First sitting on the right Lars Leksell (1907-1986) and first on the left Gösta Norlén (1906-1992) (Courtesy of Professor Lars Kihlström from the Department of Neurosurgery of Karolinska Institute).
Aarno Snellman (1893-1964) (Figure 6) is considered the founder of neurosurgery in Finland. He was a general surgeon at the beginning of the career, working with Simo A. Brofeldt (1892-1942), the head of the Helsinki Surgical Department. Other surgeons before him who were interested in neurosurgery included Ali Krogius, Richard Faltin, and A.J. Palmen. The Ph.D. thesis of the latter in 1914 was entitled “Features of Intervertebral Tumor”. Another person contributing to the field of neurosurgery in Finland was F. Langenskiöld, who was a student of Cushing in 1929 (233-235). Neurosurgical operations were performed in 1932 at the Red Cross Hospital (today Töölö Hospital) founded by General C.G.E. Mannerheim (Figures 6-8). His sister Sophie Mannerheim, a head nurse, founded in Helsinki the school of nursing at Kirurginen Hospital.

Figure 6: Aarno Snellmann (in the centre) with the head of the nurse Berrit Kihlman at the Christmas party of the Red Cross Hospital in 1942. Serious faces: there was a war on, and the previous driving chief surgeon Simo A. Brofeldt (1892-1942) had died.

Figure 7: Marshal Mannerheim cheering a patient at the Red Cross Hospital in 1942.
In spring 1935, Snellman went to the Serafimer Hospital of Karolinska Institute, Stockholm, Sweden, to study with Olivecrona for almost six months. When he returned to Finland, he performed the first neurosurgical operation (September 18, 1935). Thus, the neurosurgical department was launched at the Red Cross Hospital, and it was the only neurosurgical department in Finland until 1967. After Snellman, S.G.L. af Björkesten (1912-1974), a talented and brilliant neurosurgeon, became the chairman of the Helsinki Department of Neurosurgery on February 1, 1963. He spent six months with Olivecrona in 1952. After af Björkesten, Henry Troupp (1932- ) became the chairman of the Helsinki Department of Neurosurgery in 1976 (233-235). The craniotomy used by Snellman and later by af Björkesten and Troupp for vascular or neoplastic lesions of the anterior skull base was a large frontotemporal craniotomy (Figures 9-13).
Figure 9: On the left Professor Snellman washing the head of a patient in 1953; the anesthetist was Mirja Tappura. She was the first anesthetist of Töölö Hospital and became the first head of anesthesiology of the hospital. In 1964 she moved to Tampere. On the right af Björkesten (assistant) and Snellman together performing a neurosurgical operation in 1953.

Figure 10: On the left: sister Laina (Moisio), Professors Snellman and af Björkesten performing a neurosurgical operation. Notice the basic equipment for keeping warm the saline solution for flushing the wound. On the right Professors Troupp (assistant, left), af Björkesten (surgeon, centre) and Snellman (spectator, right) during a neurosurgical operation.
Figure 11: Left picture: Professor af Björkesten in 1960. He became Professor in 1963. Right picture: Professor Troupp, young medical student, suturing a patient wound in 1955, twenty-one years before his Professorship. In the picture sister Maire (Reuna) assisting from the outpatient clinic ward.

Figure 12: Anterior-posterior conventional angiography (left) and lateral (right) view showing a large right frontal craniotomy (arrows) for aneurysm surgery.
Figure 13: Transcript of the operation report for an aneurysm surgery performed by Professor af Björkesten on August 12, 1957.

Present state. General condition. No heart or pulmonary problems. RR 110/70. No gastric problems. Teeth cared for. Neurologic status:

5.8.-57 (af Björkesten) Verified subarachnoidal bleeding, symptom-free, except for headache more on the right side of the head. Routine examinations.

6.8.57. Image of the skull: no obvious abnormalities.

EEG: Arrhythmia not classified (labilitas functionis).

Angiography (Left internal carotid) No pathology.

12.8.57. Ligatura aneurysmatis

af Björkesten – Troupp – Valtosen – o.s. – Karu
Intub. + metatalapine (Virkkala)


the aneurysm, which is located in the central part of the bifurcation. Without major complications, I sutured below the central part of the aneurysm, but the suture slipped away from the aneurysm base, making the operation more difficult. Also close to the aneurysm and below but more on the medial side was a second vessel (choroid artery?), which could not be dissected from the neck. It would have been mandatory to close both vessels at the same time, hiding the carotid from everything. Thus, the suture attempt was abandoned. I prepared a small opening in the aneurysm base and at the periphery of the angle between the carotid and the opening. A different silver staple was applied on the neck of the aneurysm. This was done without bleeding; the clip was located well, and if it would be seen all the aneurysm neck bridging compressed.

There was no bleeding. Dura suture with silk, suture of the periosteum with silk, and the central suture of the bone with flax. The bone was fixed with two metallic sutures. Muscles, galea, and skin suture.

The patient woke up after the operation. Condition was good, no paresis.

20th Century and the Microsurgical Leadership of Yaşargil

The microsurgical era in neurosurgery started with the use of the operative microscope. In the 1950s, Theodore Kurze (1922-2002), a neurosurgeon of the University of Southern California, Los Angeles, recognized the surgical microscope as an important instrument in acoustic neurinoma surgery. In 1957, he performed the first craniotomy on a human being under the microscope (61). Thereafter, the use of the microscope became increasingly frequent worldwide.

Microneurosurgical techniques introduced by Yaşargil (1925- ) revolutionized the neurosurgical field. Yaşargil worked at the University Hospital of Zurich for 40 years. He started his training in 1953 with Hugo Krayenbühl (1902-1985). At the beginning of his career, between 1958 and 1965, Yaşargil was active in the field of cerebral angiography and functional neurosurgery. In 1965, he went to learn the microneurosurgical techniques at the University of Vermont, Burlington, Vermont, where Jacobson and Donaghy established the first microvascular training laboratory in 1958. During his training he learned how to perform microsutures on animal vessels and how to use bipolar coagulation. Upon using bipolar forceps, Yaşargil was certain that microsurgical techniques were possible (258). He returned to Zurich, where he developed his own microneurosurgical instruments between 1967 and 1993. The routine use of microneurosurgery began on January 18, 1967, and on October 30, 1967 the first extracranial-intracranial bypass was performed. Milestone microneurosurgical principles of Yaşargil were based on cisternal approaches and on the knowledge of bipolar coagulation techniques (257). Zurich became the world center for learning microneurosurgical techniques; more than
3000 foreign neurosurgeons traveled here to learn these techniques, among them the present Professor and Chairman of Helsinki Neurosurgery Department, Juha Hernesniemi. Yaşargil wrote in his biography that all visiting colleagues from abroad were stimulating with their criticism, improving the microneurosurgical techniques (258). After his retirement in 1993, Yaşargil analyzed the data collected during his years in Zurich and wrote volumes IVA and IVB of Microneurosurgery, where he described the microsurgical principles for performing anterior skull base meningioma surgery through pterional craniotomy and the transsylvian approach (258); his microsurgical techniques are still used today, routinely applied worldwide.
Microsurgical Anatomy of Anterior Skull Base

Bone Structures

Anterior Cranial Fossa

The skull is divided into the cranium and the facial skeleton. The cranium is further divided into the calvarium and the cranial base (194). The calvarium or calvaria (from Latin calva: bald, plural calvariae) is the upper part of the cranium and surrounds the cranial cavity containing the brain. The calvarium is formed by the following bones: frontal, parietal, temporal, and occipital. The cranial base has an exocranial and endocranial surface. Both of these surfaces are divided into three regions: anterior, middle, and posterior. The anterior cranial fossa (ACF) is the endocranial surface of the skull, bordered posteriorly by the sphenoid ridge and joined medially by the chiasmatic sulcus.

Lamina Cribrosa of the Ethmoid Bone

The floor of the ACF is formed by the frontal, ethmoid, and sphenoid bones. Frontal and sphenoid bones roof the orbits. At the midline anterior to the ethmoid, a ridge: the frontal crest, is formed by the frontal bones (134). Located between the frontal bones, at the ACF, is the ethmoid bone, including the crista galli and the cribriform plate. The crista galli and the frontal ridge are the anterior attachment of the falx cerebri (134, 194).

The ACF is not flat, and this is important for surgery. The lowest part is the cribriform plate; this is part of the nasal cavity roof and contains olfactory bulbs and the anterior and posterior ethmoidal foramen. Through these two foramen run the anterior and posterior ethmoidal arteries and veins. Many holes are present in the cribriform plate for the filaments of the olfactory nerve; they are covered by dura mater and arachnoid membrane.

Between the frontal ridge and the crista galli is a small hole: the foramen cecum, where a small vein comes from the nasal cavity reaching the SSS. The chiasmatic sulcus and the sphenoid ridge separate the anterior
cranial fossa from the middle cranial fossa. The distance from the foramen cecum to the frontosphenoidal suture is about 3 cm, and this is the area where OGMs originate (134, 209).

Olfactory Fossa

Olfactory epithelium is located at the roof of the nasal cavity, in the superior nasal conchae, and in the nasal septum. The nerve fibers pierce the cribriform plate to synapse in the olfactory bulb, which appears as an ovoid structure located in the olfactory groove of the cribriform plate. The olfactory groove is covered by dura mater and averages 15 mm in length and 5 mm in width. The olfactory bulb averages 12 mm in length and 5 mm in width. The olfactory tract averages 3 cm in length (26). The posterior part of the olfactory tract has a triangular section with three crests: internal, external, and superior. Right and left olfactory tracts run under the surface of the inferior frontal lobes, extending to the olfactory areas (26, 133, 177). Approaches to the anterior cranial base can involve the transection of the nerves to gain access to the posterior part of the anterior skull base; an osteotomy around the cribriform plate includes all of the olfactory nerves that exit the skull base (47). Nerve fibers piercing the cribriform plate are very fragile and often are injured by the slightest manipulation.

Sphenoid Bone

The central portion of the sphenoid bone is the pituitary fossa, which is limited by the tuberculum sellae anteriorly, the dorsum sellae posteriorly, and the diaphragma sellae superiorly. This is the dura covering the pituitary gland with a small central opening for the pituitary stalk (195). This layer of dura extends from the posterior clinoid processes to the tuberculum sellae. The tuberculum sellae is an osseous protuberance between the chiasmatic sulcus and the anterosuperior limit of the pituitary fossa (Figure 14). The chiasmatic sulcus is a shallow depression between the optic foramina, bounded posteriorly by the tuberculum sellae and anteriorly by the planum sphenoidalis. It is located anterior to the optic chiasm, explaining the early
diagnosis of TSM due to a visual deficit. The limbus sphenoidalis is the small area between the planum sphenoidalis and the chiasmatic sulcus. The planum sphenoidalis is the smooth surface of the medial portion of the lesser sphenoid wings that is in contact with olfactory tracts, the gyrus rectus, and the posterior portion of the frontal lobe. The dura mater of the planum sphenoidalis, limbus sphenoidalis, chiasmatic sulcus, tuberculum sellae, and diaphragma sellae are all sphenoidal structures from which a TSM can originate (133). Except for the dura of the diaphragma sellae, all other dura locations can be removed, achieving Simpson grade 1.

![Diagram of the planum sphenoidalis, chiasmatic sulcus, tuberculum sellae, sella turcica, and dorsum sellae of a skull specimen.](image)

**Superior Orbital Fissure**

The superior orbital fissure (SOF) is located between the less and greater sphenoid wings. Passing through this foramen are the oculomotor, trochlear, abducens, and ophthalmic nerves and the ophthalmic veins. The SOF is located laterally and inferiorly to the anterior clinoid process (ACP), and it is opened to expose the cavernous sinus structures (194).

**Anterior Clinoid Process**

The ACP is the medial part of the lesser sphenoid wing and covers the lateral part of the optic canal (194). Together with the orbital part of the frontal bone, the ACP covers the orbital roof and the lateral part of the optic canal. The ACP is an important zone of dural attachment for the falciiform ligament, extending from the ACP to the planum sphenoidale and covering the roof of the optic canal. The orbital roof and the ACP
can be pneumatized from the extension of ethmoidal and sphenoid sinuses, and this must be borne in mind when removing the ACP (209).

Vascular and Dural Structures

Ophthalmic Segment of the ICA and Dural Rings

The ICAs are located on both sides of the sphenoid bone, whereas the basilar artery (BA) lies against the posterior surface of the sphenoid bone. Both ICAs, their perforators, and all arteries forming the circle of Willis may be encased or dislocated by a meningioma originating from the ACF.

The ICA coming from the cavernous sinus makes the extradural and extracavernous anterior loop (C3 segment) between the proximal and distal rings inferomedial to the ACP.

The lateral wall of the cavernous sinus is formed by the superficial and inner dural layers. These two layers separate at the anterior portion of the cavernous sinus: the inner layer running inferior to the ACP and surrounding the C3 segment of the ICA forms the proximal ring, which is the roof of the anterior cavernous sinus; the superficial layer covering the superior surface of the ACP envelops the ICA and forms the distal ring. Anterior clinoidectomy is necessary to expose this segment of the ICA. Intradural segments of the ICA begin from the distal ring: the C2 segment consists of the ICA between the distal ring and origin of the PComA and is also called the ophthalmic segment of the ICA (52); the C1 segment arises from the origin of the PComA and extends to the ICA bifurcation (253). The ophthalmic segment of the ICA presents several branches. The largest is the ophthalmic artery (OA) arising from the dorsal or dorsomedial surface of the ICA just as it penetrates the intradural space. The OA originates below the optic nerve and extends to the optic canal. Anterior clinoidectomy is mandatory for proper exposure of the OA and ophthalmic segment of the ICA. The superior hypophyseal artery is another important perforator arising from the medial or inferomedial surface of the ophthalmic segment of the ICA just before the origin of the PComA (52). This perforator may have a horizontal direction or may ascend or descend; it supplies the optic nerve and chiasm, the superior aspect of the pituitary gland and stalk, and the dura around the cavernous sinus (Figure 15) (52, 195).
Arterial Supply to the Dura Mater of the Anterior Cranial Fossa

The dura of the ACF has many invaginations and is rather thick everywhere except in the region of the cribriform plates. The medial part of the dura is supplied by branches of the ethmoidal arteries, and the lateral parts by frontal branches of the middle meningeal artery.

Anterior and posterior ethmoidal arteries (AEAs; PEAs) originate from the OA, are the predominant vascular support of the ACF dura and of the olfactory bulb and tract and form the main supply to the OGM.

The anterior skull base receives vascular supply from the ethmoidal arteries, and consequently their coagulation, necessary during the removal of OGM, results in ischemic damage to the olfactory nerve. The external carotid artery (ECA) and ICA anastomose via the frontal branch of the middle meningeal artery (MMA), which
connects the ethmoidal branches of the OA (47, 67, 134, 194).

**Arterial Supply to the Dura of the Anterior Clinoid Process**

The ACP is the medial part of the lesser wing of the sphenoid bone. With the orbital part of the frontal bone, the ACP covers the orbital roof and the lateral part of the optic canal. Important dural attachments to the ACP are a) the anteromedial portion of the tentorium with the anterior and posterior petroclinoid folds and the interclinoid folds and b) the falciform ligament extending from the ACP to the planum sphenoidale covering the roof of the optic canal. These dural structures receive their main vascular supply from the OA and from its branches, the ethmoidal arteries (194). The optic nerve proximal to its entrance to the optic canal may be covered by the falciform ligament for a length varying between 1 mm and 1 cm (195). The main vascular supply for the optic nerve comes from the superior hypophyseal arteries, and care should be taken to avoid damaging them, as this may lead to ischemia of the optic nerve (241).
“... non ragioniam di lor, ma guarda e passa”.

Dante, The Divine Comedy, Inferno Canto III: 51

Classical Approaches to Anterior Skull Base

Pterional Approach

The frontotemporal approach applied by Dandy and Dott was later popularized by Yaşargil. In Microneurosurgery volume I, Yaşargil described the technique of the interfascial pterional craniotomy. The head of the patient is elevated slightly, rotated about 30° to the contralateral side, with the direction of the head around 20° vertex down. The frontal lobe falls away from the orbital roof and the sphenoid ridge is directed vertically in the operating field. The skin incision begins 1 cm superior to the anterior aspect of the auricle extending to the temporal crest in a direction perpendicular to the zygoma. Retraction of the temporal muscle and fascia is done through an interfascial approach. Burr holes are located 1) superior to the frontal zygomatic suture under the linea temporalis; 2) at the frontal bone 3-4 cm superior to the first burr hole and 1-2 cm above the orbital rim, avoiding the frontal sinus; 3) along the linea temporalis; and 4) in the squamous temporal bone (Figure 16). The sphenoid ridge is flattened with a drill, and the purpose of the approach is to have the sylvian fissure in the middle of the opening. Advantages of the pterional approach are to spare the SSS and frontal cortical veins, to avoid compressing the frontal lobes, and simultaneously to allow the surgeon to visualize the anterior circulation, the basal feeders, and the optic nerve and chiasm. This approach was used by Yaşargil to treat aneurysms of the anterior circulation and upper basilar region and all tumors of the sellar and parasellar regions (256).
Fronto-Orbital and Fronto-Orbitozygomatic Approaches

Jane in 1982 (114) described a modification of the frontal craniotomy applied first by McArthur in 1912 and Frazier in 1913 to reach the pituitary region (74, 155). The technique consisted in a bicoronal skin incision to expose the supraorbital nerve and artery, which are often sacrificed. Two burr holes are made: one at the midline, at the level of the orbital ridge, and the other just behind the arch of the zygomatic process (Figure 17). Both burr holes are connected by using a Gigli saw, nowadays replaced by a high-speed drill, including the superior orbital rim and part of the orbital roof. Three or four centimeters of the orbital roof can be removed by using rongeurs. Through this
approach, the brain retraction to reach the sella turcica or the anterior cerebral artery (ACA) complex is minimal. Jane's approach removes the frontal and orbital rim in one bone fragment; the disadvantage of the technique with frequent opening of the frontal sinus is often the sacrifice of the supraorbital nerve and artery with CSF leakage and disappearance of the frontal wrinkles.

This approach is recommended by Al-Mefty and Sekhar when treating OGM, ACM, and TSM (3-6, 208, 209). Al-Mefty stresses the following advantages: 1) minimal brain retraction; 2) access to the tumor via different routes (subfrontal, subtemporal, transsylvian); 3) ability to enter the cavernous sinus if needed; and 4) possibility for early interruption of the tumor blood supply through the sphenoid ridge for ACM and TSM (3, 5, 6). Haddad and Al-Mefty recommend using spinal drainage to achieve a slack brain (91). Sekhar recommend a CSF drain or the direct opening of the basal cisterns to release CSF during subfrontal dissection; furosemide or mannitol can be used if necessary (210). Sade and Lee recommend a cranio-orbital approach associated with extradural clinoidectomy and opening of the falciform ligament before ACM removal to decompress the optic nerve even if the meningioma is not in the optic canal (203). Risi et al. reported a series of 34 ACM patients with complete removal of the sphenoid wing, including the anterior clinoid and part of the planum sphenoidalis, with early devascularization of the tumor and minimal brain retraction when resecting the zygomatic arch (196).

Figure 17: 3D-CT skull reconstruction and schematic drawing showing the cranio-orbitozygomatic approach (114).
Bifrontal Approach

The bifrontal craniotomy allows the access to the ASB through an interhemispheric approach. The technique consists in a bicoronal skin incision, the burr holes are located behind the arch of the zygomatic process and frontally paramedian and anterior to the coronal suture (Figure 18). The advantage of the interhemispheric route is early access to the anterior cerebral arteries and the optic nerves without opening the frontal sinus, but care must be taken to preserve the SSS and the bridging veins (154). The frontal sinus is always opened through this approach and can be sealed with a flap of pericranial tissue. To completely remove the tumor, the dura of the skull base should be accessed with opening of the ethmoid sinus, and reconstruction of the cribiform plate is covered with a graft of pericranial tissue and Gelfoam to prevent a CSF leak.

In the microsurgical technique of Sugita, the bifrontal craniotomy is preferred for TSM surgery to avoid brain retraction. After craniotomy, the anterior portion of the tumor is removed, and after partial removal the attachment to the optic nerves can be dissected. Following the arachnoidal plane, the tumor is removed and a small piece can be left attached to the optic nerve to prevent visual function worsening. Sugita affirmed that large TSMs can be removed also through a unilateral frontal craniotomy, but the bilateral approach is preferred because of the larger operating field and less brain retraction (220).
Frontolateral Approach

Al-Mefty and Babu recommended a unilateral frontal craniotomy with orbital osteotomy to prevent bifrontal retraction, leading to possible mental changes (4, 5). A recent anatomical study compares surgical exposure of the pterional, orbitozygomatic, and minisupraorbital approaches. The authors concluded that the minisupraorbital approach with removal of the orbital rim gives a similar surgical view as the pterional and orbitozygomatic approaches. Inclusion of orbital osteotomy is not necessary or beneficial to reach and remove the ASB (71). A recent cadaveric study compares the pterional approach with the lateral supraorbital approach; the authors concluded that both approaches provide similar exposure to the sellar, suprasellar, and anterior communicating artery (AComA) areas (204). The authors further concluded that the pterional approach gives better exposure of the retrosellar area. In our opinion, the LSO approach also gives good exposure to this region.

Samii after extensive skull base surgery experience came to the conclusion that the frontolateral approach (without orbital
inclusion) is sufficient to reach and properly treat ACF lesions (159, 161).

Meningiomas: General Concepts

Meningioma is a term first used by Cushing in 1922 to describe a benign tumor originating from the meninges of the central nervous system. Meningiomas are derived from the neuroectoderm and arise from arachnoidal cap cells. Meningiomas account for 10-15% of all brain tumors (7). They are the most frequent brain tumors originating from non-neuroepithelial progenitor cells. Usually, they are benign and completely resectable. Although they can potentially occur at any site in the meninges, certain intracranial locations are more common than others; parasagittal, attached to the falx, over the cerebral convexities, in the olfactory groove, on the tuberculum sellae, along the sphenoid ridge, in the cerebellopontine angle, along the clivus, and at the foramen magnum. Most meningiomas are well-demarcated, round or oval, frequently lobulated attached to the dura. In a minority of meningiomas a dural attachment cannot be shown. The benign meningioma tend to compress the brain but not invade it (219). Approximately 15% of meningiomas have atypical features. Aggressive or malignant meningiomas are characterized by abundant mitosis and invasion into brain tissue. Less than 0.1% of meningiomas can metastatize to extracranial sites such as the lung, liver, pleura, and lymph nodes. Their etiology remains unknown and may be multifactorial, environmental (head trauma, viruses, radiation) or genetic (chromosome 22 deletions, neurofibromatosis type 2) (19, 189).

General Principles of Meningioma Surgery

The treatment options of meningiomas are surgery, radiotherapy or a combination of the two. The goal of surgery depends upon meningioma location and the patient's clinical condition. Complete resection involves removal of the dura and the bone from which the tumor originates. The surgical approaches are selected according to the tumor location. Especially for ASB meningioma, a small approach can be enough to completely remove the lesion. The major vascular supply of meningiomas comes from the dural attachment, but in larger meningiomas there can be also feeders from the surrounding arteries. The first step in meningioma surgery is to devascularize
the tumor with high power coagulation and after that to debulk it. A large meningioma is debulked with the help of ultrasonic aspirator and after that it is gradually dissected from the surrounding cerebrovascular structures; small meningioma can be removed en-block after dura coagulation (137). Simpson in 1957 (212) established four grades of meningioma resection grade I: complete meningioma resection with the dura and underlying bone; grade II: complete meningioma removal with coagulation of the dural attachment; grade III: complete meningioma removal without resection or coagulation of dural attachments; grade IV: subtotal resection. This classification is very useful in evaluating tumor recurrence. In Simpson’s series, grades I through IV had recurrence rates of 9%, 19%, 29%, and 40%, respectively, at 10 years. Jääskeläinen et al. (111) analyzed 657 meningioma patients over a 20-year period; the overall recurrence rate was 19%. Risk factors for recurrence were simple coagulation of the tumor base, invasion of bone, and soft tumor consistency. Mirimanoff et al. (156) reviewed 225 patients operated on from 1962 to 1980 and found that the degree of resection is the most important factor in recurrence. After subtotal resection, 37% of tumors had progressed in 5 years, 55% in 10 years, and 91% in 15 years. Radiation therapy can arrest the growth of some meningiomas. The indication for their use includes: residual tumor after surgery, tumor recurrence, meningioma that could not be treated surgically and malignant lesions (172).

Clinical Characteristics of Olfactory Groove, Anterior Clinoidal, and Tuberculum Sellae Meningiomas

OGMs account for 8-13% of all intracranial meningiomas (159). They arise at the cribriform plate of the ethmoid bone and at the frontosphenoidal suture at the midline of the ACF (37, 209, 236). They are usually diagnosed when they reach a large size (173). The most frequent symptom of patients with OGMs is mental change, followed by headache, visual deficit, hyp anosmia, and epileptic seizures (14, 159, 173).

ACMs are frequently attached to, or even encasing, adjacent neurovascular structures of the anterior skull base, making the complete removal challenge (5). ACMs account for less than 10% of supratentorial meningiomas and they were first described by Frotscher and Becker in 1910 in an autopsy of a 72-year-old man (75). In the past, they were often included in the group of sphenoidal meningiomas, masking their true surgical and clinical outcome (179). Medial
sphenoid wing meningiomas form a different group of meningiomas, growing mainly towards the temporal lobe in the medial cranial fossa and frequently infiltrating the cavernous sinus. We consider ACMs to be meningiomas that originate from the dura of the inferior, superior, and lateral aspects of the ACP and grow cranially or into the optic foramen. A recent report defines clinoidal meningiomas as those that have the epicenter of the tumor base on the ACP and grow upwards, forming a small peduncle (179). However, in large meningiomas, invasion to such surrounding structures as the sellar region, cavernous sinus, and the temporal portion of the medial sphenoid ridge makes it difficult to define origin before resection. In these cases, typical tumor shape and location of ACP in the center of the lesion usually reveal that the tumor belongs to the ACM group.

TSMs comprise 5-10% of intracranial meningiomas (40, 161, 214). Their location is challenging because of adjacency to neurovascular structures of the anterior skull base. Despite this, their microsurgical treatment today shows favorable results because visual field deficits usually lead to diagnosis at a stage when the tumor is still small (151). Cushing and Eisenhardt (1938), in describing their series of 28 suprasellar meningiomas, wrote: “... Few promise in the future to be easily recognized while still of small size” (40). However, with improved imaging and the introduction of microsurgical techniques, the outcome is good. TSMs form a subgroup of meningiomas often contained within the group of suprasellar meningiomas, which also includes anterior and posterior clinoid process, planum sphenoidalis, olfactory groove, optic foramen, and diaphragma sellae meningiomas (40, 112, 115, 161). Cushing and Eisenhardt, in their first classification, did not differentiate between TSMs and diaphragma sellae meningiomas. This differentiation was introduced by Kinjo et al. in 1995 (125), when they reported 12 cases of diaphragma sellae meningiomas. However, from the microsurgical point of view, we do not consider diaphragma sellae meningiomas to form a clearly different entity and include them as TSMs, defined as those meningiomas originating from the dura of the tuberculum sellae, prechiasmal sulcus, diaphragma sellae, limbus sphenoidalis, and planum sphenoidalis and growing upwards with the main location over the sella (117). In large meningiomas, invasion to the surrounding structures, anterior clinoid processes, cavernous sinus, and the temporal portion of the medial sphenoid ridge makes it difficult to define origin before resection. In these cases, typical tumor shape and main location over the sella reveal that the meningioma belongs to the TSMs. Contrary to OGMs, which are diagnosed when large-sized, ACMs and TSMs, because
of their close relationship to the optic nerve and chiasm, are diagnosed when they are small, and the most frequent symptom is visual impairment, followed by headache, epileptic seizures, and endocrinological symptoms (16, 173). A report written in 1959 by neurosurgeon Olli Heiskanen of the Helsinki Neurosurgical Department describes 14 anterior clinoidal meningioma cases; 11 presented with headache, eight with visual deficit, six with epilepsy, four with exophtalmus, and two with diplopia (98).

Microsurgical Treatment of OGM, ACM, and TSM through Classical Surgical Approaches

Olfactory Groove Meningiomas

Italian surgeons were pioneers in treating intracranial meningiomas, and the first successful surgical removal of an intracranial meningioma was performed in 1835 by Pecchioli, a Professor of Surgery at the University of Siena (80). The first surgical report of an OGM comes from Francesco Durante in Rome (88). In 1885, he performed a resection of an olfactory meningioma through a left subfrontal approach; the patient had a good outcome (63, 64). Harvey Cushing published in 1938 his lifetime experience of 29 patients with OGMs operated on via a unilateral frontal craniotomy (40). In the same year, Dandy published a bifrontal approach to treat OGMs with partial bilateral lobectomy (44). In 1935, Olivecrona operated on an OGM through a unilateral frontal craniotomy and partial frontal lobectomy (174). Tönnis reported in 1938 a bifrontal approach with closure of the anterior portion of the SSS, but preservation of the frontal lobe (232). Kempe proposed a unilateral approach by pterional route, allowing dissection of the posterior part of the lesion, thereby preserving neurovascular structures and avoiding brain retraction and opening of the frontal sinus (122). The bifrontal craniotomy with orbital removal/transbasal extension was defined by Derome in 1972 (56). In the same year, Bakay reported a personal series of 25 olfactory meningiomas: 12 cases were treated by using a unilateral frontal approach and 13 cases by using bifrontal craniotomy (13).

After these important initial surgical reports, several authors have published their operative experience, macro- or microsurgical, in the management of OGMs
using unilateral (12, 57, 96, 97, 122, 159, 154, 157, 159, 162, 173, 184, 187, 200, 206, 169, 184, 206, 214, 216, 236-238, 254, 255) or bilateral approaches (12, 14, 55, 65, 79, 94, 96, 97, 99, 120, 122, 131, 146, 147, 150, 211, 214, 216, 229).

Table 1. Macro- and microsurgical series of OGM surgeries through different approaches.

<table>
<thead>
<tr>
<th>Author(s), year (reference)</th>
<th>Approach</th>
<th>Death or morbidity/operations (mortality or morbidity)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Macrosurgery</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Durante F., 1885 (63)</td>
<td>unilateral subfrontal</td>
<td>0/1 (no mortality)</td>
</tr>
<tr>
<td>Dandy W., 1938 (44)</td>
<td>bifrontal with bifrontal polar lobectomy</td>
<td>NA</td>
</tr>
<tr>
<td>Cushing H. and Eisenhardt L., 1938 (40)</td>
<td>unilateral frontal with partial bifrontal lobectomy</td>
<td>8/29 (mortality)</td>
</tr>
<tr>
<td>Tönness W., 1938 (232)</td>
<td>bifrontal without frontal lobectomy</td>
<td>0/3 (no mortality)</td>
</tr>
<tr>
<td>Olivecrona H., 1946 (27)</td>
<td>unilateral frontal</td>
<td>NA/46</td>
</tr>
<tr>
<td>Bakay L. and Cares H.L., 1972 (13)</td>
<td>unilateral frontal</td>
<td>1/12 (mortality)</td>
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<tr>
<td><strong>Microsurgery</strong></td>
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<td></td>
</tr>
<tr>
<td>Yaşargil M.G., 1996 (255)</td>
<td>pterional-transsylvian</td>
<td>0/14 (no mortality)</td>
</tr>
<tr>
<td>Yamashita J. et al., 1980 (250)</td>
<td>NA</td>
<td>6/30 (mortality)</td>
</tr>
<tr>
<td>Rubin G. et al., 1995 (200)</td>
<td>bifrontal; pterional; unilateral frontal</td>
<td>6/67 (mortality)</td>
</tr>
<tr>
<td>Ojemann R.G., 1996 (172)</td>
<td>bifrontal</td>
<td>1/19 (mortality)</td>
</tr>
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<td>Gerber M. et al., 1998 (79)</td>
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<td>Paterniti S. et al., 1999 (184)</td>
<td>pterional</td>
<td>2/20 (mortality)</td>
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<td>Turazzi S. et al., 1999 (238)</td>
<td>pterional</td>
<td>1/37 (mortality)</td>
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<td>Tuna M. et al., 1999 (237)</td>
<td>NA</td>
<td>0/15 (no mortality)</td>
</tr>
<tr>
<td>D’Avella D. et al., 1999 (57)</td>
<td>pterional</td>
<td>0/6 (no mortality)</td>
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<td>El Gindi S., 2000 (65)</td>
<td>bifrontal</td>
<td>0/25 (no mortality)</td>
</tr>
<tr>
<td>Couldwell W.T. and Weiss M.H., 2000 (37)</td>
<td>bifrontal</td>
<td>NA</td>
</tr>
<tr>
<td>Hallaq P. et al., 2001 (94)</td>
<td>transsinal bifrontal osteoplastic</td>
<td>0/6 (no mortality)</td>
</tr>
<tr>
<td>Wei C.P. et al., 2002 (243)</td>
<td>bifrontal</td>
<td>0/1 (no mortality)</td>
</tr>
<tr>
<td>Obeid F. and Al-Mefty O., 2003 (169)</td>
<td>supraorbital subfrontal (uni-bilateral)</td>
<td>0/15 (no mortality)</td>
</tr>
<tr>
<td>Dolenc V.V., 2003 (59)</td>
<td>pterional</td>
<td>7/157 (morbidity)</td>
</tr>
</tbody>
</table>
Hentschel S.J. et al., 2003 (99) bifrontal 0/13 (no mortality)
Tuna H. et al., 2004 (236) bifrontal 0/19 (no mortality)
Spektor S. et al., 2005 (216) bifrontal 1/35 (mortality) 
\begin{itemize}
  \item unilateral subfrontal 0/9 (no mortality)
  \item pterional 0/18 (no mortality)
  \item fronto-orbital 0/7 (no mortality)
  \item subcranial 0/12 (no mortality)
\end{itemize}
Spektor S. et al., 2005 (216) bifrontal unilateral subfrontal 0/9 (no mortality)
Spektor S. et al., 2005 (216) bifrontal pterional 0/18 (no mortality)
Spektor S. et al., 2005 (216) bifrontal fronto-orbital 0/7 (no mortality)
Spektor S. et al., 2005 (216) bifrontal subcranial 0/12 (no mortality)
Reisch R. and Perneczky A. at al., 2005 (193) supraorbital subfrontal 0/21 (no mortality)
Tella Jr. O.I. et al., 2006 (229) uni-bifrontal 1/13 (mortality)
Bassiouni H. et al., 2007 (14) bifrontal pterional 3/36 (mortality)
Bassiouni H. et al., 2007 (14) bifrontal unilateral frontal 0/4 (no mortality)
Bassiouni H. et al., 2007 (14) bifrontal supraorbital 0/3 (no mortality)
Kanno T., 2007 (120) bifrontal NA
O’Brien D. et al., 2007 (168) frontal craniotomy 0/1 (no mortality)
Welge-Luessen A. et al., 2007 (244) bifrontal and frontal 0/12 (no mortality)
Colli B.O. et al. 2007 (34) bifrontal-uniorbital 2/17 (mortality)
Nakamura M. et al., 2007 (159) bifrontal 3/46 (mortality)
Nakamura M. et al., 2007 (159) frontolateral 0/34 (no mortality)
Gazzeri R. et al., 2008 (78) bifrontal 0/36 (no mortality)
El-Bahy K. et al., 2009 (66) frontolateral 1/18 (mortality)
Warren L.W. and Grant G.A., 2009 (242) fronto-orbitozygomatic 0/4 (no mortality)

For OGM surgery, Yaşargil recommended understanding the relationship between the posterior surface of the tumor and the ACA and optic nerves. The tumor must be debulked from its lateral portion and devascularized from its base. The ACA can be dissected along the lamina terminalis cistern (254, 255).

Hassler and Zenter first reported in 1989 a series of 11 olfactory meningiomas treated using the pterional approach (97). Many authors have subsequently reported this approach for OGMs (14, 26, 34, 57, 59, 96, 183, 184, 216, 238). Both pterional or minipterional approaches have the sylvian fissure in the center of the craniotomy, with partial exposure of the frontal and temporal lobes (70, 254, 255). No previous report describes the microsurgical treatment of OGMs through a minipterional approach.

Dolenc affirmed that complete opening of the sylvian fissure is mandatory when dealing with an OGM or TSM (59). Turazzi et al. reported their surgical experience of 37
OGMs through the pterional approach and emphasized the importance of opening the basal cisterns for CSF release and to get more space to visualize the necessary neurovascular structures. The author recommend that the opening of the sylvian fissure be only partial. In large meningiomas, debulking of the tumor enables dissection of the A2 branches and the posterior part of the tumor (238).

In 1996, Ojemann published 19 cases of OGM treated through bifrontal craniotomy. This approach is associated with less retraction of the frontal lobe with direct access to all sides of the tumor and allows the debulking of the tumor and simultaneous access to the base from which its vascular support is derived (172).

Colli et al. in 2007 published their series of 17 OGM cases treated through a bifrontal approach with unilateral orbitotomy (34). Mayfrank and Gilsbach reported 18 cases of OGM treated through unilateral frontal craniotomy and an interhemispheric route (154).

Nakamura et al. compared the outcome and recurrences of OGM when treated through pterional, bifrontal, and frontolateral approaches. Similar results were obtained in the pterional and frontolateral groups. The authors recommended the use of the frontolateral approach instead of the bifrontal approach (161).

**Anterior Clinoidal Meningiomas**

The two most frequently described surgical approaches to remove ACMs are pterional (16, 82, 135, 160, 179, 188, 201, 255) and orbitozygomatic (4, 5, 91, 196, 209, 210).

**Table 2.** Macro- and microsurgical series of ACM surgeries through different approaches.

<table>
<thead>
<tr>
<th>Author(s), year (reference)</th>
<th>Approach</th>
<th>Death or morbidity/operations (mortality or morbidity)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cushing H. and Eisenhardt L., 1938 (39)</td>
<td>unilateral frontal with partial lobectomy</td>
<td>1/11 (mortality)</td>
</tr>
<tr>
<td>Uihlein A. and Weyand R.D., 1953 (240)</td>
<td>NA</td>
<td>17/52 (mortality)</td>
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<td>Holub K., 1956 (106)</td>
<td>NA</td>
<td>9/19 (mortality)</td>
</tr>
<tr>
<td>Heiskanen O., 1959 (98)</td>
<td>NA</td>
<td>NA/14</td>
</tr>
<tr>
<td>Olivecrona H., 1967 (175)</td>
<td>unilateral frontal</td>
<td>11/47 (mortality)</td>
</tr>
</tbody>
</table>
2 Review of the Literature

<table>
<thead>
<tr>
<th>Author(s) and Year</th>
<th>Approach</th>
<th>Mortality/Morbidity</th>
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<tbody>
<tr>
<td>Guyot J.F., 1967 (90)</td>
<td>NA</td>
<td>NA/13</td>
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<tr>
<td>Cook A.W., 1971 (35)</td>
<td>pterional</td>
<td>2/11 (mortality)</td>
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<td>Fischer G., 1973 (72)</td>
<td>NA</td>
<td>2/6 (mortality)</td>
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<td>Ugrumov V.M. et al., 1979 (239)</td>
<td>NA</td>
<td>3/17 (mortality)</td>
</tr>
<tr>
<td>Cophignon J. et al., 1979 (36)</td>
<td>unilateral frontal</td>
<td>0/6 (no mortality)</td>
</tr>
<tr>
<td>Symon L. and Jakubowki J., 1979 (225)</td>
<td>NA</td>
<td>1/30 (mortality)</td>
</tr>
<tr>
<td>McCarty C.S. and Taylor W.F., 1979 (147)</td>
<td>NA</td>
<td>NA/47</td>
</tr>
</tbody>
</table>

Microsurgery

<table>
<thead>
<tr>
<th>Author(s) and Year</th>
<th>Approach</th>
<th>Mortality/Morbidity</th>
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<tr>
<td>Yaşargil M.G., 1996 (255)</td>
<td>pterional-transsylvian</td>
<td>0/9 (no mortality)</td>
</tr>
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<td>Konovalov A.N. et al., 1979 (129)</td>
<td>NA</td>
<td>11/92 (mortality)</td>
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<td>Bonnal J. et al., 1980 (21)</td>
<td>pterional</td>
<td>3/9 (mortality)</td>
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<td>Pompili A. et al., 1981 (186)</td>
<td>frontotemporal</td>
<td>1/10 (mortality)</td>
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<td>Hakuba A. et al., 1981 (93)</td>
<td>orbitozygomatic</td>
<td>0/7 (no mortality)</td>
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<td>Sugita K., 1985 (220)</td>
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<td>0/7 (no mortality)</td>
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<td>Jan M. et al., 1986 (113)</td>
<td>NA</td>
<td>6/19 (mortality)</td>
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<td>Jääskeläinen J., 1986 (111)</td>
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<td>NA/79</td>
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<td>Al-Mefty O., 1991 (5)</td>
<td>fronto-orbitozygomatic</td>
<td>2/24 (mortality)</td>
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<td>Ojemann R.G. and Swann K.W., 1991 (173)</td>
<td>frontotemporal</td>
<td>0/18 (no mortality)</td>
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<td>Risi P. et al., 1994 (196)</td>
<td>fronto-orbitozygomatic</td>
<td>2/34 (mortality)</td>
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<td>Rubin G. et al., 1995 (200)</td>
<td>bifrontal; pterional; unilateral frontal</td>
<td>6/67 (mortality)</td>
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<td>Benjamin V. and McCormack B., 1995 (18)</td>
<td>pterional</td>
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<td>Haddad G.F. et al., 1996 (91)</td>
<td>orbitozygomatic</td>
<td>NA</td>
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<td>Ojemann R. G., 1996 (172)</td>
<td>frontotemporal</td>
<td>1/17 (morbidity)</td>
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<td>Puzzilli F. et al., 1999 (188)</td>
<td>pterional</td>
<td>5/33 (morbidity)</td>
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<td>Tuna M. et al., 1999 (237)</td>
<td>NA</td>
<td>0/2 (no mortality)</td>
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<tr>
<td>Tobias S. et al., 2003 (231)</td>
<td>pterional</td>
<td>0/25</td>
</tr>
<tr>
<td>Chatterjee P.R. et al., 2004 (31)</td>
<td>NA</td>
<td>0/1 (no mortality)</td>
</tr>
<tr>
<td>Tao C.S. et al. 2005 (227)</td>
<td>supraorbital-orbitozygomatic</td>
<td>1/12 (morbidity)</td>
</tr>
<tr>
<td>Reisch R. and Pernecky A. at al. 2005 (193)</td>
<td>supraorbital subfrontal</td>
<td>0/18 (no mortality)</td>
</tr>
<tr>
<td>Cui H. et al., 2007 (38)</td>
<td>pterional-extended pterional</td>
<td>0/26 (no mortality)</td>
</tr>
<tr>
<td>Pamir M.N. et al., 2008 (179)</td>
<td>pterional</td>
<td>0/43 (no mortality)</td>
</tr>
<tr>
<td>Sade B. and Lee H.J., 2008 (203)</td>
<td>fronto-orbital</td>
<td>0/52 (no mortality)</td>
</tr>
<tr>
<td>Bassioungi H. et al., 2009 (16)</td>
<td>pterional</td>
<td>2/104 (mortality)</td>
</tr>
<tr>
<td></td>
<td>fronto-orbitozygomatic</td>
<td>0/2 (no mortality)</td>
</tr>
<tr>
<td>Yang Y.M. et al., 2010 (251)</td>
<td>pterional; frontotemporal;</td>
<td>1/53 (morbidity)</td>
</tr>
</tbody>
</table>
Yaşargil reported only nine cases of medial sphenoid wing meningioma through a transsylvian approach and recommended not removing the part infiltrating the cavernous sinus in order to prevent cranial nerve palsy after surgery (255). In 2008, Pamir et al. described a consecutive series of 43 ACMs treated through a pterional approach. After craniotomy, the sylvian fissure was widely opened and the CSF removed to achieve a slack brain. The MCA was followed to the ICA and the tumor dissected following the arachnoidal plane. The dura of the ACP was removed in all 43 cases (179). Bassiouini reported a multicenter series of 106 ACMs, 104 treated using a pterional transsylvian craniotomy (in only two cases an orbitozygomatic approach was applied). The tumor was removed via a unilateral subfrontal route. Intradural clinoidectomy was performed in 16 cases where the tumor was inside the orbit and in an additional seven cases to relieve optic nerve compression and avoid its further damage during tumor removal (16). Ojemann reported a series of 17 ACMs through a frontotemporal craniotomy and a subfrontal route. After initial exposure, the medial portion of the sylvian fissure can be opened, followed by tumor debulking. It is important to dissect the MCA and follow it medially to the ICA. The author recommended an intradural clinoidectomy when the tumor is inside the optic canal (173).

Al-Mefty advised a fronto-orbitozygomatic approach to remove ACMs. After craniotomy, brain relaxation is achieved through lumbar drainage and opening of the basal cisterns. Elevation of the frontal lobe should be minimal (1.5 cm) to avoid harming the olfactory tract. The sylvian fissure is opened and the tumor if large can be debulked by an ultrasonic aspirator, after which the MCA branches can be visualized. With microdissection, the tumor capsule is removed from the vessels. The dissection follows all of the vessels (ICA and ACA), becoming easier in the proximity of the PCOMA and anterior choroidal artery (ACHA), i.e. along the arachnoidal plane. The optic nerve also has an arachnoidal membrane to facilitate the dissection (5). Al-Mefty advised intradural removal of the anterior clinoid process if the ACM or TSM is inside the optic canal or orbit. The pituitary stalk can be recognized by its color and vascular network. It is usually displaced backwards and to the opposite side and can be dissected following its arachnoidal plane (5, 149).
Tuberculum Sellae Meningiomas

The anatomical region from which the TSM originates is one of the most complex of the brain for both transcranial and transsphenoidal routes. The neural and vascular relationships with the sphenoid bone are key when treating TSMs. ICA and its branches, optic chiasm and nerves, and pituitary stalk can be attached, dislocated, and encased by a TSM making challenge a complete tumor removal. We consider the transcranial route preferable than the transsphenoidal one to achieve a complete tumor removal and to preserve the neurovascular structures. The most frequent microsurgical approaches to remove TSMs are pterional (6, 15, 17, 68, 81, 95, 112, 124-126, 151, 161, 171, 178, 180, 202, 207, 214, 222, 224, 254, 255), fronto-orbital, frontoorbitozygomatic (3, 6, 9, 10, 81, 114, 117, 124, 125, 141, 149, 208) frontolateral (76, 81, 124, 141, 161) and bifrontal (6, 10, 15, 76, 77, 81, 115, 125, 161, 171, 222, 224, 230).

Table 3. Macro- and microsurgical series of TSM surgeries through different approaches.

<table>
<thead>
<tr>
<th>Author(s), year (reference)</th>
<th>Approach</th>
<th>Death or morbidity/operations (mortality or morbidity)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Macrosurgery</strong></td>
<td></td>
<td></td>
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<tr>
<td>Cushing H. and Eisenhardt L., 1938 (40)</td>
<td>unilateral subfrontal</td>
<td>3/24 (mortality)</td>
</tr>
<tr>
<td>Olivecrona H., 1946 (27)</td>
<td>unilateral frontal</td>
<td>NA/42</td>
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<tr>
<td>Hänsel G. and Seeger W., 1977 (95)</td>
<td>pterional</td>
<td>0/5 (no mortality)</td>
</tr>
<tr>
<td>Jefferson A. and Azzam N., 1979 (115)</td>
<td>bifrontal</td>
<td>1/19 (mortality)</td>
</tr>
<tr>
<td>Ugrumov V.M. et al., 1979 (239)</td>
<td>NA</td>
<td>4/17 (mortality)</td>
</tr>
<tr>
<td>Kadis G.N. et al., 1979 (118)</td>
<td>bifrontal</td>
<td>13/105 (mortality)</td>
</tr>
<tr>
<td><strong>Microsurgery</strong></td>
<td></td>
<td></td>
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<tr>
<td>Yaşargil M.G., 1996 (255)</td>
<td>pterional-transsylvian</td>
<td>1/112 (mortality)</td>
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<tr>
<td>Konovalov A.N. et al., 1979 (129)</td>
<td>NA</td>
<td>5/68 (mortality)</td>
</tr>
<tr>
<td>Bonnal J. et al., 1980 (21)</td>
<td>frontotemporal</td>
<td>NA/12</td>
</tr>
<tr>
<td>Solero C.L. et al., 1983 (214)</td>
<td>unilateral frontal craniotomy with frontal lobectomy</td>
<td>13/55 (mortality)</td>
</tr>
<tr>
<td>Chan R.C. and Thompson G.B., 1984 (28)</td>
<td>NA</td>
<td>2/12 (mortality)</td>
</tr>
<tr>
<td>Symon L. and Rosenstein J., 1984 (224)</td>
<td>unilateral frontal osteoplastic</td>
<td>6/92 (mortality)</td>
</tr>
<tr>
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<td>bifrontal osteoplastic</td>
<td>0/4 (no mortality)</td>
</tr>
<tr>
<td>Reference</td>
<td>Year</td>
<td>Procedure(s)</td>
</tr>
<tr>
<td>-----------</td>
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<td>--------------</td>
</tr>
<tr>
<td>Al-Mefty O. et al., 1985</td>
<td>6</td>
<td>bifrontal (11 cases); pterional (4 cases); subfrontal (2 cases)</td>
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<tr>
<td>Sugita K., 1985</td>
<td>220</td>
<td>bifrontal</td>
</tr>
<tr>
<td>Jääskeläinen J., 1986</td>
<td>111</td>
<td>NA</td>
</tr>
<tr>
<td>Grisoli F. et al., 1986</td>
<td>87</td>
<td>pterional</td>
</tr>
<tr>
<td>Al-Mefty O. and Smith R.R., 1991</td>
<td>3</td>
<td>cranio-orbitozygomatic</td>
</tr>
<tr>
<td>Ojemann R.G. and Swann K.W., 1991</td>
<td>173</td>
<td>frontotemporal</td>
</tr>
<tr>
<td>Benjamin V. and McCormack B., 1995</td>
<td>18</td>
<td>pterional</td>
</tr>
<tr>
<td>Rubin G. et al., 1995</td>
<td>200</td>
<td>bifrontal; pterional; unilateral frontal</td>
</tr>
<tr>
<td>Kinjo T. et al., 1995</td>
<td>125</td>
<td>pterional (5 cases); bifrontal (3 cases); unifrontal (1 case); fronto-orbital (2 cases)</td>
</tr>
<tr>
<td>Ojemann R.G., 1996</td>
<td>172</td>
<td>pterional</td>
</tr>
<tr>
<td>Tuna M. et al., 1999</td>
<td>237</td>
<td>NA</td>
</tr>
<tr>
<td>Raco A. et al., 1999</td>
<td>190</td>
<td>NA</td>
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<tr>
<td>Arai H. et al. 2000</td>
<td>10</td>
<td>bifrontal + orbital rim</td>
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<tr>
<td>Ciric I. and Rosenblatt S., 2001</td>
<td>33</td>
<td>pterional; orbitozygomatic</td>
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<tr>
<td>Zevgaridis D. et al., 2001</td>
<td>262</td>
<td>frontobasal/frontotemporal</td>
</tr>
<tr>
<td>Ohta K. et al., 2002</td>
<td>171</td>
<td>pterional (15 cases); fronto-orbitozygomatic/fronto-orbital (10 cases); bifrontal (6 cases); others (2 cases)</td>
</tr>
<tr>
<td>Goel A. et al., 2002</td>
<td>81</td>
<td>unifrontal</td>
</tr>
<tr>
<td>Fahlbusch R. and Schott W., 2002</td>
<td>68</td>
<td>orbitofrontal</td>
</tr>
<tr>
<td>Jallo G.I. and Benjamin V., 2002</td>
<td>112</td>
<td>bifrontal</td>
</tr>
<tr>
<td>Dolenc V.V., 2003</td>
<td>58</td>
<td>orbitozygomatic</td>
</tr>
<tr>
<td>Chi J.H. and McDermott M.W., 2003</td>
<td>32</td>
<td>pterional</td>
</tr>
<tr>
<td>Takahashi J.A. et al., 2004</td>
<td>226</td>
<td>pterional</td>
</tr>
<tr>
<td>Benjamin V. and Russell S.M., 2005</td>
<td>17</td>
<td>pterional</td>
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<tr>
<td>Reisch R. and Perneczky A. at al. 2005</td>
<td>193</td>
<td>supraorbital subfrontal</td>
</tr>
<tr>
<td>Pamir M.N. et al., 2005</td>
<td>180</td>
<td>pterional</td>
</tr>
</tbody>
</table>
2 Review of the Literature

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Year</th>
<th>Approach</th>
<th>Mortality/No Mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schick U. and Hassler W., 2005</td>
<td>207</td>
<td>pterional</td>
<td>2/53 (mortality)</td>
</tr>
<tr>
<td>Bassiouni H. et al., 2006</td>
<td>15</td>
<td>pterional (49 cases); bifrontal (7 cases); unilateral subfrontal (4 cases); supraorbital (2 cases)</td>
<td>10/62 (morbidity)</td>
</tr>
<tr>
<td>Nakamura M. et al., 2006</td>
<td>161</td>
<td>pterional-frontotemporal</td>
<td>0/21 (no mortality)</td>
</tr>
<tr>
<td>Park C.K. et al., 2006</td>
<td>181</td>
<td>pterional</td>
<td>0/26 (no mortality)</td>
</tr>
<tr>
<td>Otani N. et al., 2006</td>
<td>178</td>
<td>pterional</td>
<td>0/32 (no mortality)</td>
</tr>
<tr>
<td>Kitano M. et al., 2007</td>
<td>126</td>
<td>pterional</td>
<td>0/12 (no mortality)</td>
</tr>
<tr>
<td>Li X. et al., 2007</td>
<td>140</td>
<td>unifrontal</td>
<td>NA/24</td>
</tr>
<tr>
<td>Kanno T., 2007</td>
<td>119</td>
<td>bifrontal</td>
<td>NA</td>
</tr>
<tr>
<td>de Divitiis E. et al., 2008</td>
<td>54</td>
<td>pterional</td>
<td>0/36 (no mortality)</td>
</tr>
<tr>
<td>Nozaki K. et al., 2008</td>
<td>166</td>
<td>frontotemporal</td>
<td>0/22 (no mortality)</td>
</tr>
<tr>
<td>Kim T.W. et al., 2008</td>
<td>123</td>
<td>unilateral frontal (20 cases); pterional (5 cases); fronto-orbital (2 cases)</td>
<td>0/27 (no mortality)</td>
</tr>
<tr>
<td>Suri A. et al., 2008</td>
<td>222</td>
<td>pterional; bifrontal; fronto-orbito-zygomatic</td>
<td>0/18 (no mortality)</td>
</tr>
<tr>
<td>Ganna A. et al., 2009</td>
<td>77</td>
<td>bifrontal</td>
<td>0/24 (no mortality)</td>
</tr>
<tr>
<td>Sade B. and Lee H.J., 2009</td>
<td>202</td>
<td>pterional</td>
<td>0/31 (no mortality)</td>
</tr>
<tr>
<td>Jung H.W. and Park C.K., 2009</td>
<td>117</td>
<td>fronto-orbito-zygomatic</td>
<td>NA</td>
</tr>
<tr>
<td>Warren L.W. and Grant G.A., 2009</td>
<td>242</td>
<td>fronto-orbito-zygomatic</td>
<td>0/10 (no mortality)</td>
</tr>
<tr>
<td>Fatemi N. et al., 2009</td>
<td>69</td>
<td>supraorbital keyhole</td>
<td>0/7 (no mortality)</td>
</tr>
<tr>
<td>Galal A. et al., 2010</td>
<td>76</td>
<td>frontolateral (18 cases); bifrontal (3 cases)</td>
<td>1/21 (mortality)</td>
</tr>
<tr>
<td>Mahmoud M. et al., 2010</td>
<td>149</td>
<td>unilateral fronto-orbital</td>
<td>1/58 (mortality)</td>
</tr>
<tr>
<td>Xu Y.M. et al., 2010</td>
<td>249</td>
<td>bifrontal</td>
<td>0/11 (no mortality)</td>
</tr>
<tr>
<td>Bowers C.A. et al., 2011</td>
<td>22</td>
<td>pterional</td>
<td>0/22 (no mortality)</td>
</tr>
<tr>
<td>Terasaka S. et al., 2011</td>
<td>230</td>
<td>bifrontal</td>
<td>3/9 (morbidity)</td>
</tr>
</tbody>
</table>

The largest series of TSMs, comprising 112 cases, comes from Yaşargil (255). Yaşargil's protocol involves opening the sylvian fissure, as in OGM and ACM surgeries, and following the MCA to the ICA bifurcation. A window should be made in the prechiasmatic area to devascularize the tumor. Debulking of the tumor provides space to allow dissection of the optic nerves, optic chiasm, circle of Willis, pituitary stalk, and
oculomotor nerve. The tumor capsule is dissected from the pituitary stalk and can be removed. If the tumor extends into the optic canal, this can be drilled for a few millimeters, allowing mobilization of the optic nerve and the ophthalmic artery. Attention must be paid, however, to avoid entering the sinuses. Yaşargil stated that complete removal of TSMs is more often possible than removal of other skull base meningiomas (255). The surgical technique described by Yaşargil was applied by other authors (172, 173).

Jung and Parker reported a surgical technique to remove TSMs through a fronto-orbitozygomatic approach and extradural clinoidectomy. Lumbar drainage is used to achieve a slack brain. The sylvian fissure is opened and the frontal lobe gently retracted. The first step is to devascularize the tumor from the planum sphenoidalis to reduce intraoperative bleeding. Debulking of the tumor is done with suction and an ultrasonic aspirator or bipolar and microscissors. Under high magnification, the neurovascular structures are dissected. The ACA and MCA are freed from the tumor. The arterial supply to the inferior surface of the optic apparatus from the superior hypophyseal artery should be preserved by following the arachnoidal plane during the sharp microdissection. After tumor removal, its origin is coagulated (117). Ganna reported 24 TSMs where the interhemispheric approach allowed an early tumor devascularization, and after central debulking of the tumor, both ICAs were identified. The optic nerves and chiasm are not retracted because if the tumor is inside the optic canal it can be unroofed. The tuberculum sellae hyperostosis can be drilled, paying attention to reconstruct the skull base and avoid a CSF fistula (77).

Nakamura reviewed the surgical experience of Samii when treating TSMs through pterional, frontolateral, and bifrontal approaches, and emphasized the importance of the frontolateral approach (161).

**Outcome of OGM, ACM, and TSM through Pterional, Orbitozygomatic, and Bifrontal Approaches**

**Olfactory Groove Meningiomas**

Surgical complications in OGMs treatment are: CSF fistula, frontal syndrome, hyp anosmia, hemiparesis, visual worsening, postoperative hematoma, hydrocephalus, infections, seizures and mortality (159, 238). Dolenc in 2003 published his personal experience of 157 OGMs treated through the pterional approach. After surgery, improvement was seen in 112 patients, no change in 38 patients, and worsened
condition in seven patients. In all cases, the tumor was completely removed. In 25 cases, reconstruction of the floor of the ACF was required, and in all of these cases lumbar drainage was used for one week after reconstruction of the skull base. No mortality occurred in the series (59). Ojemann in 1996 published his experience of 19 OGMs, advising treatment through bifrontal craniotomy. One patient presented with CSF leakage, requiring repair of the skull base, one patient had a wound infection, and one patient required a subdural-peritoneal shunt for a subdural hygroma. Preoperative visual symptoms and disturbance of mental function were completely alleviated (172). Colli reported a series of 17 OGM patients treated through bifrontal craniotomy and unilateral orbitotomy. Two patients died, four had local infections, two presented with epilepsy, one had postoperative edema, and one had transient ptosis (34). Spektor in a series of 80 OGM patients treated through different surgical approaches reported CSF leakage in 10 patients (12.5%), eight resolved with lumbar drainage and two underwent skull base sealing. Five of their 10 patients underwent bifrontal craniotomy, and one patient of the bifrontal group died. No mortality was found in the patients undergoing unilateral subfrontal, pterional, or fronto-orbital craniotomy (216). Tuna et al. reported 25 OGMs treated through bifrontal and pterional approaches. No patient died, but four had CSF leakage, one had epilepsy, and three developed frontal lobe edema (236). Nakamura compared the treatment of OGM through bifrontal, pterional, and frontolateral approaches; four patients died in the bifrontal group, whereas no mortality occurred in patients treated through the frontolateral or pterional route (159).

Anterior Clinoidal Meningiomas

The close relationship of ACM with ICA, optic nerve and other neurovascular structures make their total removal challenge and associated with postoperative complications (CSF leakage, visual worsening, hemiparesis, aphasia, hydrocephalus, endocrinological symptoms, hematoma, infections) and mortality (16, 179). Pamir reported a series of 43 ACMs treated through pterional approach. Eight patients presented with surgical complications (three meningitis, postoperative hematoma, one hydrocephalus, one hemiparesis for venous infarction, one epilepsy, one pneumonia). No mortality was reported (179).

Of 24 patients treated by Sade and Lee through a skull base approach with fronto-
orbital craniotomy and extradural anterior clinoidectomy, preoperative visual deficit improved in 17 cases. No patients died (203). In the multicenter series of 106 ACM cases reported by Bassiouni et al. through pterional craniotomy (104 cases) or an orbitozygomatic approach (two cases), postoperative complications included aphasia (eight cases), transient hemiparesis (four cases), and CSF leakage (four cases) treated by lumbar drainage. Two patients died. Of 52 patients with preoperative visual deficits, 21 improved and 7 worsened (16). Ojemann described one patient treated through frontotemporal approach; this patient had permanent morbidity with dysphasia and hemiparesis. The author was uncertain of total tumor removal because of complicated attachment to vessels (172).

Puzzilli reported a series of 33 ACMs treated through pterional craniotomy. Four patients died after surgery. At the end of the follow-up of 19 patients for a mean of 53.7 (range 12-108) months, there were five recurrences (188). In the Risi series treated by orbitozygomatic approach, three patients had CSF leakage, two patients died, and three patients had permanent morbidity. Of the 20 patients with preoperative visual deficit, 13 improved, one remained unchanged, and six worsened (196). Al-Mefty treated 24 meningioma cases through a fronto-orbitozygomatic approach and reported two deaths. Furthermore, one patient became blind, one had permanent 3rd nerve palsy, one had CSF leakage, and three had diabetes insipidus (two transitory and one permanent) (5).

**Tuberculum Sellae Meningiomas**

Although the relation of the optic chiasm to the sellar region frequently affects the visual outcome, other complications can occur after TSM surgery. The most common complications are: CSF leakage, endocrinological disturbances, infections; less frequent complications are: hematoma, hemiparesis, and mortality (6, 68, 81). Yaşargil reported through a pterional transsylvian approach 104 patients with good outcome, seven with moderate disability, and one with undetected rhinorrhea and meningitis who subsequently died. Forty-five patients had improvement of visual function, 29 unchanged, and 11 impaired (255). Ojemann described a series of 21 cases operated on through a pterional approach; 18 had good outcome, one had mild frontal lobe syndrome and worsening of visual function, one had severe frontal lobe syndrome, and one had already undergone four earlier operations. No patients died. Visual function
worsened in two cases (172). Nakamura compared the simple frontolateral approach (very similar to our LSO approach) with the bifrontal approach in microsurgery of TSMs, and two patients in the bifrontal group died due to postoperative brain edema. No deaths occurred in the frontolateral or pterional groups. The authors concluded that the anterior third of the SSS should be preserved during OGM surgery, and this is better achieved with the frontolateral approach. The visual improvement rate was significantly better in patients who underwent frontolateral tumor resection compared with the bifrontal group (161).

Mahmoud reported 58 cases; no mortalities occurred and three patients presented with a worsening of visual function, four had CSF leakage with one requiring reoperation, three had unilateral olfactory tract damage with anosmia, seven had postoperative hyposmia, one had infection, and one died due to pulmonary embolism (149). With the bifrontal approach, the most frequent complication is anosmia, reported in seven TSM patients by Ganna et al., only one patient had visual worsening after surgery (77).

Recurrences of OGM, ACM, and TSM when Using Classical Approaches

In the series of OGMs reported by Ojemann, no patients who underwent scans (13/19 patients) had a recurrence during a mean follow-up of 4.4 years (172). Snyder et al. reported four OGM recurrences after a mean of 6 years (213). An extensive review of the literature on meningiomas by Black unearthed a 10-year recurrence rate of 9-20% for totally resected meningiomas (19). Chan and Thompson reviewed their experience of 257 meningiomas, including 20 OGMs and 12 TSMs, noting recurrences in three and two patients, respectively, over a mean follow-up of 9 years (range 6 months-22 years) (28). The surgical approach was not specified in their series. Snyder et al. reported four late OGM recurrences; one of the patients was treated through bifrontal craniotomy and for the other three the approach was not specified. In three of these patients, the dura was coagulated (without removal), and in one a subtotal tumor resection was achieved. No recurrences occurred in a series of 20 (total 25) OGMs treated through bifrontal and pterional approaches during a mean follow-up of 58.4 (range, 14-112) months (213). Nakamura reported OGM and TSM resection through different surgical approaches and concluded that the rate of total tumor removal (Simpson grade 1 or 2) did not differ significantly among the approaches. It was 92.7% in the frontolateral group and 93.5% in the bifrontal group, and the overall recurrence
was 4.9% during a mean follow-up of 5.3 years (2.9% in the frontolateral group and 6.5% in the bifrontal group) (159, 161). The recurrence rate was 0 in 15 OGM patients treated by Obeid and Al-Mefty through a supraorbital subfrontal approach (unilateral or bilateral) (169). In a series of 106 ACM patients treated through pterional (104 cases) and orbitozygomatic approaches (two cases), 10 patients experienced a recurrence during the mean follow-up of 4.8 (range, 2-8) years. Two had Simpson grade I and eight Simpson grade II removals. Three of these patients underwent a second surgery and three fractionated radiotherapy for a high cellular proliferative index (16). Of the 17 ACM cases treated by Ojemann, three had a recurrent tumor with two requiring reoperation and radiotherapy (172). Al-Mefty reported one ACM recurrence in a series of 24 cases followed up for 57 months (5).

None of the 112 patients operated on by Yaşargil had a recurrence during a 10-year follow-up (255). In Nakamura's TSM series, the recurrence rate was 2.8% (2/72 patients) during a mean follow-up of 45.3 (range, 4-238) months (161). In Mahmoud's series, one recurrence was recorded over a mean follow-up of 23 months (149).

**Anterior Clinoidectomy**

The medial portion of the lesser wing of the sphenoid bone is the ACP (109). Its anatomical location is extremely important for the relationship to the optic nerves, ICA, and other parasellar neurovascular structures. Anterior clinoidectomy allows the exposure and safe mobilization of the optic nerve at its proximal entrance to the optic canal and the ICA in its transitional segment from the cavernous to the intradural space (226); anterior clinoidectomy is a key microsurgical step for the successful and safe management of paraclinoid aneurysms and parasellar neoplastic lesions (52, 60, 261). Drake reported performing an anterior clinoidectomy in 1968 when treating carotid-ophthalmic aneurysms, although he later claimed it was unnecessary (62). A few years later, Guidetti (89), Yaşargil (259), and Sundt (221) described the microsurgical technique of intradural anterior clinoidectomy for the treatment of carotid-ophthalmic aneurysms.
### Table 4. Anterior clinoidectomy through different surgical approaches.

<table>
<thead>
<tr>
<th>Author(s), year (reference)</th>
<th>Approach (lesions)</th>
<th>Intradural/Extradural Clinoidectomy (number of cases)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drake C.G. et al., 1968 (62)</td>
<td>pterional (carotid-ophthalmic aneurysms)</td>
<td>intradural (14 cases)</td>
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<td>Guidetti B. and La Torre E., 1975 (89)</td>
<td>frontotemporal (carotid-ophthalmic aneurysms)</td>
<td>intradural (26 cases)</td>
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<td>Yaşargil M.G. et al., 1977 (259)</td>
<td>pterional (carotid-ophthalmic aneurysms)</td>
<td>intradural (30 cases)</td>
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<td>Iwabuchi T. et al., 1978 (110)</td>
<td>unilateral frontal (carotid-ophthalmic aneurysms)</td>
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<td>Sundt T.M. and Piepgras D.G., 1979 (221)</td>
<td>pterional (giant aneurysms)</td>
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<td>Heros R.C. et al., 1983 (105)</td>
<td>pterional (paraclinoid aneurysms)</td>
<td>extradural (34 cases)</td>
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<td>Dolenc V.V., 1985 (60)</td>
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<td>extradural (14 cases)</td>
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<td>Perneczky A. et al., 1985 (185)</td>
<td>pterional (infraclinoid aneurysms)</td>
<td>intradural (NA)</td>
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<td>Knosp E. et al., 1988 (127)</td>
<td>pterional (paraclinoid aneurysms)</td>
<td>intradural (NA)</td>
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<td>Nutik S. L., 1988 (167)</td>
<td>NA</td>
<td>intradural (NA)</td>
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<td>Kobayashi S. et al., 1989 (128)</td>
<td>pterional (carotid cave aneurysms)</td>
<td>intradural (32 cases)</td>
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<td>Ohmoto T. et al., 1991 (170)</td>
<td>pterional (intracavernous aneurysms)</td>
<td>intradural (7 cases)</td>
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<td>Korosue K. and Heros R.C., 1992 (130)</td>
<td>pterional (carotid aneurysm)</td>
<td>intradural (1 case)</td>
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<td>Day J.D. et al., 1994 (53)</td>
<td>orbitozygomatic (upper basilar and infrachiasmatic lesions)</td>
<td>extradural (22 cases)</td>
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<tr>
<td>Yonekawa Y. et al., 1997 (261)</td>
<td>pterional (parasellar lesions)</td>
<td>extradural (40 cases)</td>
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<td>Tobias S. et al., 2003 (231)</td>
<td>pterional (ACMs)</td>
<td>extradural (23 cases)</td>
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<td>Huynh-Le P. et al., 2004 (109)</td>
<td>NA</td>
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<td>Takahashi J.A. et al., 2004 (226)</td>
<td>pterional (ICA aneurysms, TSMs)</td>
<td>intradural en-bloc (37 cases)</td>
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<td>Avci E. et al., 2005 (11)</td>
<td>frontotemporal</td>
<td>intradural (NA)</td>
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<td>Benjamin V. and Russel S.M., 2005 (17)</td>
<td>pterional (TSMs)</td>
<td>extradural (NA)</td>
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<tr>
<td>Noguchi A. et al., 2005 (165)</td>
<td>orbitozygomatic (40 aneurysms and 20 tumors)</td>
<td>extradural (60 cases)</td>
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<td>Chang H.S. et al., 2006 (30)</td>
<td>frontotemporal (parasellar)</td>
<td>extradural (8 cases)</td>
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### Review of the Literature

<table>
<thead>
<tr>
<th>Authors</th>
<th>Year (ID)</th>
<th>Approach</th>
<th>Location</th>
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<tr>
<td>Otani N. et al.</td>
<td>2006 (178)</td>
<td>pterional (TSMs)</td>
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<td>Andaluz N. et al.</td>
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<td>pterional</td>
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<td>Gonzalez-Darder J.M.</td>
<td>2007 (84)</td>
<td>pterional (paraclinoid aneurysms)</td>
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<td>Sade B. and Lee J.H.</td>
<td>2008 (203)</td>
<td>pterional (ACMs)</td>
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<td>(52)</td>
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<tr>
<td>Nozaki K. et al.</td>
<td>2008 (166)</td>
<td>frontotemporal (TSMs)</td>
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<td>Jung H.W. and Park C.K.</td>
<td>2009 (117)</td>
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<td>extradural</td>
<td>(NA)</td>
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<td>Chang D.J. et al.</td>
<td>2009 (29)</td>
<td>pterional (NA)</td>
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<td>Sade B. and Lee J.H.</td>
<td>2009 (202)</td>
<td>pterional (TSMs)</td>
<td>extradural</td>
<td>(28)</td>
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<tr>
<td>Bassiouni H. et al.</td>
<td>2009 (16)</td>
<td>pterional (ACMs)</td>
<td>intradural</td>
<td>(23)</td>
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<tr>
<td>Park S.K. et al.</td>
<td>2009 (182)</td>
<td>NA (PComA aneurysms)</td>
<td>intradural</td>
<td>(6)</td>
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<tr>
<td>Li-Hua C. et al.</td>
<td>2010 (141)</td>
<td>fronto-orbital; frontolateral (TSMs)</td>
<td>extradural</td>
<td>(27)</td>
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<tr>
<td>Son H.E. et al.</td>
<td>2010 (215)</td>
<td>pterional (paraclinoid aneurysms)</td>
<td>extradural</td>
<td>(22)</td>
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<td>Golshani K. et al.</td>
<td>2010 (83)</td>
<td>NA (PComA aneurysms)</td>
<td>intradural</td>
<td>(NA)</td>
</tr>
<tr>
<td>Nanda A. and Javalkar V.</td>
<td>2011 (163)</td>
<td>pterional (carotid-ophthalmic aneurysms)</td>
<td>intradural</td>
<td>(86)</td>
</tr>
</tbody>
</table>

The milestone description of extradural anterior clinoidectomy by Dolenc for the treatment of carotid-ophthalmic aneurysms appeared in 1985 (60). All of these reports describe the anterior clinoidectomy through pterional or orbitozygomatic approaches (52, 60, 89, 226, 259, 261).

### Anterior Clinoidectomy through Pterional or Orbitozygomatic Approach

A few recent reports describe surgical techniques to remove the ACP. Takahashi reported intradural en-bloc removal of the ACP through a pterional approach (226). After dura incision and its removal posteriorly, a diamond drill (diameter 1 mm) is used starting at the posterior edge of the optic canal to 1 cm anterior of the medial margin of the optic canal. Drilling continues until the deeper side of the cortical bone is reached. With a small rongeur, the ACP is ruptured and removed en-bloc. Understanding the relationship between the ACP and the ICA or optic nerve is crucial (226). A similar technique and the same pterional approach but through an extradural route are described by Yonekawa (261). He also advised en-bloc removal of the ACP;
however, if en-bloc is not possible, a small piece can be removed by drilling and by microrongeur (261). Otani reported 32 cases of TSM treated through pterional craniotomy and 20 underwent extradural clinoidectomy. The ACP was removed by using a diamond drill under microscope (178). Noguchi reported a microsurgical technique to extradurally remove the ACP and SOF through an orbitozygomatic craniotomy. First the sphenoid ridge is flattened, the dura dissected, and the SOF opened. The lesser wing of the sphenoid over the SOF and also the greater wing are then opened to expose the inferior margin of the SOF. The dura over the ACP is dissected and the ACP removed. A 2-mm diamond drill is used during the procedure (165). Chang described an interesting technique to perform anterior clinoidectomy extradurally and through a pterional approach without the use of a high-speed drill but only microrongeurs of different sizes (29).

Anesthesiological Procedures

Anesthetic management can significantly affect the prognosis of a patient undergoing removal of an anterior skull base meningioma (164). No previous reports describe neuroanesthesia procedures for different ASB approaches; only general principles in dealing supratentorial procedures have been published (1, 25, 164, 191). General principles of neuroanesthesia for supratentorial procedures include: 1) optimize brain oxygenation; 2) maximize venous drainage ensuring adequate head position (15-30° tilt); 3) reduce oxygen metabolism: deepen anesthesia, bolus intravenous of anesthetic agents or lidocaine; 4) reduce extracellular fluid volume with mannitol or hypertonic saline, 5) consider hypocapnia or an anticonvulsant in some cases (25, 191).
3 Aims of the Study

I-III: To describe the microneurosurgical technique and assess the effectiveness and safety of the lateral supraorbital (LSO) approach in removing:
   I: Olfactory Groove Meningiomas
   II: Anterior Clinoidal Meningiomas
   III: Tuberculum Sellae Meningiomas.

IV: To assess the principles of neuroanesthesia in achieving a slack brain when removing meningiomas of the anterior cranial fossa through the LSO approach.

V and VI: To describe the microneurosurgical technique and assess the effectiveness and safety of the LSO approach when performing extradural or intradural anterior clinoidectomy for the treatment of vascular and neoplastic lesions.
4 Patients and Methods

This study is based on retrospective data and the analysis of operative videos of 66 OGM, 73 ACM, and 52 TSM patients treated through the LSO approach between September 1997 and August 2010. Anesthesiological data of these 191 consecutive patients were analyzed to determine the principles necessary to achieve a slack brain when treating OGMs, ACMs, and TSMs through an LSO approach.

The microsurgical technique and outcome of 82 consecutive patients undergoing an anterior clinoidectomy through the LSO approach between June 2007 and January 2011 were retrospectively analyzed. All patients were treated at the Department of Neurosurgery of Helsinki University Central Hospital between September 1997 and January 2011 by a single neurosurgeon (J.H.).

Treatment of OGM, ACM, TSM through LSO Approach (Publications I-IV)

Patients and Imaging

The publications I-III are based on 191 consecutive meningioma patients (66 OGMs, 73 ACMs and 52 TSMs) operated on between September 1997 and August 2010 at the Department of Neurosurgery, Helsinki University Central Hospital, Finland, by the senior author (J.H.), with a total personal series of meningiomas exceeding 1200 cases. The Table 5 reports the demographics and clinical findings of the patients. Clinical conditions, preoperative and postoperative, were expressed by the Karnofsky performance score (121), and Glasgow outcome score (GOS) was used to express the postoperative clinical outcome (116).
Computed tomography (CT) or magnetic resonance imaging (MRI) of the brain was performed prior to surgery. For 13 OGM, 21 ACM, and 19 TSM patients, magnetic resonance angiography (MRA) was also performed to evaluate the tumor's vascular supply and relation to the ACAs. Possible tumor-related pathological changes of the ICA, AComA, and middle (MCA) and ACA were investigated (Figure 19). CT angiography (CTA) was performed in three ACM and TSM cases, and digital subtraction angiography (DSA) was performed in four ACM, one OGM, and one TSM case. Preoperative tumor embolization was not performed on any of the patients. When treating OGM, ACM, and TSM the main blood supply comes from the AEAs and PEAs, which originate from the OA and they are difficult to close endovascularly (67, 134, 194). The preoperative images were evaluated for tumor size and lateralization, brain shift, edema, possible calcifications, signs of sellar and ethmoidal hyperostosis, erosion and infiltration; intraorbital, cavernous sinus, anterior clinoid, and planum sphenoidalis involvement; attachment, dislocation, or encasement of ACA, MCA, ICA, and BA; involvement of optic nerves and the optic chiasm; and pituitary stalk lateralization. An immediate postoperative CT scan was performed on 55 OGM patients and 37 TSM patients. An immediate postoperative MRI scan was performed on 55 ACM patients, a CT scan only was performed on 17 ACM and 12 TSM patients. One ACM patient died of a cardiac infarction before the postoperative radiological examination. An early postoperative MRI with gadolinium enhancement was done when a tumor remnant was suspected.
Patients and Methods

Figure 19: Large OGM as seen on preoperative MRI. A, MRA showing ACAs attached to the posterior part of the tumor (arrows). B, T2-weighted MRI showing lateral dislocation of the ACAs (arrow).

Intraoperative Videos

The videos of all operations were analyzed and selected to show the microsurgical technique used when treating OGMs (Supplementary videos 2-5), ACMs (Supplementary videos 6-9), and TSMs (Supplementary videos 10-12) of different sizes and consistencies through a LSO approach.

Anesthesia Records

The anesthesia methods of 64 OGMs, 71 ACMs, and 52 TSMs were analyzed. Data collection included duration of anesthesia and surgery, anesthetic agents and their doses, total amount of administered vasoactive agents (phenylephrine, ephedrine, dopamine, or atropine), total amount of administered crystalloids (Ringer’s acetate), colloids (hydroxyethyl starch solution, HES, or albumin), mannitol, red blood cell concentrates, fresh frozen plasma, or platelet concentrates. Heart rate and non-invasive blood pressure was recorded before anesthesia. Intraoperatively invasive arterial blood pressures (arterial transducer set to zero at the level of the foramen Monroe) were registered at 5-min intervals for 40 min and thereafter at 10-min intervals until the end of surgery. Hypertension (systolic arterial pressure, SAP > 160 mmHg) was scrutinized during the immediate postoperative phase. The evaluation of the surgical conditions during craniotomy was based on surgical charts and was classified as
good, satisfactory, or poor retrospectively. Patients’ preoperative medical comorbidities, such as hypertension, and the use of any medication were registered.

**Follow-up**

The patients were periodically seen at the outpatient clinic, first at three months after discharge and then at 1- to 2-year intervals for up to seven years depending on the grade and extent of removal. Patients with a known postoperative residual tumor usually had a clinical examination and MRI follow-up once a year.

**Statistical Analysis**

Data were analyzed with the statistical software package SPSS (SPSS Inc., Chicago, IL, USA). Categorical variables were compared with the Fisher exact two-tailed test or the Pearson $\chi^2$ test and the Kruskall Wallis test, and continuous variables between two groups with the Mann-Whitney U-test. Univariate association of continuous variables was tested with Spearman rank correlation coefficients. Univariate and multivariate odds ratios (ORs) with 95% confidence intervals (CIs) were estimated using unconditional logistic regression to determine factors predicting good clinical outcome (GOS=5) at the end of follow-up, good neurosurgical condition, and extubation time. The tested variables included age, preoperative symptoms of anosmia, visual deficit, size of meningiomas, peritumoral edema, duration of preoperative visual deficits, memory impairment, preoperative Karnofsky score, and method of anesthesia. Tumor size, consistency, attachment to ACAs, ICA, MCA, AComA, or the optic nerve or chiasm, and infiltration into the paranasal sinuses were also analyzed in the OGM group. The maximum likelihood stepwise forward and backward elimination procedures were used with selection of variables based on the magnitude of their probability values ($P<0.1$). A two-tailed probability value of less than 0.05 was considered significant.
Anterior Clinoidectomy through LSO Approach (Publications V and VI)

Patients and Imaging

Between June 2007 and January 2011, a total of 82 patients underwent anterior clinoidectomy through an LSO approach for vascular and neoplastic lesions. The lesions and clinical data of these patients are presented in Table 6. Preoperative clinical conditions were expressed on the Karnofsky performance score (121) for neoplastic lesions. The Hunt-Hess (HH) scale (108) was used for vascular patients. The GOS (116) was used to reflect the postoperative clinical outcome of vascular and neoplastic patients.

Table 6. Patients and lesions.

<table>
<thead>
<tr>
<th>Demographic data</th>
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<tbody>
<tr>
<td>Men; n</td>
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<tr>
<td>Woman; n</td>
<td>61</td>
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<tr>
<td>Age [years]; median (range)</td>
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<table>
<thead>
<tr>
<th>Preoperative condition</th>
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<tbody>
<tr>
<td>Karnofsky score of 35 tumor patients; median (range)</td>
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</tr>
<tr>
<td>Hunt-Hess (n. of vascular patients)</td>
<td>Grade</td>
</tr>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>3</td>
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<tr>
<td></td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Visual impairment</td>
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<tr>
<td>Duration of preoperative visual deficit</td>
<td>&lt; 6 months</td>
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<tr>
<td></td>
<td>6-12 months</td>
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<td></td>
<td>&gt;12 months</td>
</tr>
<tr>
<td>Frontal syndrome-memory deficit</td>
<td>5</td>
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<tr>
<td>Oculomotor nerve deficit</td>
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</table>
4 Patients and Methods

Seizures 1
Headache 17
Hemiparesis 2
Abducens paresis 1
Exophthalmus 5
Trigeminal hypoestesia 1

Location of the lesions

<table>
<thead>
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<td>Carotid-ophthalmic aneurysms</td>
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<tr>
<td>Other carotid aneurysms</td>
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<tr>
<td>Basilar bifurcation aneurysm</td>
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<td>Carotid cavernous fistulas</td>
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<table>
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<th>Tumor cases</th>
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<tbody>
<tr>
<td>Meningiomas</td>
<td>26</td>
</tr>
<tr>
<td>Other lesions</td>
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</table>

All tumor patients underwent MRI before surgery. All patients with aneurysms, ruptured or unruptured, underwent CT and CTA before surgery. Postoperative 3D reconstructions of CT or CTA imaging were analyzed to evaluate the extent of removal of the ACP in all cases.

Intraoperative Videos

Intraoperative videos of 82 patients were analyzed for nuances of the anterior clinoidectomy technique, and illustrative cases were selected to show extradural and intradural clinoidectomy for vascular and neoplastic lesions (Supplementary videos 13-15).

Follow-up

We reported early clinical outcome at discharge and at three months in the outpatient clinic with special attention focused on visual outcome.

Statistical Analysis

The statistical analysis was performed using SPSS 18.0 software (SPSS Inc., Chicago, IL, USA). Groups were compared using Mann-Whitney U-test or Pearson’s $\chi^2$ test. P-values
of less than 0.05 were considered significant. Risk factors (aneurysms, high score of HH, opening of the superior orbital fissure, extradural clinoidectomy, and use of ultrasonic bone device) with P-values of less than 1.0 in the univariate analysis were included in the binary logistic regression analysis used for multivariate comparison of potential risk factors for postoperative visual deficits. P-values of less than 0.05 were considered significant.
Patients and Methods

“There is nothing more difficult, more dangerous nor more least likely to succeed than to initiate a new order of things”.

Niccolo’ Machiavelli, The Prince (1469-1527)

Microsurgical Techniques (Publications I-VI)

Lateral Supraorbital Approach

Patient Position

The patient is in supine position (Figure 20 A). The head fixed to the head frame is a) elevated around 20 cm or more above cardiac level; b) rotated 20º to 30º towards the contralateral side of the tumor or aneurysm; and c) the neck is slightly flexed and tilted laterally to obtain a better view of the anterior part of the anterior fossa, enabling optimal venous return. It is our practice also to adjust the position of the fixed head and body during the operation as needed, but the frequency of this maneuver could not be assessed retrospectively. No local anesthetics are infiltrated for pins of Sugita frame. A bolus of remifentanil is given to prevent hypertension.

Craniotomy

After minimal shaving and injection of a vasoconstrictive agent, an 8- to 10-cm skin incision is made behind the hairline (Figure 20 B). Following an oblique frontotemporal skin incision, behind the hairline a one-layer skin-muscle flap is retracted frontally with spring hooks, and the superior orbital rim and the anterior zygomatic arch are exposed (Figure 20 C). The upper part of the temporal muscle is split and retracted towards the zygomatic arch. The extent of craniotomy depends on lateralization and size of the ACM or TSM. Usually, a classic LSO craniotomy is all that is necessary. A single burr hole is placed just under the temporal line of the bone, i.e. the superior insertion of
the temporal muscle (Figure 20 D). A bone flap of 4 x 3 cm is detached mostly by side-cutting drill, and the basal part can be drilled before lifting (Figure 20 E). The dura is incised curvilinearly with the base sphenoidally and elevated by multiple stitches extended over the craniotomy dressings (Figures 20 F and 21). From this point onwards, all surgery, including skin closure, is performed under the operating microscope.

Figure 20: (A) Position when performing the LSO approach, (B) skin incision, (C) muscle detachment, (D) burr hole, (E) size of craniotomy, and (F) brain exposed after an LSO approach (199).

Figure 21: Exposure of the right ICA and optic nerve after performing a right LSO in a cadaveric specimen (Courtesy of Dr. Asem Salma of Columbus University, Ohio) (204).

LSO Approach with Minimal Temporal Exposure (Publications II and V)

In the classic LSO, the sylvian fissure remains at the inferior border of the dural opening, and, if needed, it can be easily opened, as our large experience on anterior
and even posterior circulation aneurysms demonstrates (48-51, 100, 102, 138, 139, 198, 199). In 20 ACM cases and in 20 patients who underwent anterior clinoidectomy, we performed an LSO approach with temporal extension, i.e. the classic LSO with additional lateral extension towards the middle cranial fossa for minimal temporal exposure. This means extending the exposure for approximately one centimeter or so to the temporal side of the sylvian fissure (Figures 22 and 23). The head position is the same as in a classic LSO approach, with a more caudal and posterior skin-muscle cut. Size of the tumor or aneurysm with a significant temporal component is the only indication for temporal extension of the LSO approach.

Figure 22: (A) A CT-3D skull base reconstruction showing the classic LSO (continuous black line) and the minimal temporal extension (dotted line). (B) The origin of the OGM (dotted circle, small); ACM (continuous circle) and TSM (dotted circle, large) of the anterior skull base reached through an LSO approach.

Figure 23: The brain exposed (A) after a left LSO with minimal temporal extension and (B) after a right classic LSO.
Removal of OGM, ACM, TSM through LSO Approach (Publications I-III)

Neuroanesthesia is mandatory to achieve a slack brain (191). The floor of the ASB is followed towards the ipsilateral optic nerve and carotid artery, and CSF is released from the basal cisterns. We seldom open the sylvian fissure. If needed, it can be easily performed through the LSO approach, especially for removing larger tumors (48-51, 100, 102, 138, 139, 198, 199).

Tumor Devascularization

The first step, after opening the basal cisterns and achieving more space, is to reach the dural attachments of the tumor. When treating OGM the blood supply comes from the AEAs and PEAs, which originate from the OA and they are difficult to close endovascularly (67, 134, 194). We coagulate the major arterial supply to the tumor before further dissection to ensure minimal intraoperative blood loss. With bipolar coagulation we devascularize the dural attachment of the tumor, taking care to preserve olfactory tract function. At the beginning of OGM removal, coagulation of the AEAs and PEAs is necessary with the risk of ischemic damage to the olfactory tract (47, 79). The dura of the ACP is coagulated with bipolar forceps using high power (Malis 50) to interrupt the vascular supply to the tumor in order to devascularize the tumor and minimize intraoperative bleeding.

Small and Medium-Sized OGM (< 6 cm)

The olfactory tract ipsilateral to the tumor is early identified and dissected from the tumor in small and medium-sized tumors (< 6 cm) (Figure 24 A). The olfactory tract is protected by small cottonoids and the tumor is debulked with suction and high-power bipolar forceps (Malis® CMCIII Codman, Synergetics™, Inc., values 50-60). Debulking of the tumor gives more room for manipulation and allows the dissection between the tumor surface and the surrounding brain along the arachnoid plane. We routinely use the ‘water dissection’ technique, that is very effective in dissecting meningiomas (158). Preservation of both olfactory tracts depends on the tumor's size,
Patients and Methods

4  Patients and Methods

consistency, and attachments (Figure 24 B). Usually the ipsilateral olfactory tract is identified at the beginning of the dissection and it is easier to dissect than the contralateral one. After tumor debulking the dissection should be directed to the posterior aspect of the tumor to identify and save the contralateral olfactory tract. Usually one olfactory tract is compromised by the tumor, and a slight manipulation can abolish its function.

Figure 24: Intraoperative view showing involvement of the tumor with the olfactory tract. A, right olfactory tract (arrow) is preserved in a small meningioma; B, both olfactory tracts (arrows) are preserved after removal of a small OGM; C, large (> 6 cm) OGM and extremely atrophic olfactory tract (arrow) compressed by the tumor.

**Small and Medium-Sized ACM and TSM (< 4 cm)**

A classic LSO approach allows a complete removal of small and medium-sized ACMs and TSMs (< 4 cm). The dura is opened and slack brain is achieved by modern neuroanesthesia (191). The first step is to devascularize the tumor pay attention not to coagulate the dura too close to the optic canal; high power coagulation of the dura close to the optic canal could damage the optic nerve. For this purpose low-power coagulation (Malis 20-25) should be used in the proximity of the optic nerve. Water dissection technique is used to dissect the tumor from the surrounding brain (158). The dissection can be safely performed, in soft tumor, along the arachnoid plane by using sharp bipolar forceps and water dissection technique (158). In our experience ACMs and TSMs meningiomas smaller that 2 cm can be safely removed en-bloc. Medium-sized ACMs and TSMs (2-4 cm) can be attached to the ICA, the optic nerve, the oculomotor nerve, the MCA, and the ACA. After tumor devascularization we debulk it to gain adequate space to reach the basal cisterns and ensure safe dissection. A micro-Doppler can be used to find the ICA and prevent its accidental injury when the tumor envelops the ICA. In hard meningioma without an arachnoidal plane, the tumor detachment should proceed by using sharp bipolar forceps, low-power coagulation
(Malis 20-25), microdissector, and microscissors. Based on the severity of preoperative visual deficit, the optic nerve and optic chiasm can be manipulate and dissected avoiding postoperative visual deficits.

**Large OGM (> 6 cm)**

Both olfactory tracts can be compressed or destroyed by a large OGM (> 6 cm) (Fig. 24 C). An attempt is made to enter the basal cisterns and to release CSF and if this is not possible the tumor is partially debulked. We use high power bipolar forceps coagulation, high-power suction and/or microscissors. We rarely use an ultrasonic aspirator, as the combined repetitive movement of suction and bipolar forceps gives the same result with less bleeding. ACA’s branches can give some feeders to a large OGM (Figure 25). Preservation of ACA’s branches is mandatory to avoid ischemic lesions on the medial aspect of the frontal lobe. We avoid the use of mechanical retractors that can increase edema in the frontal lobe. The tumor is debulked and it is carefully dissected from the surrounding brain and neurovascular structures by using water dissection (158).

![Figure 25: Surgical view. (A) Small branches of the ACA supplying the OGM (arrows). (B) OGM attached to right optic nerve and right ICA (arrows).](image)

**Large ACM and TSM (> 4 cm)**

The LSO approach can be extended 1-cm to the temporal side in large ACMs (> 4 cm) (Figures 22 and 23) and this allows a better visualization of the temporal portion of the medial sphenoid wing. The dura is opened and the sylvian fissure is visualized. The first step is to debulk a large ACMs and TSMs by using suction and high-power (Malis 50)
4 Patients and Methods

coadulation with bipolar forceps. After this step the basal cisterns can be entered for CSF removal. The vascular support to the tumor coagulated and with water dissection technique (158) the lesion is dissected from the brain. Also for large tumor ultrasonic aspirator is never used and we prefer the combined use of suction and bipolar forceps. In case of hard tumor without arachnoidal plane, a micro-Doppler is used to find the ICA and other vessels. The ICA is gently freed from the tumor by using sharp bipolar forceps and suction. The attachment of the tumor to the ICA is coagulated (Malis 20) and cut. The perforators coming from the ICA and ACA (Figures 26 and 27 C) should be preserved; they are often inside the tumor and they can be confused with the tumor's vascular supply. The ICA 3-5 mm proximal to its bifurcation (253) gives branches to the dura of the ACP and these can be coagulated and cut. ICA, ACA, MCA, optic nerve, and optic chiasm can be enveloped or dislocated from a large ACMs or TSMs and sometimes small pieces of the tumor may need to be left attached to the vessels or to the optic nerve(s), preventing postoperative visual deficits or ischemia.

Figure 26: (A) Small branches of MCA. (B) After complete removal of a left large ACM, the dura of the ACP is coagulated (*) and all vessels are preserved.

Figure 27: Intraoperative view of a medium-sized TSM and the right optic nerve (A); atrophic optic nerve compressed by a large TSM (B); and perforators from the ACA attached to a large TSM (C).
Attachment to Surrounding Vascular Structures

The tumor vascular supply comes from the ethmoidal arteries and small branches of the ACA and ICA that can be coagulated and cut. The recurrent artery of Heubner has to be preserved and not confused with these branches. Small perforators coming from the ACA, in the region of the AComA, run above the optic chiasm and courses anterior to the ACA and they should be preserved (102, 252). ICA in its intradural C1 and C2 segments may be attached to or encased by the tumor. Small veins can be attached to the tumor and these also should be preserved whenever possible. They can be coagulated, if necessary. If these veins are torn accidentally they tend to contract backwards and unless previously coagulated, keep oozing, often from behind a corner, and are much more difficult to deal with later.

OGMs, ACMs, and TSMs, can be attached to the supraclinoid carotid arteries and the optic nerves or chiasm (Figure 27 A and B). We use high magnification, sharp bipolar forceps (Malis +20, +25), and sharp dissection to preserve all of the small perforators, including the blood supply of the optic chiasm.

The dura of the ASB is carefully coagulated (Simpson grade 2) after tumor removal. We remove the dura of the origin of the meningioma in patients with long life expectancy. The hyperostotic bone (Figure 28) is drilled away (Simpson grade 1) by using a high-speed diamond drill sometimes resulting in opening of the ethmoid sinuses; care should be paid to seal the sinuses with muscle, TachoSil (Human Fibrinogen, 4.8 x 4.8 cm, NYCOMED, Austria GmbH, Linz) and fibrin glue to prevent postoperative CSF leakage.

Figure 28: Sagittal MRI scan showing hyperostosis (arrows) of the ethmoidal bone in a large OGM.
Intraorbital Extension of ACM-TSM and Anterior Clinoidectomy (Publications I-III and V)

ACMs and TSMs can sometimes grow inside the optic canal and an anterior clinoidectomy is necessary to remove the tumor. We usually perform anterior clinoidectomy when there is tumor-related hyperostosis of the ACP and encasement of the ICA by the tumor (Figures 29 and 30). The policy of the senior author (J.H.) is to perform an intradural anterior clinoidectomy (see Discussion). The technique consists in cutting and removing the dura of the ACP 1 cm from the medial border. High-speed diamond drill and ultrasonic bone curette (Sonopet Omni, Model UST-2001 Ultrasonic surgical system, Synergetics™, Inc., Miwatec Co., LTD, Kawasaki, Japan) are both used to remove the ACP. Sometimes the senior author uses a microrongeur (Mizuho Rongeurs Series 16 cm curved, Japan). The bone of the ACP is formed by a surface of cortical bone and diploe of cancellous bone, which sometimes communicate with the cavernous sinus (209), and fibrin glue can be used to control the bleeding coming from the cavernous sinus through these venous channels. The unroofing of the medial portion of the orbital roof allows the exposure of the optic nerve and laterally the C3 segment of the ICA. The intraorbital portion of the meningiomas is removed in small pieces, taking care not to damage the optic nerve. Extradural anterior clinoidectomy is seldom used in ACMs and TSMs surgery. After performing a LSO approach the dura is gently detached from. The orbital roof is removed 1 cm distal to the medial border of the ACP by using an ultrasonic bone curette or high-speed drill, or a microrongeur.

Figure 29: Left large meningioma in a 58-year-old man. (A) Anterior view of DSA showing vascular support to the meningioma from the ICA (arrow). (B) Coronal 2D reformatted image from Dyna CT during left carotid arteriogram showing small branches (arrow) of the anterior clinoid process to the ACM. (C) Preoperative coronal contrast-enhanced T1-weighted MRI showing the large ACM. (D) Postoperative coronal contrast-enhanced T1-weighted MRI showing the complete removal of the tumor.
Tailored Anterior Clinoidectomy (Publications V and VI)

We prefer to perform a tailored clinoidectomy, i.e. to remove only the necessary amount of bone for the treatment of the aneurysm or the tumor. Figure 31 shows the classification of a tailored clinoidectomy: A) minimal clinoidectomy refers to resection of the tip of the ACP, usually less than 1/3 of total ACP; B) partial clinoidectomy refers to removal of the tip and head of the ACP, i.e. approximately 1/3 of total ACP; C) subtotal clinoidectomy refers to removal of the tip, head, and body of the ACP, i.e. approximately 2/3 of total ACP; and D) total clinoidectomy refers to removal of the tip, head, body, and base of the ACP.

Figure 30: Coronal 2D CTA of a right large ACM in a 39-year-old woman. Vascular support comes from small vessels of the ACP (arrow), which appears hyperostotic (*).

Figure 31: A 3D CT skull base reconstruction (left) and a schematic drawing (right) showing a right ACP and a tailored clinoidectomy through an LSO approach (grid). A) minimal clinoidectomy with removal of the tip of the ACP (less than 1/3 of total ACP); B) partial clinoidectomy with removal of the tip and head of ACP (1/3 of total ACP); C) subtotal clinoidectomy with removal of the tip, head, and body of the ACP (2/3 of total ACP); and D) total clinoidectomy with removal of the tip, head, body, and base of ACP (whole ACP).
5 Results

Characteristics of Meningiomas (Publications I-III)

Tumor Size

The average OGM tumor size was 47 (range 20-85) mm. Twenty-five (38%) of 66 OGMs were large (> 6 cm), 27 (41%) medium (3–6 cm), and 14 (21%) small (< 3 cm) (Figure 32). Tumors were located in the midline in 45 patients (68%), extended to the right in 11 patients (17%), and extended to the left in 10 patients (15%).

![Figure 32: Sagittal contrast-enhanced T1-weighted MRI. Examples of (A) small (with ethmoidal infiltration), (B) medium, and (C) large OGMs, which presented also with sellar involvement (arrows).](image)

The mean ACM tumor size was 32 (range 4-72) mm. We considered ACMs and TSMs > 4 cm to be large and distinct from OGMs because the close relationship with the neurovascular structures makes the surgery challenging. Twenty (27%) of 73 ACM tumors were small (< 2 cm), 32 (44%) were medium-sized (2-4 cm), and 21 (29%) were large (> 4 cm) (Figure 33).
The mean TSM tumor size was 31 (range 6-84) mm. Seven (13%) of 52 TSMs were small (< 2 cm), 34 (66%) were medium-sized (2-4 cm), and 11 (21%) were large (> 4 cm) (Figure 34). Both ACMs and TSMs size were associated with the presence of edema, brain shift, and involvement of neurovascular structures, but the tumor size did not predict tumor consistency and was not related to the existence of preoperative visual deficits.

**Peritumoral Edema**

Preoperative edema was present in medium and large-sized OGMs, ACMs, and TSMs. Four small OGMs (< 3 cm) presented also with peritumoral edema.
5 Results

Side of Approach in OGM and TSM

For midline meningiomas as OGMs and TSMs we prefer a right (non-dominant) LSO approach, more convenient for a right-handed neurosurgeon. Fifty-five OGMs were removed via right side even if the tumor extends more to the left side; 11 OGMs patients were approached from left because of marked tumor extension to the left; the other three patients were approached from left because: in one there was a separate posterior clinoid meningioma on the left removed together with the OGM; in one there was preoperative left-sided optic nerve dysfunction; and in one there was an extensive scarring on the right due to previous surgery. Preoperative visual deficit and main tumor location were the determinant factors in the choice of the side of the craniotomy.

Hyperostosis and Infiltration of Ethmoid Sinuses in OGM

Thirty-two OGM patients presented preoperative hyperostosis, and it was related to the tumor size (p<0.001) (Figure 28). The hyperostotic bone was drilled during surgery with a high-speed diamond drill. Twenty-five OGMs infiltrated the ethmoid sinus, irrespective of hyperostosis or tumor size. Four patients of 25 with OGM inside the ethmoidal sinus were deliberately left with extracranial tumor tissue behind.

Temporal Extension and Clinoidectomy in ACM and TSM

Twenty (27%) ACM patients (two small, five medium-sized, and 13 large ACMs) underwent a LSO with temporal extension predicted by the tumor size (p<0.001). In 53 (73%) ACM patients (eight large ACMs) a classic LSO was enough to remove the tumor. Twenty-one ACMs patients required anterior clinoidectomy, six of whom had an intraorbital extension of the tumor; in twelve cases the anterior clinoidectomy was predicted by the hyperostosis of the ACP (p<0.05). Sixteen patients underwent intradural clinoidectomy and five extradural. The LSO approach with temporal extension was used to treat one TSM patient.
Infiltration of the Sellar Region (OGM and ACM) and Cavernous Sinus (OGM, ACM, and TSM)

Five OGM and 16 (12 large) (p<0.001) ACM patients had tumors infiltrating the sellar region. Seven ACM patients with sellar infiltration also had the tumor attached to the dura of the cavernous sinus (p<0.05). One small, six medium, and 10 large ACMs (p<0.05) and four TSMs (two large and two medium-sized), presented attachment to the dura of the cavernous sinus.

Intraorbital Tumor Extension and Attachment to the Optic Chiasm and Nerve

Thirty patients presented with OGM which was attached to the optic chiasm, 14 of whom had preoperative visual deficit. Ten ACMs had an intraorbital extension and six of which required an anterior clinoidectomy. The size of ACM predicted optic nerve and chiasmatic compression (p<0.001). Chiasmatic compression was observed in 12 large, two medium-sized, and one small ACM. In 11 ACMs (10 large and one small), sellar involvement was also observed. Chiasmatic compression was associated with preoperative visual deficit in 12 of 15 cases (p<0.05). An intraorbital extension of TSM was seen in one large TSM.

Meningioma Attachment to the Vessels

Attachment of ICA to ACM and TSM

ACM and TSM size predicted tumor attachment to the ICA (p<0.05). ICA attachment was found in 60 ACM and 49 TSM cases. In seven ACMs (four large and three medium-sized), and two TSMs (one large and one medium-sized) the ICA was dislocated by the tumor. Encasement of ICA inside the tumor, present in 27 ACM and nine TSM cases, was also related to tumor size (p<0.001). In 33 TSM cases, both ICAs were involved. The ICA was narrowed in only one medium-sized TSM. In one large and one medium-sized ACM the ICA was closed.
Attachment of ACA to ACM and TSM

ACA was attached to 41 ACM and 38 TSM cases, and it was related to tumor size \( (p<0.001) \). In 12 ACMs and four TSMs ACA was encased by the tumor \( (p<0.05) \). The ACA was dislocated by the ACM in 17 patients but remained patent in all of them. In 30 TSM cases, both A1s were involved. In 14 cases, the ACA was dislocated by the TSM; this was related to tumor size \( (p<0.05) \). In 10 cases, both A1s were dislocated; in four cases, only one.

Attachment of AComA to TSM

Forty-one meningiomas were attached to AComA and it was related to tumor size \( (p<0.05) \). In 15 cases, the vessel was also dislocated, and in three cases only encased by the tumor. In no case was the vessel closed or narrowed by the tumor (Figure 35).

Figure 35: A 3D-CTA reconstruction showing a large TSM and its vascular relationship.

Attachment of A2 to OGM and TSM

In 33 OGM and 36 TSM patients the A2s were involved, and it was related to tumor size \( (p<0.001) \). Postoperative ischemic complications in OGM surgery were not predicted by the attachment to A2s.

In 31 TSMs both pericallosal were involved (Figure 35). Both pericallosal arteries were dislocated by the TSM in 13 cases.

Attachment of M1 to ACM and TSM

Attachment to M1 was found in 48 ACMs, and tumor size again predicted this \( (p<0.001) \). In 19 of these ACMs, the vessel was also dislocated \( (p<0.001) \). In 14 ACMs, the vessel was encased by the tumor, but had remained patent. Seven TSMs were attached
to M1 predicted by tumor size (p<0.05).

**Attachment of BA to TSM**

Two TSMs (one medium and one large) were attached to the BA.

**Pituitary Stalk Involvement in TSM**

The pituitary stalk was involved in 42 TSM patients and was associated with tumor size (p<0.05). In 20 cases, it was encased, in four cases dislocated by the tumor and in 18 cases only attached to the tumor. Three patients with pituitary stalk involvement had preoperative endocrinological deficits. The pituitary stalk was preserved in all cases.

**Tumor Consistency**

Tumor consistency was not predicted by tumor size, patient’s age, or preoperative neurological deficits, nor was it related to postoperative clinical or surgical complications. Twenty-eight OGM, 30 ACM, and 24 TSM patients had a soft (suckable) tumor. Twenty-four OGM and ACM, and 14 TSM patients had a tumor of medium consistency (some parts can be removed with suction). Fourteen OGM patients had a hard (not suckable) tumor; 18 ACM and 14 TSM patients also had hard tumors.

**Tumor Calcifications**

Tumor calcifications presented in 13 ACMs (seven medium- and six-large- sized) and 11 TSMs (nine medium- and two large-sized) did not affect the time meningioma removal and was not related to postoperative surgical complications, but eight ACM patients presented with postoperative clinical complications (p<0.05).
Operative Time

The mean OGM operative time from skin to skin was 158 (range, 60-350) min: 84 (range, 60-120) min for small, 142 (range, 73-255) min for medium-sized, and 217 (range, 115-350) min for large OGMs (p<0.001).

The mean ACM duration of operation from skin to skin closure was 120 (range, 35-285) min: 87 (range, 35-235) min for small, 98 (range, 50-190) min for medium-sized, and 186 (range, 111-285) min for large tumors. Interestingly, the duration of surgery was affected by tumor size (p<0.001), attachment to M1 (p<0.05), ICA (p<0.05), and ACA (p<0.001), and encasement of M1 (p<0.001), ICA (p<0.001), and A1 (p<0.05).

The mean duration of all TSM operations from skin to skin closure was 116 (range, 43-442) min: 62 (range, 43-75) min for small, 107 (range, 53-180) min for medium, and 182 (range, 83-442) min for large tumors. Duration of surgery was affected by TSM size (p<0.05). Duration of surgery also depended on attachment to the optic chiasm (p<0.05), A1 attachment or encasement, and AComA and A2 attachment (p<0.05). Interestingly, tumor consistency did not affect operation time in any meningioma group.

Histological Grading of Tumors

All meningiomas were grade 1, except for 10 (two OGMs, seven ACMs, and one TSM) patients with atypical grade 2 meningiomas.

Surgical Complications

CSF Leakage

Six OGM patients (9%) developed CSF leakage from the nose; three of them had tumor infiltration into the ethmoid sinuses. Four of the six patients were treated with lumbar drainage for a few days. The other two patients required a fascia lata graft.

Three ACM and three TSM patients had cranionasal CSF leakage. All three ACM patients underwent clinoidectomy during the operation. All six patients were treated using an external spinal drainage for a few days.
Postoperative Hematoma and Infection

One OGM patient had a postoperative hematoma in the resection cavity requiring evacuation.

Two ACM postoperative hematomas in the resection cavity were observed; only one required evacuation. One TSM patient had a subdural hematoma that did not require evacuation. Postoperative infection occurred in four OGM and one ACM patient.

Anosmia, Frontal Syndrome, and Visual Outcome

New postoperative anosmia appeared in six OGM patients and was unrelated to tumor size. All six tumors were of either hard (three cases) or medium consistency. Three of these six patients had tumor infiltration into the ethmoid sinuses. Olfactory function improved in two patients, both of whom had a medium-sized tumor extending more to the right side.

Three OGM patients had postoperative frontal syndrome. One ACM patient had anosmia and one frontal syndrome. No TSM patients had postoperative hypo- or anosmia or frontal syndrome.

Fourteen of 30 OGM patients with optic chiasm attachment, had preoperative visual deficits. Of the 16 patients with normal preoperative vision, five developed new deficits (two were large and soft; one was small, one was medium, and one was large; all were of medium consistency). No patients with a hard tumor developed new postoperative visual deficits. Of the 14 OGM patients with a preoperative visual deficit, three improved after surgery and 11 remained unchanged. Neither tumor size nor tumor consistency predicted occurrence of new postoperative visual deficits.

Three ACM patients had new visual deficits: one transitory decline of visual acuity ipsilateral to the tumor, one unilateral quadrantopsia, and one temporal hemianopsia.

Eleven of 39 ACM patients experienced an improvement to pre-existing visual deficits after the operation. Improvement was unrelated to tumor size (two large, four medium, and five small) and tumor consistency (three soft, five medium, and three hard).

One TSM patient had a de novo visual deficit with right-sided eye blindness and left temporal quadrantopsia. Pre-existing visual deficits improved because of the operation in
22 (52%) of 42 TSM patients. This was related to tumor size (two large, 18 medium, and two small), but not tumor consistency (12 soft, six medium, and four hard). Improvement of visual outcome was predicted by duration of the preoperative visual deficit (p<0.05). A preoperative visual deficit that had lasted for less than six months improved in 13 of 20 patients, a deficit lasting between 6 and 12 months improved in seven of 11 patients, and a deficit lasting over 12 months improved in only two of 11 patients.

Outcome

Early Outcome

Clinical outcome at discharge was good in 43 OGM (65%), in 54 ACM (74%) and in 45 TSM patients (87%). Fifteen OGM (23%) and ACM (21%) and six TSM patients (12%) had moderate disability. Eight OGM (12%), one ACM (1%) and one TSM (2%) had severe disability. Three ACM patients died for surgery.

Residual Tumor

Six OGM patients (9%) showed a residual tumor in the early postoperative MRI. Five were benign meningiomas (G1) and one was atypical (G2). Five of the residuals were attached to the ACAs. Four of the six tumors infiltrated the ethmoid sinuses on preoperative images and were deliberately left behind, but two were unexpected findings. Three of the tumors were large, two were medium, and one was small. Three of the six patients underwent redo surgery for the tumor remnant, and one had radiosurgery. One of these three patients was reoperated on one month after the first surgery because some tumor had been left behind a corner in the operative field, as documented by the postoperative CT scan and MRI. Two of the six patients were followed up only with MRI, receiving no additional treatment. Sixteen ACM patients had residual tumor; all were benign, but one was atypical (G2); this patient was treated in 1997 by another neurosurgeon, underwent reoperation of the residual tumor in 2004 and 2006, followed by radiosurgery (20 Gy). Two other patients were previously operated on by another surgeon. One patient had been operated on twice, in 1977 and 1992, and presented again with a residual tumor (benign, medium-
Results

sized, medium consistency) and an intraoptic component with documented growth, and therefore underwent a right LSO approach with subtotal removal in 2003. Since then, the residual has been stable and the patient has had a good recovery. The second patient was treated in 1994. There was a residual tumor attached to the optic nerve that was growing and was reoperated in 2000 (the tumor was small, medium consistency, and benign). After the operation, the residual was treated with radiotherapy (50.4 GY) and has been stable since (last MRI performed in January 2008). In two patients, an intraoperative laceration of the vessel interrupted tumor removal and some tumor was left behind. Both patients had good recovery. In the remaining 11 patients, the residual tumor was attached to the optic nerve (five patients), located at the medial sphenoid wing (three patients), located at the cavernous sinus (two patients) and one was intraorbital.

Seven TSM patients had residual tumor. Two were reoperated on by the senior author (J.H.), one was treated by radiosurgery, and four were only followed up. All tumors were benign (G1), but the one patient who underwent radiosurgery presented with multiple meningiomas.

Tumor Recurrence during Follow-up

Four OGM cases (7%) recurred during a median follow-up of 45 (range, 2-128) months. All of these G1 tumors infiltrated the ethmoid sinuses and had a hard consistency. Their initial diameters were 61 mm, 53 mm, 43 mm, and 20 mm (redo case). Tumor recurrence was observed in three ACM patients during a median follow-up of 36 months (range, 3-146). One patient had a small, soft, benign tumor (maximum diameter 10 mm) operated on in 2001. The recurrence of about 4 mm, attached to the medial side of the optic nerve, was discovered in an MRI performed in September 2009. One patient presented with a medium-sized ACM, which recurred two years after surgery at the medial sphenoid wing and was reoperated on. One patient presented a small recurrent tumor at the medial sphenoid wing five years after the first operation for a large-sized ACM; the residual was stable during a six-year follow-up.

Tumor recurrence affected only one TSM during the follow-up. This patient had a medium-sized (maximum diameter 24 mm) soft tumor attached to both optic nerves, the optic chiasm, both A1s and ACAs, the AComA, and the right ICA. After the first operation in 2001, the patient’s preoperative visual deficit (bilateral visual deficit and bitemporal hemianopsia) improved, but in 2005 and 2009 a sudden decrease in visual acuity led to the discovery of a recurrent
tumor that was reoperated twice, in 2006 and 2009.

**Long-term Clinical Outcome and Mortality**

The median follow-up of OGM patients was 45 (range, 2-128) months. During the follow-up 53 patients (80%) had a good recovery, five patients (8%) moderate disability and eight patients severe disability (12%); the median Karnofsky score was 90. Of the 13 patients with moderate or severe disability, all but one had a medium (seven patients) or large (five patients) tumor. Multivariate analysis showed that only the preoperative Karnofsky score significantly (p<0.001) predicted good outcome (OR 2.8, 95% CI 1.6–5.0, per 10 points of Karnofsky score). Age, tumor size, and tumor consistency were not independent risk factors.

The median follow-up of ACM patients was 36 (range, 3-146) months. The median Karnofsky score was 90. At the three-month outpatient visit, 60 patients (82%) had good recovery, nine patients (12%) had moderate disability and three patients (4%) died for surgery-related reasons. One patient with a medium-sized hard tumor attached to the ICA, MCA, and ACA developed a severe vasospasm with hemispheric infarction and died 19 days after surgery. One patient died on the second postoperative day because of acute myocardial infarction after a good initial recovery from the operation. One patient with a large, medium consistency tumor attached to the ACA and MCA and encasing the ICA developed hemiparesis and died because of severe lung infection one month after the operation.

The median follow-up of TSM patients was 59 (range, 1-133) months. At the outpatient clinic 47 patients (90%) with good recovery and four patients (8%) with moderate disability. One patient (2%), already in poor condition preoperatively, died 40 days after surgery due to cardiac arrest. The median Karnofsky score was 80.

**Method of Anesthesia for OGM, ACM, and TSM Surgery (Publication IV)**

Data analysis includes surgical data for 191 patients and anesthesiological records for 187 patients. Anesthesiological charts were not available for two OGM patients and two ACM patients. The surgical conditions were classified as good (slack brain achieved) for 154 patients.
(82%), as satisfactory for 18 patients (10%), and as poor for 15 patients (8%).

Induction of Anesthesia

Diazepam (5-15 mg) was given orally to all patients one hour before surgery. Tiopental (median dose 377 mg, range 300-500 mg) was used in 186 (99%) patients to induce anesthesia. Etomidate (14 mg) was used in an 80-year-old patient with congestive heart disease and a medium-sized TSM. The mean (range) total intraoperative amount of fentanyl was 0.56 (0.150-3) mg, mainly given as a single bolus at the induction of anesthesia.

Table 7. Method of anesthesia.

<table>
<thead>
<tr>
<th>Method</th>
<th>Number of patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intravenous anesthesia</td>
<td></td>
</tr>
<tr>
<td>Propofol infusion</td>
<td>46 (25%)</td>
</tr>
<tr>
<td>Volatile agents</td>
<td></td>
</tr>
<tr>
<td>Sevoflurane</td>
<td>74 (40%)</td>
</tr>
<tr>
<td>Isoflurane</td>
<td>33 (17%)</td>
</tr>
<tr>
<td>Combined anesthesia</td>
<td></td>
</tr>
<tr>
<td>Sevoflurane/Isoflurane + propofol infusion</td>
<td>34 (18%)</td>
</tr>
</tbody>
</table>

Maintenance of Anesthesia and Tumor Size

Propofol infusion (46 patients/25%), sevoflurane (74/40%), or isoflurane (33/17%), or a combination of propofol infusion and sevoflurane/isonflurane (34/18%) were used for anesthesia (Table 7). Anesthesia was maintained with Nitrous
Results

Oxide (N₂O) in 140 patients (75%). N₂O was most often combined with sevoflurane or isoflurane (95/51%) (p<0.05). Twenty-one medium and 21 large meningioma received propofol anesthesia. Only four patients anesthetized with propofol had a small meningioma. Twenty-four patients anesthetized with propofol presented with peritumoral edema. Sevoflurane or isoflurane anesthesia was given to 37 large-, 45 medium-, and 25 small-sized meningioma patients received, and 40 of them (10 medium and 30 large meningiomas) presented with peritumoral edema. Univariate analysis disclosed no correlation between tumor size and method of anesthesia.

One-hundred sixty-six patients (89%) received remifentanil infusion. A combination of remifentanil with sevoflurane (71 cases) or isoflurane (20 cases) was used in 91 patients (49%) or with propofol in 41 patients (22%). Neuromuscular block was achieved by non-depolarizing muscle relaxants (rocuronium or vecuronium) in all study patients. In 33 patients neostigmine was necessary to reverse the neuromuscular block at the end of surgery.

Brain Relaxation and Anesthesia

Brain relaxation was good in 154 patients (82%). In 18 patients, brain relaxation was classified as satisfactory (10%) and optimal slack brain was achieved by opening the basal cisterns during surgery. In 15 patients (8%), the brain swelled intraoperatively. Thirteen of these patients had large tumors (p<0.001). The median Karnofsky score was 80 (range 50-90), and 14 of the 15 patients had peritumoral edema.

Nine patients with brain swelling had either sevoflurane (six cases) or isoflurane (three cases) anesthesia. In multivariate analysis, swelling of brain was associated with medium- to large-sized meningiomas, peritumoral edema, volatile or combined anesthesia, and poor preoperative clinical condition (Karnofsky score <70) (p<0.01).

Osmotic Agents

The administration of 15% mannitol according to meningioma size is presented in Table 8. The use and amount of mannitol were significantly associated with meningioma size and preoperative cerebral edema (p<0.05). However, in two small-meningioma patients without peritumoral edema, 500 ml of mannitol was administered...
before surgery because they had been operated on before the year 2000, when mannitol began to be given routinely. Hypertonic saline was not administered to any patient.

The median cumulative amount of urine during surgery was 350 (range 0-348) ml for 177 patients (95%); for 25 of these patients, it was recorded as 0 ml.

Table 8. Size of tumor and amount of mannitol used (p=0.01).

<table>
<thead>
<tr>
<th>Mannitol ML</th>
<th>Small &lt; 2 cm</th>
<th>Medium 2-4 cm</th>
<th>Large &gt;4 cm</th>
<th>Total of patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>4</td>
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<td>200</td>
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<tr>
<td>250</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>270</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>350</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>400</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>500</td>
<td>2</td>
<td>12</td>
<td>35</td>
<td>49</td>
</tr>
</tbody>
</table>

Total of Patients 2 16 44 62

**Hemodynamics and Vasoactive and Antiepileptic Drugs**

Systolic and diastolic arterial pressures and heart rate are shown in Figure 36. The mean systolic blood pressures ranged between 95 and 110 mmHg during surgery. Heart rate remained stable. Extreme hemodynamic changes were not observed. Hemodynamic data on the size and type of tumor were similar. The mean preoperative systolic and diastolic blood pressure was 125 and 70 mmHg, respectively. The majority of the patients (157/84%) had a systolic blood pressure of less than 160 mmHg for the first six hours after the operation. Intraoperative phenylephrine infusion was given to 60 (32%) patients and dopamine to four (2%) patients. Sixty-nine patients were also administered a bolus of phenylephrine. A bolus of ephedrine (mean 3.9; range, 5-75 mg) was given to 52 (28%) patients. Labetalol (mean 14 mg; range, 9-120 mg)
5 Results

was given to 68 (36%) patients. Other vasoactive agents used in 29 (16%) patients were dihydralazine sulfate (15 cases), clonidine (six cases), metoprolol succinate (three cases), and atropine (two cases). Droperidol was administered to three (2%) patients. The use of any vasoactive agent was unrelated to type or size of tumor.

Figure 36: A graphic illustration showing the mean pre-, intra-, and post-operative arterial pressure.

One-hundred-four (56%) patients received antiepileptic drugs perioperatively. These drugs comprised fosfenytoin (95 cases), carbamazepine (six cases), fenyoitn (two cases), and lorazepam (one case). The administration of antiepileptic drugs was not related to tumor location, but was related to tumor size (p<0.05).

Intraoperative Bleeding and Blood Transfusion

Blood loss was related to tumor size (p<0.001). The median cumulative intraoperative blood loss was 200 (0-2000) ml. In 44 patients (23%), the estimated intraoperative blood loss was less than 50 ml. Two patients had blood loss above 1500 ml. In one patient (blood loss of 1800 ml) the internal carotid artery lacerated accidentally during the removal of a small ACM; and the laceration was repaired with microsuture. The other patient (blood loss of 2000 ml), had a very large vascularized (maximum diameter > 8 cm) OGM meningioma. Red blood cell transfusions were administered to 17 patients (9%) (Table 9). Interestingly, 170 patients (91%) did not require a red blood cell transfusion. Fresh frozen plasma and platelet concentrates were given to two patients each.


<table>
<thead>
<tr>
<th>Red blood cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>unit (ml)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>29</td>
</tr>
<tr>
<td>80</td>
</tr>
<tr>
<td>61</td>
</tr>
<tr>
<td>170</td>
</tr>
</tbody>
</table>

One-hundred and fifty-seven patients (84%) were extubated on the day of the surgery. The median (25\textsuperscript{th}/75\textsuperscript{th} percentiles) time to extubation after surgery was 18 (8/105) min. Fifty-three patients (28%) were extubated within 10 min of completion of surgery (14 small, 33 medium, and six large meningiomas). Forty-five patients (24%) were extubated within 30 min of surgery (13 small, 24 medium, and eight large meningiomas). Fifty-nine patients (32%) were extubated within 1 h (10 cases), 5 h (36 cases), or more than 5 h postsurgically, but nevertheless on the same day of the surgery (13 cases).

Twenty-nine patients (16%) were extubated during the following days after surgery: 21 patients on the first postoperative day, three patients on the second postoperative day, one patient on the third postoperative day, two patients on the fourth postoperative day, and one patient on the fifth or sixth postoperative day (one case each). In univariate and multivariate analyses, preoperative clinical status (Karnofsky score < 70) (p<0.001), tumor size and location (OGM) (p<0.001), peritumoral edema (p<0.001), and brain swelling at surgery (p<0.05) were predicting factors for prolonged extubation time after surgery (days after surgery).
Surgical Complications and Outcome after Anterior Clinoidectomy (Publications V and VI)

Tailored Anterior Clinoidectomy

We performed a tailored clinoidectomy in 82 patients (Table 10). We removed only the necessary amount of bone for the treatment of the aneurysm or the tumor. We classify this removal as follows 1) the tip of ACP (less than 1/3 of all clinoid); 2) the tip and the head of the ACP (around 1/3 of ACP); 3) the tip, the head and the body of the ACP (around 2/3 of ACP); 4) the whole ACP. In eight patients (three vascular and five tumor cases) the anterior clinoidectomy was extended laterally to open the SOF.

Table 10. Site of the lesions and tailored anterior clinoidectomy.

<table>
<thead>
<tr>
<th>Tailored clinoidectomy</th>
<th>Minimal</th>
<th>Partial</th>
<th>Subtotal</th>
<th>Total Clinoidectomy</th>
<th>Total number of cases</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vascular cases</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carotid-ophthalmic aneurysm</td>
<td>1</td>
<td>0</td>
<td>8</td>
<td>12</td>
<td>21</td>
</tr>
<tr>
<td>Other carotid aneurysms</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>16</td>
<td>23</td>
</tr>
<tr>
<td>Basilar bifurcation aneurysm</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Carotid-cavernous fistula</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td><strong>Tumor cases</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meningioma</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>15⁺</td>
<td>26</td>
</tr>
<tr>
<td>Other lesions</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td><strong>Total (vascular + tumor cases)</strong></td>
<td>5</td>
<td>8</td>
<td>18</td>
<td>51</td>
<td>82</td>
</tr>
</tbody>
</table>

⁺ In one case orbital roof was also removed.

Visual Outcome

Preoperative visual deficits were present in 27 patients (33%) and worsened after surgery in three patients (4%). One patient with bilateral carotid-cavernous fistula had previously undergone two sessions of endovascular treatment and radiosurgery. After these the patient had right oculomotor palsy, chemosis and bilateral decrease of visual acuity. Extradural anterior clinoidectomy was performed with Sonopet.
and drill and the fistula was successfully closed. The visual deficit improved in the left eye but worsened in the right. One patient had preoperative bilateral visual acuity deficit due to anterior clinoidal meningioma and developed a unilateral blindness after surgery. One patient presented with intraorbital fibrous dysplasia and both visual acuity and visual field deficit, which worsened after surgery.

Four patients (5%) with preoperatively intact vision had new visual deficits postoperatively. One patient with a small unruptured carotid-ophthalmic aneurysm developed unilateral blindness. One patient with a medium-sized unruptured carotid-ophthalmic aneurysm developed temporal hemianopsia. One patient with a ruptured blister-like ICA aneurysm and HH Grade 5 subarachnoid hemorrhage had a unilateral decrease of the visual acuity. One patient with intraorbital cavernoma developed unilateral blindness after surgery (Table 11). Sonopet was used in five out of these seven cases that experienced postoperative visual complications. The whole ACP was removed in five cases. However, univariate or multivariate statistical analyses did not reveal any factors that would statistically significantly associate with the occurrence of postoperative visual deficits.

Twelve patients (15%) with preoperatively existing visual deficits improved after surgery (the patient with bilateral carotid-cavernous fistula and an improvement of the left but worsening of the right eye visual acuity not included). Again, statistical analysis did not reveal factors associating with improvement of visual deficits. Interestingly, however, intradural clinoidectomy was performed in all patients with improvement in visual deficits.

<table>
<thead>
<tr>
<th>CSF leakage</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wound infection</td>
<td>1</td>
</tr>
<tr>
<td>ICA rupture</td>
<td>1</td>
</tr>
<tr>
<td>Meningitis</td>
<td>1</td>
</tr>
<tr>
<td>Oculomotor palsy (transient)</td>
<td>16</td>
</tr>
<tr>
<td>Oculomotor palsy (permanent)</td>
<td>1</td>
</tr>
<tr>
<td>Visual deficits</td>
<td>7</td>
</tr>
</tbody>
</table>

Table 11. Postoperative complications in 82 patients who underwent tailored anterior clinoidectomy.
Results

Ophthalmoplegic Complications

Seventeen patients (21%; ten aneurysm and seven tumor cases) developed oculomotor palsy after surgery and they were not related to anterior clinoidectomy. Thirteen of them had recovered completely at three months, three had improved significantly, and symptoms persisted in only one patient. This patient was operated on for an unruptured giant basilar bifurcation aneurysm, and the oculomotor palsy was not related to the anterior clinoidectomy itself (only the medial tip of the ACP was removed). In only one of these patients was the SOF opened; this patient had an anterior clinoid–cavernous sinus meningioma, and the whole ACP was removed extradurally. This patient also developed a transient abducent nerve palsy.

CSF Leakage

Five patients (6%; three aneurysm and two tumor cases) had postoperative CSF rhinorrhea (Table 11). Three of them required a reoperation and duraplasty to occlude the cranionasal fistula, and in two an external lumbar drainage for a few days was sufficient.

Other Surgical Complications

One patient presented with unruptured carotid-ophthalmic and intracavernous carotid aneurysms, and the operation was planned to treat only the ophthalmic aneurysm. During the extradural removal of the ACP with microrongeur, the intracavernous aneurysm attached to the ACP ruptured together with the parent vessel. The rupture site was repaired with AnastoClip (AnastoClip Vessel Closure System 1.4 mm; LeMaitre Vascular, Burlington, MA, USA) (Figures 37 and 38). This case has previously been published as a technical case report (197). One patient had meningitis and one patient severe wound infection (Table 11).
Figure 37: Sagittal view of a 2D reconstruction CT showing the relationship between the anterior clinoid process (arrows) and the intracavernous aneurysm.

Figure 38: 3D-DSA, intraoperative view and schematic drawing of left ICA aneurysms showing the tear of the ICA repaired by using AnastoClips.
Clinical Outcome at Discharge and at Three Months

At discharge, 66 patients (80%) had good recovery, seven patients (9%) had moderate disability, seven patients (9%) had severe disability, and two patients (2%) were unconscious. These two patients were admitted because of Hunt-Hess grade 5 subarachnoid hemorrhage. Disability was not related to the anterior clinoidectomy itself in any of the patients. At three months, 71 patients (87%) had good recovery, six patients (7%) had moderate disability, four patients (5%) had severe disability, and one patient (1%) remained in a vegetative state. Three patients experienced a worsening of neurological condition that did not improve in three months: one patient with a giant unruptured basilar bifurcation aneurysm had hemiparesis and severe disability; one patient with kidney failure who underwent clipping for giant carotid-ophthalmic aneurysm had a slow recovery and severe disability still at three months; one patient with a sphenoorbital meningioma suffered from severe wound infection at one week from surgery and had moderate disability at three months. There was no surgical mortality in the series.


6 Discussion

This series of 273 patients treated through the LSO approach and by a single-surgeon is the largest series published to date. The LSO approach is simpler, faster, and less extensive than the previously advocated pterional, bifrontal and orbitozygomatic approaches, while producing comparable results in terms of safety and extent of tumor removal. The LSO approach can be performed in 10 minutes, allows the neurosurgeon to remove the tumor with minimal blood loss, and avoids brain damage or contusion with most of the patients extubated the same day of surgery.

Lateral Supraorbital Approach versus Pterional, Bifrontal, and Fronto-Orbital Approaches

LSO Approach versus Pterional Approach (Publications I-III)

Both pterional or minipterional approach were used by the senior author (J.H.) to treat 39 OGM patients since 1979. The pterional or minipterional approaches have the sylvian fissure in the center of the craniotomy, with partial exposure of the frontal and temporal lobes (70, 254). During the years, with experience the senior author noted that the middle fossa extension was unnecessary and only the frontolateral part of the approach was needed during the surgery. This subsequently led to the development and use of the LSO approach for vascular and neoplastic lesions (101). The sylvian fissure remains at the border after a LSO approach and can easily be opened if necessary, as our experience with MCA and other anterior circulation and even posterior circulation aneurysms shows (48-51, 100, 102, 138, 139, 198, 199).

The most widely described approach for OGM, ACM, and TSM surgery in the literature has been the pterional one (14, 59, 68, 188, 238, 255, 260, 261). This approach, described by Dandy in 1942 (46) and later perfected and popularized by Yaşargil (254), is commonly used for vascular and neoplastic lesions of the anterior and medial cranial fossa. When treating OGMs, ACMs, and TSMs the pterional approach allows to
visualize the anterior circulation, the basal feeders, and the optic nerve and chiasm. In larger tumors with more temporal extension, the LSO may be modified with a 1-cm temporal extension to fully visualize the temporal portion of the sylvian fissure. This modified approach was applied in 20 ACM patients. However, for small or medium-sized meningiomas, the classic LSO approach is generally sufficient to safely and completely remove the tumor. The LSO approach gives the same advantages as the classic pterional approach, but is less traumatic and faster. The LSO approach can be performed in 10 minutes, allows the neurosurgeon to remove the tumor with minimal blood loss (median cumulative blood loss in meningioma patients was 200 ml), and avoids brain damage or contusion with most of the patients extubated the same day of surgery (157 meningioma patients). Modern neuroanesthesia (191) and CSF release after opening the basal cisterns give space to visualize the necessary neurovascular structures. A recent cadaveric study demonstrates that the LSO approach gives the same advantages than the pterional one (204).

**LSO Approach versus Bifrontal Approach (Publications I and III)**

OGMs and TSMs can be treated by using a bifrontal transbasal interhemispheric approach. This approach provides an easier anatomical orientation to both optic nerves, the optic chiasm, and vascular structures, and allows the surgeon to devascularize the tumor. LSO approach gives less exposure of the frontal lobes than the bifrontal approach, with minimal surgical manipulation. Bilateral retraction of the frontal lobe and the sacrifice of the anterior third of the SSS and of the frontal draining veins are not needed when using the LSO approach with minimal risk of postoperative infarction or increased edema. The frontal sinus is always opened when performing the bifrontal approach with the risk of postoperative CSF leakage and infections. In our experience the frontal sinus is seldom opened during the LSO approach. In a recent study comparing a simple frontolateral approach (very similar to our LSO approach) with the bifrontal approach in microsurgery of OGMs, three patients in the bifrontal group died due to postoperative brain edema. No deaths occurred in the frontolateral group. The authors concluded that the anterior third of the SSS should be preserved during OGM surgery, and this is better achieved with the frontolateral approach (159). These authors also compared the frontolateral and the bifrontal approach for TSM surgery, the incidence of postoperative brain edema and venous infarction being higher in patients undergoing bifrontal craniotomy. The authors concluded that the anterior third of
the SSS should be preserved because its closure is not safe, often resulting in complications or death (161).

**LSO Approach versus Orbitozygomatic Approach (Publications I-III)**

Frazier in 1913 first described the orbitozygomatic approach to reach the pituitary gland (74). This approach was later refined by Jane (114) and it is recommended by many authors to remove OGMs, ACMs, and TSMs (3, 5, 149, 209, 216).

For OGM surgery, Al-Mefty and Babu recommended a unilateral frontal craniotomy with orbital osteotomy to prevent bifrontal retraction, leading to possible mental changes (3, 5, 149, 209, 216). The orbitozygomatic approach is recommended by Al-Mefty and Sekhar when treating ACMs and TSMs (3, 5, 209). When performing the orbitozygomatic approach there is a minimal brain retraction; there is possibility to access to the tumor via different routes (subfrontal, subtemporal, transsylvian); the cavernous sinus can be entered if needed; the vascular support to the tumor can be easily reached (4, 5). Haddad and Al-Mefty recommend using a spinal drainage to achieve a slack brain (91). The LSO approach provides the same advantages as the orbitozygomatic approach, especially if the operator enters from the side of the head to have a better angle, but is by far simpler, less traumatic, and faster. A slack brain can be achieved by modern neuroanesthesia (191) without spinal drainage. In small and medium-sized meningiomas additional space and brain relaxation is achieved by opening the basal cisterns. In large tumor debulking with high power bipolar and suction is one of the first steps of the operation, followed by the opening of the basal cisterns. When using the LSO approach, the tumor can be reached subfrontally, but the sylvian fissure can also be easily opened. The subtemporal route is not needed when treating ACMs or TSMs because the main vascular support comes from the dura of the anterior clinoid, planum sphenoidale, and orbital roof via the AEA and PEA.

Pterional, orbitozygomatic, and minisupraorbital approaches were compared in a recent cadaveric study (71). The minisupraorbital approach with removal of the orbital rim gives a similar surgical view as the pterional and orbitozygomatic approaches. In our experience, inclusion of orbital osteotomy is not necessary or beneficial when the LSO approach is used to remove OGMs, ACMs, and TSMs.
Based on our review on 187 neuroanesthesia procedures in patients who underwent LSO approach, we found that patient position, method of anesthesia, osmotherapy, and adequate cerebral perfusion pressure, all together gives a slack brain. One-hundred and fifty-four patients (82%) had slack brain, 17 (10%) had a satisfactory neurosurgical conditions and 15 (8%) had brain swelling after craniotomy. Volatile anesthesia was given to nine (5%) patients with brain swelling. The LSO approach with a bone flap about 3-4 cm in diameter is not traumatic (100, 101, 103, 104) and intraoperative bleeding was high in only two patients due to accidental ICA lesion or a well-vascularized tumor.

The head of the patient should be elevated 30° and should be as neutral as possible to facilitate the venous return (153). The senior author (J.H.) used in all patients a round firm pillow under the shoulders of the patient and the position of the head is adjusted so that the operating table was usually 20 cm over the cardiac level.

Brain relaxation can be achieved during craniotomy by regulating cerebral blood flow (CBF) and cerebral perfusion pressure (CPP). Physiological pressure-flow autoregulation, ventilation (CO2 reactivity), method of anesthesia regulate CBF.

An arterial transducer set at zero at the level of the foramen of Monroe optimized the CPP according to the systemic blood pressure measurement. The safe lower limit of CPP was determined individually by assessing the overall hemodynamic profile. The systolic blood pressure varied on average between 95 and 110 mmHg, providing a CPP of above 60 mmHg. The targeted CPP was achieved by use of relatively small doses of vasoactive drugs, i.e. phenylephrine or ephedrine, without excessive intravenous fluid administration. During removal of a brain tumor it is also essential to avoid peak increases in systolic arterial blood pressure to minimize bleeding. Clinical assessment of CPP was optimal in all patients since none of the patients had ischemic brain lesions postoperatively and blood loss was minimal intraoperatively.

Adequate depth of anesthesia and analgesia gave hemodynamic stability. A bolus of fentanyl (5-7 microg/kg) following infusion of remifentanil blunts sympathetic activity during craniotomy. Inhaled anesthetics were used in patients with all tumor sizes. Our observations confirm the results of previous studies showing that inhaled anesthetics are suitable in patients undergoing resection of a brain tumor (25, 37).

In patients with high intracranial pressure (ICP) (large tumor) inhaled anesthetics are contraindicated. To counteract the vasodilatory effect of inhaled anesthetics on cerebral arteries, the patient must be slightly
hyperventilated. Propofol anesthesia was given to 43% of study patients, most often patients with medium or large tumors, supporting the capacity of propofol to decrease ICP. Mannitol before opening of the dura increases brain relaxation especially in large tumor or in presence of brain edema. The use of Mannitol should be reserved in selected cases because it may induce unfavorable side-effects such as disturbances in electrolyte concentrations, renal dysfunction, or coagulation disorder (143, 144).

Careful microsurgical technique, optimal brain relaxation, and cerebral hemodynamics all minimize blood loss during brain tumor surgery. Furthermore, the duration of surgery was short, even in patients with a large tumor. Indeed, the intraoperative blood loss was on average only 200 ml, and very few patients received red blood cell transfusion. No previous report has described intraoperative bleeding after OGM, ACM, and TSM. The uneventful intraoperative phase is also reflected in the immediate postoperative period. Most of the patients were extubated on the day of surgery, and the median early Karnofsky score was 80.

**LSO and Anterior Clinoidectomy (Publications II-VI)**

The choice of intradural or extradural anterior clinoidectomy and the extent of ACP removal are related to the size and location of the lesion. The policy of the senior author (J.H.) for all surgeries is to minimize the procedure and its risks, and when performing skull base approaches to remove just enough bone to treat the lesion. In aneurysm surgery, the goal of anterior clinoidectomy is to achieve proximal control of the ICA. Sometimes the ACP is not at all removed, but merely coagulate the dura over the ACP to gain a few millimeters of space, sufficient for the proximal control of the ICA. Based on the senior author’s (J.H.’s) experience, we perform anterior clinoidectomy in all vascular cases intradurally.

Intradural anterior clinoidectomy is choosen when needed in ACM or TSM surgery which conforms to the opinion and technique of many other authors (68, 81, 149). The ACP is removed after the tumor resection unless the tumor is completely intraorbital or inside the optic canal.

Extradural anterior clinoidectomy is preferred by other author (165) who emphasized the role of the opening of the SOF through the orbitozygomatic approach for the treatment of both aneurysms and tumors. Opening of the SOF allows a better exposure of the cavernous sinus and mobilization of the cranial nerves inside (165). We have also performed extradural anterior clinoidectomies and we nowadays
use the intradural-extradural approach for neoplastic lesions, i.e. after orienting ourselves carefully with the anatomy using the intradural approach, we switch to the extradural route for actual ACP removal. Similarly, Dolenc in 1985 advised opening the dura before complete unroofing of the optic canal in giant carotid-ophthalmic aneurysms or aneurysms extending over the ACP or into the cavernous sinus (60). Many authors (29, 52, 105, 151, 261) consider the extradural route safer because the dura protects the neurovascular structures, whereas other authors (68, 141, 149, 170) prefer the intradural route. Intradural visualization of the ICA and the optic nerve is mandatory for exact anatomical orientation and safe anterior clinoidecotomy. We recommend intradural anterior clinoidecotomy for all vascular and most neoplastic lesions.

Operating Time with the LSO Approach (Publications I-III)

LSO approach can be performed in only 10 min from skin incision to opening of the dura, which is far less than the time and workload needed for either the bifrontal approach or the fronto-orbital approach, not to mention one of the more extensive skull base approaches. Skin-to-skin operative time includes the approach, tumor removal, hemostasis, and wound closure. Closing time is usually three times longer than opening time. Opening and closure are shorter in the LSO approach than in the pterional, bifrontal, or other skull base approaches. In our OGM series, the mean operative time from skin to skin was 158 min, which was less than a previous OGM series of 18 consecutive patients operated on by using a bifrontal approach (230 min) (154). In all 191 patients the operative time was related to the size of the meningiomas, but, surprisingly, unrelated to tumor consistency. From the economic viewpoint, the relatively short operating times with the LSO approach allow more efficient use of the operating room, as more surgeries can be performed in the same room over the course of a single working day and also shorter operation times are presumably beneficial for patients.
Surgical Complications

Olfactory Function Preservation (Publications I-III)

Olfactory function preservation is one of the key factors driving the development and improvement of different surgical approaches for OGMs. Excessive retraction and manipulation or excessive coagulation around the base of the tumor near the vascular supply to the olfactory tract can easily harm the olfactory function (79). Cribriform plate osteotomy through bifrontal craniotomy for extradural lesions of the ACF has been reported to preserve or even improve olfactory function (218). Dare stresses the need to know the exact distance below the cribriform plate to transect the ethmoidal bone in order to preserve olfactory function; skull base approaches to the anterior cranial base often involve the transection of olfactory nerves (47). We believe that preservation of olfactory function is only possible in small and some medium-sized OGMs. Large OGMs presenting with anosmia showed no improvement after surgery. In small and medium-sized tumors, preoperative anosmia was less frequent, and it was often possible to preserve the function of the contralateral olfactory tract. Welge-Luessen reported potential preservation of the olfactory tract contralateral to the tumor in OGMs of less than 3 cm (244). Although the function of the ipsilateral olfactory tract is often lost, the surgical technique should aim at preservation of both olfactory tracts by delicate dissection in all areas, as this improves the general level of the surgery even in large tumors. In patients with good olfactory function, coagulation of the dura of the cribiform plate (Simpson grade II) should be limited to preserve blood supply to the olfactory tracts (79). Our considerable experience with anterior circulation aneurysms indicates that olfactory lesions may be caused by the slightest retraction and are often difficult to avoid (102). Six OGM patients had new postoperative anosmia; only one ACM patient had postoperative anosmia, and no TSM patients had hypo- or anosmia.

CSF Leakage (Publications I-VI)

Other surgical series with OGM surgery have reported CSF leakage in 3-16% of patients operated on via the frontolateral or bifrontal approach (14, 65, 159, 236). This high rate of CSF leakage in OGM surgery is due to infiltration of the tumor of the ethmoid bone
and also to its drilling to prevent recurrences; leakage in OGM surgery can occur irrespective of the approach used. CSF leakage was a postoperative complications in six OGM patients; two patients required a reoperation and three patients had infiltration into the ethmoid sinuses. In previous ACM reports, CSF leakage incidence rates have ranged between 4% and 9% (4, 196). Three ACM patients had cranionasal CSF leakage, which was successfully treated with temporary lumbar drainage in all cases. Clinoidectomy was performed on all three patients, probably leading to opening of the ethmoid sinus.

In TSM surgery, CSF leakage ranges from 4% to 33% (10, 76, 161, 207, 224, 230). Three TSM patients in our series experienced postoperative cranionasal CSF leakage, which was successfully treated with temporary lumbar drainage in all cases. Incidence of CSF leakage after anterior clinoidectomy has ranged between 0% and 6% (112, 178, 210, 215, 226, 261). The anatomical continuity between the ACP and the ethmoid sinuses can lead to CSF fistula with leakage from the nose. Five patients (6%) in our series experienced postoperative cranionasal CSF leakage; two of them were treated with temporary lumbar drainage for a few days and three required new operations for plastic repair of the skull base. All of these patients had good recovery at discharge.

Visual Outcome (Publications I-III)

Especially in large OGM tumors visual deterioration is a known complication. The range of visual complications has ranged between 7-12% in patients operated on via a bifrontal or unilateral/subfrontal approach (65, 169, 214). In our series, five OGM patients had new postoperative visual deficits; in four of these, the OGM was attached to the chiasm and the ACAs. Two of these five patients improved.

Eleven of 39 ACM patients with preoperative visual deficit experienced improvement of their pre-existing visual deficits. Five of these patients underwent anterior clinoidectomy (four intradurally and one extradurally). In our series, 22 of 42 TSM patients with preoperative visual deficits experienced improvement in these deficits. Improvement was related to the preoperative duration of the deficit. Vision in 10 of these TSM patients was restored
completely after the operation; the deficit had lasted less than six months in six cases and between 6 and 12 months in four cases. Seven TSM patients experienced a worsening of the preoperative visual deficit, and one patient presented a new visual deficit. The visual deficit remained stable in 13 of 42 patients with pre-existing visual deficits. The range of visual improvement in previous TSM series has been between 19% and 91%, and the range of visual deterioration between 3% and 39% (15, 68, 76, 151, 160, 178, 180, 181, 202, 207, 222, 224, 230).

Pamir and colleagues recently reported a series of 43 ACMs, noting that during the extradural clinoidectomy when the dura is retracted the tumor is also retracted, leading to additional pressure to the optic nerve and possible damage. The authors believed that the intradural procedure is safer in preserving the optic nerve (179). Lee and coworkers published a series of 15 patients with ACMs (including one patient with hemangiopericytoma), with improvement of the preoperative visual deficits in six patients and no change in two patients. Otani et al. published a series of 32 patients with TSMs; 20 patients received a selective extradural anterior clinoidectomy (178). The preoperative visual deficit improved in 15 (90%) of these patients, compared with 83% in patients without a clinoidectomy. The authors attributed this good outcome to the extradural clinoidectomy, to opening of the SOF, to sectioning of the falciform ligament, and to decompression of the optic nerve (136, 178). Mathiesen and Kihlström reported on a series of 23 TSM patients treated by a pterional and extradural clinoidectomy approach, hypothesizing that early optic nerve release can improve visual outcome (151). The senior author (J.H.) prefers to remove the ACP intradurally in ACM and TSM surgery to maintain good control of all neurovascular structures. We also recommend use of low-power coagulation on the dura in the proximity of the optic nerve to avoid nerve damage.

All patients with new visual deficits presented with an ACM where the ICA and its branches were attached to or encased by the tumor. During surgery the vascular support to the optic nerve, mainly from the superior hypophyseal arteries, may be damaged, with subsequent optic nerve ischemia and visual deficits (241). Al-Mefty and Smith state that direct compression of the tumor on the vascular support to the optic chiasm and optic nerve is the main cause of visual impairment (3).
Visual Outcome after Anterior Clinoidectomy (Publications V and VI)

Worsening of the visual acuity affected seven (9%) of the 82 patients and pre-existing visual deficits improved after surgery in almost half of cases (12/27) who underwent anterior clinoidectomy. Intradural route was used in all patients in whom vision improved. Visual worsening after anterior clinoidectomy has ranged from 0% to 13% (29, 128, 149, 151, 178, 202, 215, 261). Yonekawa reported in 1997 thirty-two patients who underwent a pterional and extradural anterior clinoidectomy for supra- and parasellar lesions and three had visual worsening after surgery (261). The “no drill” technique to remove ACP extradurally was reported by Chang in 2009, and two of 45 patients had postoperative visual deficits (29). The role of the extradural anterior clinoidectomy, sectioning of the falciform ligament and opening of the SOF to improve postoperative visual outcome in ACM and TSM surgery, is emphasized by some authors (151, 178, 202). However, we do not routinely perform anterior clinoidectomy for all ACM and TSM in accordance with some other authors (15, 17, 68, 81, 112, 117, 126, 141, 207). When anterior clinoidectomy is required for complete tumor removal, we prefer a tailored clinoidectomy and remove only as much of the ACP as required. No statistically significant factors were found in our series when analyzed the critical factors affecting visual outcome, such as opening of the SOF, extra- or intradural route, duration of pre-existing visual deficits, and instruments used to perform the clinoidectomy. This is probably due to the rather small number of patients with visual complications and the subsequent lack of statistical power. However, after scrutiny of the operative videos, we consider that usage of the ultrasonic bone dissector (Sonopet in our case) too close to the optic nerve may have a role in optic nerve injury.

The most widely used technique to remove the ACP is high-speed drilling. Chang scrutinized 45 consecutive cases undergoing anterior clinoidectomy through a frontotemporal craniotomy, and assumed that high-speed drilling can injury the surrounding neurovascular structures directly (mechanical) or indirectly (thermal damage) (29). The ultrasonic bone aspirator has been introduced to avoid the risks of drilling and few reports exist regarding its use in anterior clinoidectomy (29, 92). Chang supposes the possibility of ultrasound-related cranial nerve damage. Furthermore, the ultrasonic bone dissector is a very expensive piece of instrument with additional accessory device costs. Recently has been published a report about the use of the ultrasonic bone dissector
Discussion

in spinal surgery (123) and the authors report six cases of dural injury and one case of spinal cord injury attributable to the use of the device. In our series, in the patient with no pre-existing visual deficits and a small carotid-ophthalmic aneurysm, the ultrasonic bone dissector was used close to the optic nerve, and this may have caused the postoperative blindness of the eye. Also, in one patient with a carotid-cavernous fistula and another patient with intraorbital fibrosis, both of whom experienced postoperative visual deficits, ultrasonic bone dissector was used close to the optic nerve. We therefore believe that ultrasonic bone dissectors are certainly not harmless and may cause optic nerve injuries.

Surgical Mortality (Publications I-III)

The closure of the SSS and frontal cortical veins and compression of both frontal lobes after bifrontal craniotomy had a high mortality (65). The advantage of the LSO approach is to preserve the SSS and the frontal cortical veins, avoiding bifrontal compression. No OGM patient in our series had increased edema postoperatively and no immediate deaths occurred after the surgery. Surgical mortality in OGM surgery had ranged between 0% and 28% in previous series (13, 39, 65, 94, 157, 159, 169, 228, 236, 244).

Mortality in ACM and TSM surgery has been relatively high in published patient series (4-6, 76, 81, 82, 112, 149, 161, 188, 196, 214, 224). This is explained by the close proximity of important neurovascular structures.

In previously published ACM series, the mortality has ranged between 2% and 15% when orbitozygomatic and pterional approaches were applied (4, 5, 82, 188, 196). In our ACM series, three patients (4%) died. One had severe vasospasm and died 19 days after the operation; one developed hemiparesis and died of severe pneumonia one month after surgery; one patient had a good initial recovery, but died two days after the operation of myocardial ischemia.

Nakamura et al. report the surgical results of 72 TSMs removed via the bifrontal, pterional, and frontolateral approaches (161). Two patients died in the bifrontal group. No patients died with the pterional or frontolateral craniotomy (161). In our series, one patient with severe disability preoperatively and a large tumor (diameter 60 mm) died 40 days after surgery due to cardiac arrest. She had slowly recovered and was able to walk one month after the operation. Surgical mortality reported in all TSM series has ranged from 0% to 44% when using pterional, bifrontal, supraorbital, and orbitozygomatic approaches (6, 76, 81, 112, 149, 161, 214, 224).
Tumor Recurrence during Follow-up (Publications I-III)

In our OGM series, with a median follow-up of 45 months, tumor recurrences was 6%. The tumor recurrence rate for OGMs varies between 5% and 41%, depending on the extent of the initial resection, but more importantly, on the duration of follow-up (2, 19, 111, 152, 156, 159, 212, 214, 250). Ethmoid sinus infiltration predisposes to tumor recurrence, and a radical resection of the tumor tissue from these sinuses leads to lower recurrence rates (169). In older patients, we do not advocate (overly) radical surgeries because of the associated higher risk of complications and only the intracranial tumor mass should be removed. In young patients with preoperative anosmia, we perform a radical resection of the tumor with extensive ethmoidal bone drilling. Previously reported tumor recurrence of ACMs has varied from 9% to 15% (250). In the present report, with a mean follow-up of 36 (range, 3-146) months, three patients (4%) had a recurrence. Published tumor recurrence rates in TSMs have varied from 0% to 8% using different approaches (9, 68, 76, 81, 149, 161, 202, 207, 214). One patient (2%) of our TSM series had a recurrence five years from the first operation. Mahmoud et al. reported 58 TSMs with total resection in 88%, and a recurrence rate of 2% over a mean follow-up of 23 months (149). Nakamura et al. compared the incidence of recurrence in 72 TSM patients treated using frontolateral, bifrontal, and pterional approaches and observed no differences during a mean long-term follow-up of 45 months (161). A previous series of 657 meningioma patients treated at our department was carefully reviewed, and the overall recurrence rate over 20 years was estimated to be close to 20% (111). Risk factors for recurrence were coagulation without removal of the dural insertion, invasion of bone, and soft consistency of the tumor (111). With a longer follow-up, the recurrence rate would certainly have been higher in our series, but in general the OGM, ACM, and TSM recurrence rates do not seem to be higher with the LSO approach than with other approaches.
Future Perspectives

Near Future

Preoperative Imaging

Preoperative high-field magnetic resonance imaging may provide a better view of the anatomical relationship between the lesion and the surrounding neural and vascular structures. The location of the optic nerve and chiasm relative to the tumor or aneurysm and to the anterior skull base may be visualized by novel MR diffusion tensor imaging techniques in the future, whereas the anatomy of small perforators may be better imaged by advanced MRA techniques. A careful preoperative anatomical study will reduce surgical complications. It may be possible to localize the ethmoid sinus and prevent its opening during anterior clinoidectomy, thereby avoiding postoperative CSF leakage. Predicting the exact consistency of the tumor and its dural origin may also be possible. A neuronavigator system will be used routinely to specify the tumor or aneurysm relationship to the skull base. The progress in the endovascular field will make possible to close preoperatively all the vascular support to the tumor even if coming from small arteries challenges to reach.

Skull Base Simulators

Virtual reality may be used to improve technical skills. An operation performed in virtual reality before the real one will provide skull base visualization and elucidate the relationship between neurovascular structures and the tumor or aneurysm, allowing a precise operative plan to be formulated that specifies all potential difficulties and complications. Virtual reality will enable the surgeon to perform
increasingly more challenging procedures on the anterior skull base through small approaches.

Microsurgical Techniques

Refinement of neurosurgical instruments will allow the neurosurgeon to perform simple, elegant, and definitive procedures. Smaller instruments must be designed. A higher magnification microscope with different devices for visualization of the vascular anatomy of the tumor, for instance, will allow devascularization of the lesion without intraoperative bleeding or a risk of ischemia. A new computerized device in the microscope together with preoperative imaging will facilitate total removal of lesions, avoiding residual tumors. The microsurgical instrument of the future as a bone removal device will be lighter, stable, and without a risk of lesions in the surrounding vascular or neural structures. Smaller and flexible endoscope will be used routinely to visualize the tumor behind the corner of bone and neurovascular structures. The microscope will be replaced by simple glasses connected to a fiber optic devices which will allows the neurosurgeon to have huge magnification avoiding the encumbrance of the microscope. Robot-assisted surgery can physically replace the presence of the neurosurgeon in the operative field as nowadays the daVinci robot does in urology field.

Neuroanesthesia

Advancements in neuroanesthesia will enable a slack brain to be achieved, avoiding diuretic osmosis, especially in large tumors. An optimal surgical condition may be accomplished by using only one drug, eliminating anesthetic drug interactions. The procedures will be shorter, as will also the postoperative intensive care period of the patient.
Far Future

A better understanding of brain function will improve the prevention and cure of vascular and neoplastic lesions of the brain. Medical treatments may in the distant future reduce the need for invasive treatments, such as surgery or radiotherapy, but this will require accurate non-invasive diagnosis of brain diseases and considerable developments in specially targeted minimally invasive treatment methods.
7 Conclusions

The simple and fast LSO approach can be used for OGMs, ACMs, and TSMs of all sizes and has a relatively low morbidity and low mortality.

Surgical results and tumor recurrence during follow-up with this fast and simple method were similar to those obtained with more extensive, time-consuming approaches.

High-power coagulation should be avoided in the proximity of the optic nerve and chiasm, taking special care to preserve the vascular support coming from the ICA.

The anterior clinoid process can be removed through the LSO approach without mortality and with low morbidity. The ultrasonic bone device carries the risk of a postoperative visual deficit. We recommend the intradural approach for anterior clinoidectomy in all vascular and most tumor cases.

The LSO approach requires good operating site conditions and a slack brain. The latter is achieved by correct patient positioning and neuroanesthesia. In small or medium-sized lesions, both intravenous and volatile anesthesia can achieved a slack brain. In large meningiomas, we prefer propofol anesthesia and mannitol. Early devascularization of the tumor and intraoperative hypotension reduce intraoperative bleeding. Postoperative ventilator therapy is related to tumor size and the patient's preoperative clinical condition.
List of 15 Supplementary Videos on Microneurosurgery of OGMs, ACMs, TSMs and Anterior Clinoidectomy through Lateral Supraorbital Approach

The supplementary CD includes 15 videos on microneurosurgery of OGMs, ACMs, TSMs, and anterior clinoidectomy through LSO approach:

1. Lateral supraorbital approach (right side)
2. Microneurosurgical treatment of a small (30 mm) OGM through a right LSO
3. Microneurosurgical treatment of a medium-sized (50 mm) OGM through a right LSO
4. Microneurosurgical treatment of a large (> 60 mm) OGM through a right LSO
5. Microneurosurgical treatment of a large (> 60 mm) OGM through a right LSO
6. Microneurosurgical treatment of a small (13 mm) ACM through a right LSO
7. Microneurosurgical treatment of a medium-sized (28 mm) ACM through a right LSO
8. Microneurosurgical treatment of a large (59 mm) ACM through a right LSO
9. Microneurosurgical treatment of a large (60 mm) ACM through a right LSO
10. Microneurosurgical treatment of a medium-sized (24 mm) TSM through a right LSO
11. Microneurosurgical treatment of a medium-sized (25 mm) TSM through a right LSO
12. Microneurosurgical treatment of a large (60 mm) TSM through a right LSO
13. Microneurosurgical treatment of intra-extradural ICA junction aneurysm through a left LSO and intradural anterior clinoidectomy
14. Microneurosurgical treatment of an ACM through a right LSO and intradural anterior clinoidectomy
15. Microneurosurgical treatment of a sphenoorbital meningioma through a right LSO and extradural anterior clinoidectomy

Eleven videos are selected reviewing all operations on microneurosurgical treatment of OGMs, ACMs, and TSMs, performed by Professor Hernesniemi at the Department of Neurosurgery, Helsinki University Hospital, between September 1997 and August 2010. Three videos are selected from all operations in which anterior clinoidectomy, through LSO approach, was performed by Professor Hernesniemi between June 2007 and January 2011.
“A l'alta fantasia qui mancò possa; ma già volgeva il mio disio e 'l velle, si come rota ch'igualmente è mossa, l'amor che move il sole e l'altre stelle.”

Dante, The Divine Comedy, Paradiso, Canto XXX: vv.142-145

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