PETROCLIVAL MENINGIOMAS: CLINICAL PROFILE AND SURGICAL OUTCOME

SREE CHITRA TIRUNAL INSTITUTE FOR MEDICAL SCIENCES AND TECHNOLOGY
LIBRARY
THIRUVANANTHAPURAM

Submitted for MCh Neurosurgery

By

Dr. GANESH DIVAKAR

October 2008

Department of Neurosurgery

Sree Chitra Tirunal Institute for Medical Sciences & Technology

Thiruvananthapuram

PETROCLIVAL MENINGIOMAS: CLINICAL PROFILE AND SURGICAL OUTCOME

Submitted by	**:**	**Dr. GANESH DIVAKAR**
Programme	**:**	**MCh Neurosurgery**
Month & Year of submission	**:**	**October 2008**

CERTIFICATE

This is to certify that the thesis entitled "**Petroclival meningiomas: Clinical profile and surgical outcome**" is a bonafide work of Dr. Ganesh Divakar and was conducted in the Department of Neurosurgery, Sree Chitra Tirunal Institute for Medical Sciences & Technology, Thiruvananthapuram under my guidance and supervision.

30/9/2008

Dr. Suresh Nair
Professor and Head
Department of Neurosurgery
SCTIMST, Thiruvananthapuram

DECLARATION

This thesis titled **"Petroclival meningiomas: Clinical profile and surgical outcome"** is a consolidated report based on a bonafide study done by me during January 2006 to October 2008 under the Department of Neurosurgery, Sree Chitra Tirunal Institute for Medical Sciences and Technology, Thiruvananthapuram.

This thesis is submitted to SCTIMST in partial fulfillment of rules and regulations of MCh Neurosurgery examination.

Dr. Ganesh Divakar
Resident ,
Department of Neurosurgery,
SCTIMST,
Thiruvananthapuram.

ACKNOWLEDGEMENT

*I owe a deep sense of gratitude to **Dr. Suresh Nair**, Professor and Head of the Department of Neurosurgery, for his many contributions and suggestions that have been instrumental in the successful completion of this study.*

*I am eternally grateful to **Dr. Ravi Mohan Rao** and **Dr. Girish Menon** for their invaluable advice, enthusiastic support and encouragement without which this work would not have been possible.*

*I would specially like to thank **Dr. Mathew Abraham, Dr. Easwer H V, Dr. Krishnakumar K, Dr. Biji B, Dr. Gopalakrishnan and Dr. Dilip** for their constant encouragement & support.*

*I would also like to acknowledge the invaluable help of **Medical Records Department staff** in retrieving the medical records of all the patients included in the study.*

A special thanks goes to my fellow residents for their help in completion of this study.

Last but not the least, I thank my parents, wife and daughter for all their support in making this thesis a reality.

GANESH DIVAKAR

CONTENTS

AIM OF THE STUDY	7
INTRODUCTION	9
REVIEW OF LITERATURE	11
MATERIALS AND METHODS	45
RESULTS	50
DISCUSSION	74
CONCLUSIONS	81
BIBLIOGRAPHY	83

AIM OF THE STUDY..

To analyze the clinical profile and surgical outcome in a series of 64 patients operated for petroclival meningiomas at our institute from 1990 to 2007

INTRODUCTION..

Meningiomas account for approximately 20% of all primary intracranial tumors[48]. Approximately 10% of the intracranial meningiomas occur in the posterior fossa of which clival and petroclival meningiomas account for only 3 to 10%[9,10], giving an overall incidence of less than 2%. Meningiomas arising from the apical petrous bone and clivus have always been challenging to neurosurgeons. The deep location of these lesions and their proximity to eloquent neurovascular structures greatly increase the risks of surgical treatment. These lesions were initially considered inoperable[12,62,69], and the first surgical resections were associated with significant morbidity and mortality rates[19,32]. Later, several reports demonstrated marked evolution in the microsurgical management of petroclival meningiomas.[17,52,61,70,74,82,90] Despite these advances, radical excision seems to be incompatible with good postoperative quality of life in some cases. On the basis of this experience, radiosurgical treatment of these tumors has been proposed.[36,60,83] The results, in terms of tumor growth control, seem promising, although follow-up periods were short in most studies. A recent study with long term follow-up evaluation of patients treated with aggressive surgery, reports excellent quality of life post operatively and warrants aggressive but judicious microsurgical resection of these tumors, with or without postoperative radiotherapy.[59]

REVIEW OF LITERATURE..

Classification and nomenclature:

Classifications of posterior fossa tumors have been put forth by Castellano and Ruggiero[15] and Yasargil, *et al.*[90] Using postmortem studies, Castellano and Ruggiero classified posterior fossa tumors by site of dural attachment. They described their location as cerebellar convexity (10%), tentorium (30%), posterior petrous (42%), clivus (11%), or foramen magnum (4%). They also noted a group of tumors that extended from Meckel's cave into the posterior fossa. Yasargil, *et al.*, classified posterior fossa tumors based on intraoperative observations into those with primary attachment to clival, petroclival, sphenopetroclival, foramen magnum, or cerebellopontine angle locations. Couldwell and associates[16,17]define "petroclivals" as those meningiomas with basal attachment at or medial to the entrance or exit of cranial nerves V through IX, X, and XI . Al-Mefty and Smith[3] opined that only those meningiomas arising medial to the trigeminal nerve should be included in the petroclival group to differentiate them from those arising more laterally which are termed cerebellopontine angle meningiomas and excluded these from the petroclival group. Bricolo & Turazzi[10] emphasize that posterior cranial base meningiomas must be classified according to dural attachment and by the manner in which the cranial nerves are displaced by the tumor. They classified basal posterior fossa meningiomas into petroclival, anterior petrous, posterior petrous, jugular foramen and foramen magnum meningiomas. According to these authors, when a tumor is exposed through a classical suboccipital route the relationship of the tumor to the cranial nerves gives an idea of the site of dural origin and the related difficulties in its removal. The position of VII and VIII cranial nerves is the landmark for dividing these meningiomas into the premeatal group which displace VII & VIII complex posteriorly and the postmeatal group which displace the cranial nerves VII and VIII anteriorly. The petroclival and the anterior petrous meningiomas displace cranial nerves VII and VIII posteriorly and inferiorly. What differentiates the two groups is the position of the trigeminal nerve. In petroclival meningiomas its position is posterior-superior whereas in the anterior petrous group it is anterior-superior. When the fifth nerve is visible over the posterior superior surface of the tumor, its dural origin is in the clival area.

Kawase et al[41] classified petroclival meningiomas based on development patterns and characteristic symptoms into (a) upper clivus type (clival origin medial to the trigeminal nerve) (b) cavernous sinus type (clival origin with dumbbell extension to the cavernous sinus) (c) tentorium type (tentorial origin over the trigeminal nerve) and (d) petrous apex type (petrous apex origin lateral to the trigeminal nerve). Ichimura et al[35] recently analyzed 91 cases of petroclival meningiomas and concluded that this classification is useful to predict the relation between the tumor and the cranial nerves based on symptoms and images.

Unfortunately, these classification schemes do not differentiate the clinically recognized petroclival location exclusively from other tumor locations. Petroclival meningiomas represent only a percentage of meningiomas that reside in the posterior fossa. Tumors emanating at or medial to the entrance or exit of cranial nerves at the base of the skull are those that should be strictly classified as within the petroclival area. These tumors present a surgical challenge: cranial nerves are interposed between the surgeon and the pathology, and the tumor often displaces or engulfs the basilar artery or its major branches and the perforating vasculature supplying the brainstem. The one exception in classifying these lesions by this method is the tumor that commonly emanates directly from the region of Meckel's cave, to which Cushing and Eisenhardt[18] ascribed the name "gassero-petrosal" (equivalent to the sphenopetroclival tumors of Yasargil[90]). With continued growth, such tumors invariably become both supra- and infratentorial, and occupy both medial and lateral positions to the fifth nerve. From a clinical perspective, these tumors are to be considered together with those originating medial to Meckel's cave (either apical petroclival or pure clival), as surgical strategies for their attack will be similar. They are considered by most authors to be included in the petroclival classification. Thus, the strict definition of petroclival tumors was suggested by Couldwell et al[17] in his series of 109 patients, with particular attention being paid to the location of dural attachment in relation to the foramina of specific cranial nerves, critical when determining the difficulties inherent in surgical resection. As noted in Fig. 1, tumors emanating from the lower third of the clivus at or medial to the hypoglossal canal are best considered as foramen magnum in location.

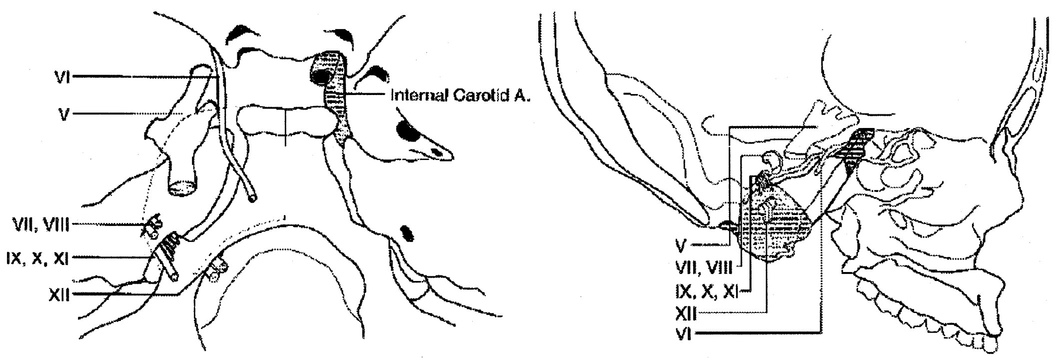

Fig. 1: Illustrations showing definition of petroclival meningiomas. Tumors defined as petroclival are those with basal attachments at or medial to the skull base foramina of cranial nerves V through IX, X, and XI. This area is demonstrated by the *shaded region* in the basal view *(left)*. The upper and middle clival region includes the posterior clinoid processes, the dorsum sellae, and the clivus down to the jugular foramina. Lesions of the lower third of the clivus (*medium shaded region* of the lateral view, *right)* are best considered as foramen magnum in location when planning surgical strategies (from Couldwell and Weiss[17])

Natural history:

The natural history of meningiomas is characterized by slow but relentless growth resulting in compression of adjacent structures. Petroclival meningiomas are no exception to this rule. Cushing and Eisenhardt[18], described these tumors as relentlessly progressive with ultimately fatal outcomes. Studies by Bricolo et al[10] and recently Jung et al[38] provided indirect information on the natural history of these tumors after partial resection. The relentless evolution of these tumors is clearly reflected in the progressive involvement of cranial nerves.

Early on, the young meningioma growing on the petroclival line into the lateral clivus proceeds with the protection of the arachnoid from the superior cerebellopontine, prepontine, and ambient cistern, making surgical manipulation a good deal easier and safer. Later on, the tumor's base grows larger, digs through the dura, and invades the underlying bone, violating the arachnoid layers and implicating cranial nerves and arteries.

Factors influencing the growth rate:

To date very little is known about the growth rates of petroclival meningiomas. Jaaskelainen et al[37] reported the growth rates of intracranial meningiomas in general. They studied the growth rate of intracranial meningiomas in 43 patients against a histologic grading based on the degree of anaplasia. The mean time for doubling of the tumor volume was 415 days in grade I or benign, 178 days in grade II or atypical, and 205 days in grade III or anaplastic. The difference between grade I and the combined grades II-III was highly significant. They found that the mitotic index and the absence of calcification on the computed tomography scan correlated strongly with the doubling time.

In a recent article, Jung et al[38] reported growth rate data for residual petroclival meningiomas after partial resection. They observed growth rates ranging from 0.37 to 4.94 cm^3/ year in volume with significant correlations between lower growth rates and old age as well as occurrence of menopause. However, Van Havenbergh et al[88] studied 21 patients with petroclival meningiomas who did not undergo surgery for a period of four years. The significant correlations between lower growth rates and old age and the occurrence of menopause reported by Jung et al[38] were not confirmed by their data. They found the overall growth rates were 0.81 mm/yr in diameter and 0.81 cm^3/yr in volume when non growing tumor data were included in those calculations. When only growing tumors were considered, the mean growth rates were 1.16 mm/yr in diameter and 1.10 cm^3/yr in volume. These growth rates differ substantially from those reported by Jung et al. It could be concluded that remnants of partially surgically treated petroclival meningiomas grow faster, however it is likely that these studies were dealing with tumors of differing proliferative potentials.

The proliferative index also has been linked to the growth rate of these tumors. Matsuno et al[51] studied proliferative potentials of meningiomas from 127 patients immunohistochemically using the anti-Ki-67 monoclonal antibody, MIB-1, on paraffin sections, and the correlation among MIB-1 staining index, histopathological finding, and clinical course of the disease. Higher MIB-1 staining index was observed for younger patients. The mean MIB-1 staining index in these patients was 1.6%, 3.6%, and 8.8%, respectively for non recurrent meningiomas, recurrent meningiomas at the time of initial surgery and at surgery for the recurrence. Statistical analyses revealed that meningiomas with a MIB-1 staining index of 3% or more have a significantly high tendency for recurrence during the clinical courses, especially within the first 10-year follow-up periods. Moreover, there was statistically significant correlation between MIB-1 staining index and recurrence in each Simpson's grade. They also observed that there was no statistically significant relationship between cellularity and MIB-1 staining index of meningiomas. Abramovich et al[2] also observed that there is a statistically significant difference in the increasing MIB-1 labelling index between benign, aggressive, and malignant meningiomas.

Diagnosis:

Unfortunately, these tumors are still being diagnosed too late, as shown by the long duration of reported symptoms, 35 months on an average.[10,49,70,75] To date, tumor size at the time of surgery emerges as the prime factor influencing the patient's final outcome.[11] It has to be stressed that, whenever surgeons detect impairment of any cranial nerve from 3rd nerve to 10th, however isolated, they should immediately request a CT scan and MRI brain. CN V is often the first to show signs in the early stage of tumor development, and it stands to reason that nowadays, with the MRI scan widely available, earlier diagnosis should be the rule, with the attendant benefits in terms of easier surgery and reduced morbidity.[11]

At the time of objective examination shortly before surgery, the clinical picture is usually dominated by deficits of the intermediate cranial nerves, which are present in varying degrees in nearly all patients, with concomitant cerebellar signs in over half of the patients. The typical sign of a petroclival meningioma is a relatively fair preservation of hearing, in contrast to severe trigeminal involvement and impairment of the cranial nerves below VIII, with accompanying cerebellar signs.[11]

Currently, high-resolution computed tomography (CT) scanning, bone algorithms, magnetic resonance imaging (MRI), and selective digital subtraction angiography, affords accurate diagnosis of these meningiomas, covering their size and location as well as the extent of tumor implantation on the skull base. With this information at hand, the surgeon can build a realistic mental image of the lesion and its relationships to neighboring nerves and blood vessels, thereby minimizing the risk of unforeseen difficulties. The surgeon will also be able to choose the surgical approach most suitable for the individual patient, although that choice will always depend largely on personal experience.

Accurate preoperative analysis of the radiological studies may reveal important predictive signs of high-risk petroclival meningiomas that can help the surgeon to calculate the surgical risks for each patient.[30] The preoperative presence of irregular tumor margins, especially in the brainstem, may be indicative of disruption of the arachnoidal plane and infiltration of the brain tissue. Peritumoral brain edema significantly influenced both the degree of tumor removal and long-term outcomes. Extension of the tumor caudally toward the JF and FM, however, did not affect the degree of tumor resection but did affect negatively the long-term follow-up of the patients. Finally, tumor extension from the clivus region beyond the IAC and radiological signs of infiltrative pattern are the most important risk factors regarding the anatomic preservation of the cranial nerves.

Microsurgical anatomy of the petroclival region:[67]

The petroclival region is located where the posterior surface of the petrous temporal bone meets the clival part of the occipital bone along the petroclival fissure. The junction of the two bones forms a line that extends from the jugular foramen to the petrous apex. From a surgical standpoint, the intradural compartments of the petroclival region are divided along this petroclival line into 1) an inferior space related to the medulla and to the structures around the region of the foramen magnum; 2) a middle space related to the pons and to the structures in the prepontine and cerebellopontine angle; and 3) a superior space related to the contents of the interpeduncular cistern, and to the sellar and parasellar regions.

The inferior petroclival space:

The inferior petroclival space corresponds to the anterior surface of the medulla and adjacent part of the clivus and anterior margin of the foramen magnum. The neurovascular structures in this region are those contained in the premedullary cistern. The superior limit is the junction of the pons and medulla. The inferior limit is the rostral margin of the first cervical nerve root, the site of the junction of the spinal cord and the medulla. The inferior petroclival space includes the lower four cranial nerves, lower part of the cerebellum, the vertebral artery and its branches, and the structures around the occipital condyle.

The middle petroclival space:

The middle petroclival space corresponds to the anterolateral surface of the pons and cerebellum. Its superior limit is at the pontomesencephalic sulcus and the lower limit is at the pontomedullary sulcus. The lateral limits are formed by the posterior surface of the petrous bone and by the contents of the cerebellopontine angle including the trigeminal, abducens, facial, and vestibulocochlear nerves, the basilar artery, and the anterior inferior cerebellar artery and the superior petrosal veins.

The superior petroclival space:

The superior petroclival space is located anterior to the midbrain and corresponds to the anterior part of the tentorial incisura. It extends anteriorly and laterally to the sellar and parasellar regions. Its roof is formed by the diencephalic structures forming the floor of the third ventricle. The posterior limit is formed by the cerebral peduncles and the posterior perforated substance. The inferior limit is situated above the origin of the trigeminal nerve at the pontomesencephalic sulcus. It includes the intradural segment of the oculomotor and trochlear nerves, the basilar artery and its branching into the posterior cerebral artery (PCA) and superior cerebellar artery (SCA), and the cavernous carotid and its intracavernous branches to the dura of the upper clivus. The medial edge of the tentorium divides the superior petroclival space into infra- and supratentorial compartments.

Relevant surgical anatomy:

Petroclival meningiomas are located in an anatomically demanding region replete with critical neurovascular structures. Despite a better understanding of the microsurgical anatomy and the great advances in standard operative technique, the surgical resection of petroclival meningiomas remains a substantial challenge. The transpetrosal corridors to the clival region are commonly used approaches, with the advantages of a short trajectory and minimal brain retraction. As shown in Fig. 2, the clivus and petroclival area can be divided into three zones, based on anatomic findings and clinical experience with the transpetrosal approaches[1].

Zone I: represents the area from the dorsum sellae to the internal auditory canal and it is exposed via the anterior petrosal approach.

Zone II: represents the area of the petroclival region between the internal auditory canal and the upper border of the jugular tubercle. The lateral portion of Zone II is easily exposed via the posterior petrosal approach.

Zone III: represents the area between the upper border of the jugular tubercle to the foramen magnum. Lesions reaching or affecting Zone III are considered to be in the foramen magnum. Zone III of the clivus and the petroclival region is exposed via the lateral suboccipital/transcondylar approach.

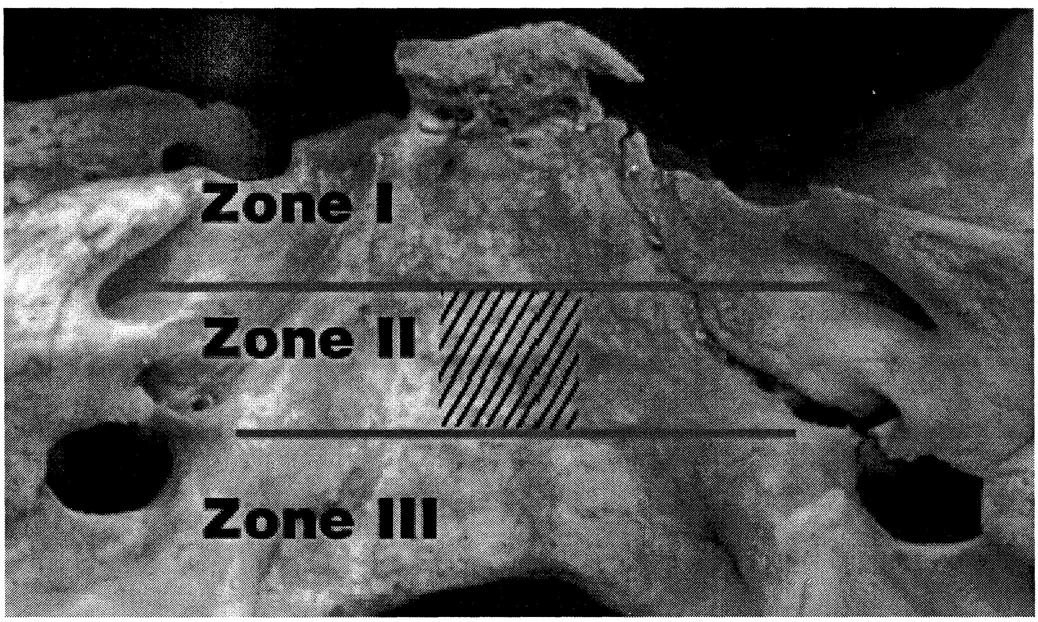

Fig. 2: Photograph of a dry human skull showing the three clival zones separated by horizontal lines[1]. Zone I (upper zone) extends from the dorsum sellae to the upper border of the internal auditory canal. Zone II (middle zone) extends from the upper border of the internal auditory canal to the upper border of the jugular tubercle. The central clival depression is shown by the hatched area. Zone III (lower zone) extends from the upper border of the jugular tubercle to the lower edge of the clivus.

The paramedian portion of Zone II, or the central clival depression, cannot be exposed via the posterior petrosal approach because the remaining temporal bone poses an immovable obstacle around which the surgeon cannot adequately see. Therefore, tumors with dural attachment in the central clival depression cannot be totally resected with the posterior petrosal approach. It is noteworthy that some meningiomas occupying the central clival depression, without attachment, do roll out easily. A distinction should be made between merely occupying the space of the central clival depression, which is a favorable situation, and being attached to the dura of the central clival depression, which is an unfavorable situation. The greater the depth of the central clival depression from the intermeatal plane, the more likely that the tumor is potentially left in a relatively inaccessible region. Exposure of the central clival depression necessitates the posterior petrosal translabyrinthine / transcochlear approach with posterior mobilization of the facial nerve.

Surgery:

The preferred approach for the resection of petroclival meningiomas is controversial. Some surgeons prefer the retrosigmoid approach in the sitting position, arguing for the simplicity of the approach.[11,27,28,70,71,84] Others prefer the petrosal approaches.[4,23,46,81] The transpetrosal partial labyrinthectomy petrous apicectomy approach or the orbitozygomatic frontotemporal approach take a much longer time to perform than the retrosigmoid approach and involve temporal lobe retraction rather than extensive cerebellar retraction. Although surgeons differ in their preferences for approaches, many experienced surgeons have developed sophisticated techniques of tumor resection and complication avoidance, which positively influence the outcome.[59]

Surgical approaches:

Petroclival meningiomas present a challenging neurosurgical problem. The deep location of these lesions and their proximity to eloquent neurovascular structures greatly increase the risks of surgical treatment. Advances in cranial base surgery have improved the margin of safety for approaching the petroclival region. Even large tumors have been resected with resulting low rates of morbidity and mortality.[4,11,32,46,75,82] The multidisciplinary approach to treating these tumors has spurred the development of a variety of surgical techniques. These include various degrees of petrosal resection to minimize brain retraction and increase exposure to the petroclival region.[6]

The approaches for petroclival meningiomas has changed over the years from the classical three routes, namely the retromastoid, the subtemporal, and the combined supratentorial and subtentorial presigmoid transpetrosal routes to complex approaches involving anterior petrosectomy, posterior petrosectomy or both.

The retromastoid route:

The classical retromastoid approach, with unroofing of the transverse and sigmoid sinuses to keep them out of the surgical field and moderate, readily tolerated, cerebellar retraction, affords the simplest access to the region of the cerebellopontine angle. The surgeon must conduct the whole phase of removal through the fissures made by the tentorium and by cranial nerves V, VII-VIII, and IX-XI, all of which may be contused in the process. Supratentorial, subtemporal, and parasellar tumor expansion do not alone disqualify or contraindicate this simple and thoroughly tested approach, which has rewarded many surgeons with excellent results. Access to the area is prepared by the tumor itself, located in the tentorial hiatus, and it can be amplified by resection of the tentorial flap. Thus, even the upper pole of the tumor, if not attached to the parasellar dura, can be dislocated downward and removed by being separated from the arachnoid of the interpeduncular and chiasmatic cisterns. Conventional posterior cranial fossa surgery can be suitable for a select group of petroclival meningioma. Goel et al[28] in his series of petroclival meningiomas operated through this route mentions that this approach provides easy and quick exposure of the tumor without any petrous bone drilling. It also provides a direct and early exposure of the tumor-cranial nerve-brainstem interface facilitating the dissection. The lateral and inferior tumor extensions in relationship to the clivus can be more easily accessed. The site of attachment of the tumor to the dura overlying the posterior face of the petrous apex can be seen directly. However, the surgeon needs to operate between the cranial nerves 5th to 9th which will be stretched over or encased by the posterior capsule of the tumor.

Middle fossa approaches:

Approaches through the middle fossa[75,77,90] afford immediate visibility and complete control of the supratentorial tumor bulge. However, it is also a highly hazardous route. Both the pterional and, even more so, the posterior subtemporal approaches actually afford excellent exposure of the parasellar area and tentorial notch. Yet, retraction of the temporal lobe, however limited, causes some postoperative morbidity, especially on the dominant side. Access to the posterior fossa also remains narrow and tedious, affording insufficient command of cranial nerves below V. The combined posterior subtemporal and presigmoid transpetrous approach without sinus division embodies some important refinements[4,70,72] of the original approach described by Hakuba.[32] In the combined retroauricular and preauricular transpetrosal-transtentorial approach,[31] via radical mastoidectomy, the sigmoid sinus is exposed down to the jugular bulb, and via the transmastoideal-subtemporal approach the retroauricular petrosal bone, 1 cm in depth from the petrosal ridge, and the roof of the internal auditory meatus are removed, the middle ear and fallopian canal being left intact. Additionally, via a transzygomatic-subtemporal approach, the preauricular petrosal bone is removed anteriorly up to the petrosal tip and laterally as far as the petrosal portion of the internal carotid artery, while the cochlea is preserved. By this means, the triangular portion of the posterior petrosal dura mater, delimited by the superior petrosal sinus, inferior petrosal sinus, and sigmoid sinus, is well exposed extradurally. By opening the subtemporal and posterior petrosal dura mater, in combination with a tentoriotomy, adequate exposure of the basilar artery, vertebral arteries, ventral and lateral portions of the brainstem, and cranial nerves is achieved with minimal retraction of the temporal lobe and cerebellum.

The original approach by Hakuba[32] and his associates turns out to be the more elegant and less dangerous way to reach petroclival meningiomas that involve a large portion of the skull base from the lower clivus to the parasellar area. The access afforded by the retromastoid or subtemporal route is too restricted unless one is willing to face a two-stage operation. Hakuba's approach allows the surgeon to work about 2 cm closer to the tumor than would be possible through the retrosigmoid approach and in front of the brain stem. Division of the tentorium materially reduces the need for retracting the cerebellum and temporal lobe, preserves drainage of the vein of Labbé, and creates an excellent exposure, opening an unimpeded vista from the lowest cranial nerves to the sella. In particular, it affords control of the whole intracranial course of cranial nerves III and IV with less risk of injuring those structures. The trunk of the basilar artery and its terminal branches are eventually well exposed, as are the contralateral V and III cranial nerves and the pituitary stalk. The approach requires good knowledge of periotic bone anatomy to spare the labyrinth and facial nerve. It also requires a good deal of patience and meticulousness because, like the retromastoid, this approach forces one to work lateral to cranial nerves V-XI as well as between them.

Combined supra- and infratentorial presigmoid approach

In this approach, the skin incision is started in the temporal region above the zygoma, and extends above the ear and downward in the suboccipital area medial to the mastoid process. The skin flap is reflected forward to the level of the external auditory canal. The temporal muscle is elevated and reflected anteriorly, and the muscles over the mastoid and suboccipital areas are swept inferiorly. A temporo-occipital craniotomy is performed and the transverse sinus is exposed. After the bone flap is elevated, a mastoidectomy is carried out without entering the labyrinth. The sigmoid sinus is skeletonized from the sinodural angle to the jugular bulb. Bone is removed superiorly to expose the floor of the middle fossa and the superior petrosal sinus. Trautman's triangle is exposed in the area lateral to the otic capsule. The dura mater is then incised along the base of the temporal craniotomy, while preserving the junction of the vein of Labbe with the transverse sinus. The posterior fossa dura is opened anterior to the sigmoid sinus in Trautman's triangle. The dural incision is extended across the superior petrosal sinus to join the dural incision in the temporal dura. After division of the superior petrosal sinus, the tentorium is incised parallel to and just behind the petrous ridge and superior petrosal sinus. This dural incision is extended from the site of division of the superior petrosal sinus through the medial edge of the tentorium to the incisura behind where the trochlear nerve enters the tentorial edge. Care is taken to avoid injury to the IV cranial nerve in its course near the tentorial margin. The posterior portion of the temporal lobe is elevated and the sigmoid sinus is displaced posteriorly along with the cerebellar hemisphere while preserving the junction of the vein of Labbe´ with the sigmoid sinus. The sigmoid sinus limits the ability for superior retraction of the temporal lobe and can be ligated to improve the exposure if bilateral venous angiography shows adequate communication through the torcular to the opposite side. The petroclival region can be exposed from the middle fossa and tentorial incisura to near the foramen magnum, although access to the lower petroclival region may be limited by the jugular bulb. The presigmoid exposure provides a shorter working distance to the petroclival area and provides multiple angles for dissection. The major arteries in the posterior fossa are easily accessible. The exposure can also be combined with a far-lateral approach.

Petrosal approaches:

These approaches have been shown to offer distinct advantages over traditional operations in approaching lesions of the petroclival area. Confusion about these approaches exists due to the variety of names given to these procedures and the lack of detailed descriptions needed to perform them. After extensive review of the literature, Miller et al[54] have determined that all transpetrosal techniques fall into one of two categories: anterior petrosectomy or posterior petrosectomy. Combining one of these procedures with existing conventional procedures accurately describes all existing transpetrosal operations and eliminates confusion over nomenclature. In addition, through a series of cadaveric dissections and operative experience, they have detailed each of these procedures as a series of steps that will enable the surgeon to understand the unfamiliar anatomy of the temporal bone and to perform these transpetrosal techniques.

Features of four stages of the petrosal approach to the petroclival region[33]

Stage	**Temporal Bone**
retrolabyrinthine	semicircular canals remain fully intact
transcrusal	superior & posterior semicircular canals are removed from ampulla to common crus
transotic	otic capsule entered w/ complete removal of semicircular canals & skeletonization of facial nerve; wall of external auditory canal resected & ear canal oversewn & reflected forward
transcochlear	as with transotic, but includes posterior mobilization of facial nerve with completion of cochlear removal & exposure of petrous carotid artery

Anterior petrosectomy:

This approach was originally described by Kawase.[42] Here the anatomic boundaries of the Kawase and Glasscock triangles are identified initially after subtemporal extradural approach. The boundaries of Glasscock's triangle are laterally, a line from the foramen spinosum to the facial hiatus; medially, the greater superficial petrosal nerve; and at the base, V3. The boundaries of Kawase's triangle are laterally, the greater superficial petrosal nerve; medially, the petrous ridge; and at the base, the arcuate eminence. The ICA is exposed in Glasscock's triangle. The posterior fossa dura is exposed down to the level of the inferior petrosal sinus by resection of the bone of Kawase's triangle. A section of inferior temporal lobe dura, elevation of temporal lobe, sacrifice of superior petrosal sinus, section of tentorium cerebelli, and opening of posterior fossa dura is done in a sequential manner.

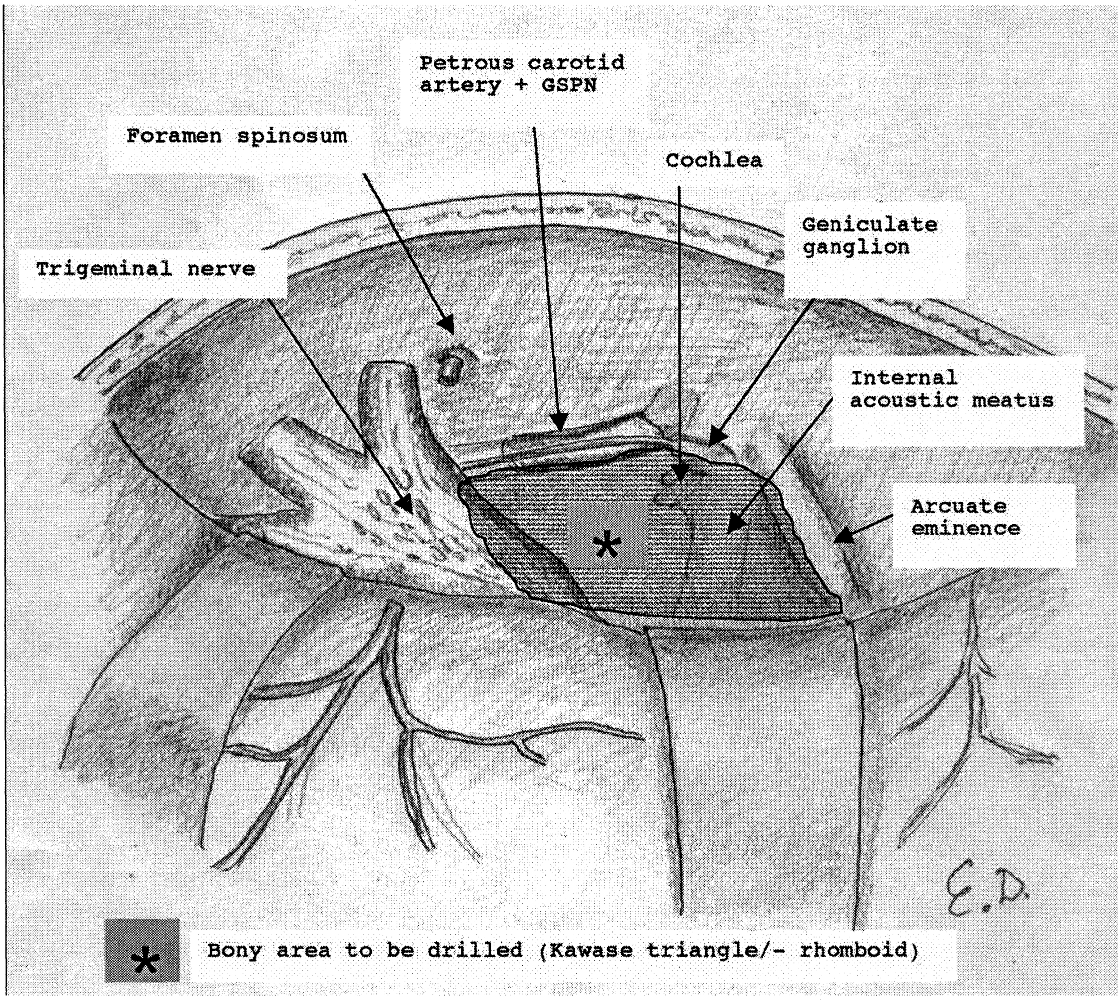

Fig. 3: Surgical view[24] after the extradural steps of the Kawase approach have been completed, depicting the rhomboid shaped area to be drilled. GSPN, greater superior petrosal nerve.

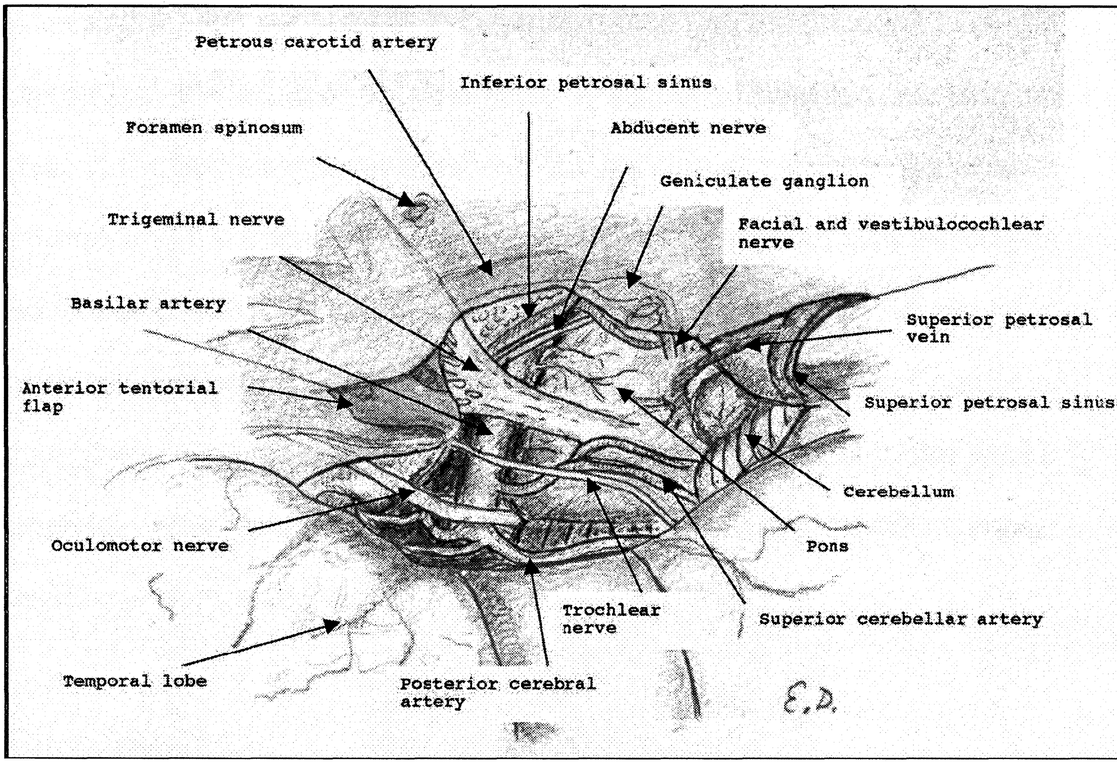

Fig. 4: Surgical view[24] after the extradural and intradural steps of the Kawase approach have been completed.

Posterior petrosectomy:

The posterior petrosal approach consists of a temporal craniotomy combined with a presigmoid craniectomy. Depending on the preoperative hearing status and the need for additional exposure, either a retrolabyrinthine or a translabyrinthine bony exposure is chosen. The dural opening is made as follows: 1) dura is incised along the undersurface of the temporal lobe parallel to the superior petrosal sinus, taking care to preserve the vein of Labbe´, which generally enters the transverse sinus within 1 cm of the transverse-sigmoid junction; 2) the posterior fossa dura in the presigmoid space is incised longitudinally between the superior petrosal sinus and the jugular bulb; 3) with gentle traction on the temporal lobe and cerebellum, the superior petrosal sinus is sectioned between two titanium clips; 4) the tentorium is sectioned into the incisura at a point posterior to its junction with the trochlear nerve; and 5) an incision that relaxes the dura is made along the upper border of the transverse sinus. This allows for a generous exposure between the trigeminal nerve and the upper border of the jugular tubercle. If additional exposure is required caudal to the jugular tubercle, a retrosigmoid craniectomy with or without partial condylar resection (transcondylar approach) is performed.

Complications:

Wound related problems can be prevented by meticulously planning the scalp flap so that the blood supply is maintained to promote wound healing especially in recurrent surgery or after irradiation. Cerebral edema and contusions are the most serious postoperative complications. Paying particular attention to posterior temporal draining veins lessens risk of contusion and edema and they should be preserved at all costs. Venous infarction can be caused by excessive or extensive retraction on the brain. Surgical decompression of the temporal lobe should be performed if there is any clinical indication to do so such as poor mental status or hemiparesis.[45] CSF fistulae can be prevented by putting a ventricular catheter or a lumbar drain at the time of surgery and leaving it for a few days giving time for wound to heal. Cranial nerves from III to the lower cranial nerves are all at risk during surgery at the petroclival region. The most serious problems are those related to the lower cranial nerves. Unilateral paralysis gets compensated in young patients. A feeding gastrostomy and a tracheostomy is life saving and hastens recovery and these tubes can be removed once the patient gets compensated for the deficit. Cornea should always be protected from neuroparalytic keratitis by temporary tarsorrhaphy. If facial nerve in continuity has not recovered in 12 months, an extracranial facial to hypoglossal anastomosis can be performed or reanimation with facial slings can be considered in long standing situations to provide some cosmetic relie.f[45] Somatomotor deficits are a significant contributor to overall neurologic deterioration. Hence aggressive physiotherapy is a boon for these patients recovery. Sigmoid / transverse sinus thrombosis is a life threatening complication that must be immediately recognized and treated with intravenous heparin.

Subtotal surgery with radiation:

Complete curative resection of petroclival meningiomas is frequently impossible. The likelihood of complete resection varies between 26 and 91%, even when recently published reports are included.[1,11,17,38,59,70,71,75] Most recent additions to the literature, however, also describe significant morbidity associated with surgical intervention. From 2 to 10% of patients die as a direct result of surgery. The risk of hemiparesis varies from 7 to 45%, and persistent coma has been reported in 12 to 27% of surgical patients. Permanent cranial nerve deficits resulting from surgery were noted in 22 to 91% of patients. On average, 54% of patients will develop new neurological deficits as a result of surgery.[5,11,17,52,63,71,77] Some surgeons have opted for a less aggressive approach to resection, such as tumor debulking or subtotal resection, to reduce morbidity associated with the procedure. Unfortunately, incomplete resection alone fails to affect tumor progression rates.[56] In a retrospective review of 53 meningioma patients, Marks et al[50] observed that the rate of tumor recurrence after complete resection was 9.5% at 5 years, in contrast with a 20% recurrence rate after subtotal resection. Similarly, Kallio et al[39] studied 225 patients with meningiomas after complete resection and found recurrence rates of 7, 20, and 32% at 5, 10, and 15 years, respectively, after surgery. In contrast, the rates for tumor progression after subtotal resection were 37, 55, and 91%, respectively, for the same time intervals. These relatively high rates of tumor progression and recurrence support the addition of a secondary treatment modality for better tumor control. The role of external beam fractionated radiation in the management of meningiomas has generally been limited to postoperative adjunctive treatment. Recent studies have demonstrated improved outcome and survival rates in patients who underwent subtotal resection plus radiation therapy.[7,65,85,89] These studies have determined a 10-year progression-free survival rate of 18% after subtotal resection alone, 77% after gross total resection, and 82% after subtotal resection plus radiation therapy. In general, tumor control rates after subtotal resection and fractionated radiation therapy range from 72 to 95%, with variable lengths of follow-up.[7,14,26,29,55,65,85] However, despite the apparent improvement in tumor control rates, approximately one-third of patients experienced related complications. Al Mefty et al[4] evaluated 58 patients, an average of 8.1 years after radiation therapy. Twenty-two patients (38%) developed major complications, such as visual loss, pituitary dysfunction, and radiation necrosis. Miralbell et al[55] reported that 6 of 36 patients (17%) developed radiation-related complications during an 88-month follow-up period.

Radiosurgery :

The considerable postoperative morbidity and mortality rates, even in very experienced hands, have led to the use of stereotactic radiosurgery for these tumors. Obviously, the objective differs essentially from that of surgery, because the goal is prevention of tumor progression instead of cytoreduction. Subach et al[83] reported on a series of 62 patients who were treated with stereotactic radiosurgery (as a primary treatment in 23 cases). With a follow up period of 38 months there was 100 percent tumor control. Iwai et al[36] reported 11 cases of petroclival meningiomas treated with radiousurgery with 100 percent tumor control during a period of 30 months. Nicolato et al[54] presented a series of 62 posterior fossa meningiomas (23 petroclival meningiomas) that were treated with Gamma knife surgery. The treatment was used as primary therapy, as well as adjuvant therapy for recurrent or residual tumors after surgery. With a follow up period of 29 months, those authors observed tumor or mass reduction in 95 percent cases; there was tumor progression in 5 percent of cases. For this total of 13 patients treated with stereotactic radiosurgery, there was a morbidity rate of 5.9 percent. The main disadvantages remain the relatively short follow up and the possible negative effects of radiosurgery on tumor biological process.

Stereotactic radiosurgery provides a conformal, highly focused, single fraction radiation field essentially confined to the tumor, which may reduce the incidence of complications that are occasionally associated with fractionated radiation therapy.[22,43,44,87] Multiple isocenter dose planning, using small beam diameters facilitates precise delineation of the radiation dose to the often irregular margins of the tumor. The steep radiation fall-off of radiosurgery significantly protects adjacent critical structures from delayed radiation-induced injury. This benefit is eventually limited, however, as tumor volumes increase. Unfortunately, the indolent nature of petroclival meningiomas generally brings them to clinical attention only after significant growth has occurred. In general, tumors larger than 25 to 30 mm in average diameter are associated with significant local brain compression that may require initial surgical resection.[21,39] The risk of complications after radiosurgery is considerably lower than those risks reported after microsurgery.[8,25] Roche et al[68] in his study concluded that stereotactic radiosurgery with a Gamma knife provides effective management of small to middle sized petroclival meningiomas and is an alternative to microsurgery It is possible that younger patients present with more aggressive tumors that require initial surgical intervention; such patients may also have a higher risk of recurrence. In contrast, older patients may be less suitable candidates for resection because of age related medical risks. Longer follow-up is clearly necessary to define long-term tumor control rates. Fractionated radiation therapy, which may improve both outcome and survival rates after subtotal resection, has a higher risk of radiation induced complications than does radiosurgery. With the use of relocatable stereotactic guidance, the safety of fractionated radiation therapy may be enhanced. For patients with malignant meningiomas, fractionated radiation therapy remains the primary treatment and should be initiated early after resection.[83] Stereotactic radiosurgery may be of benefit to patients with malignant meningiomas as a "boost" technique to a previously radiated tumor.

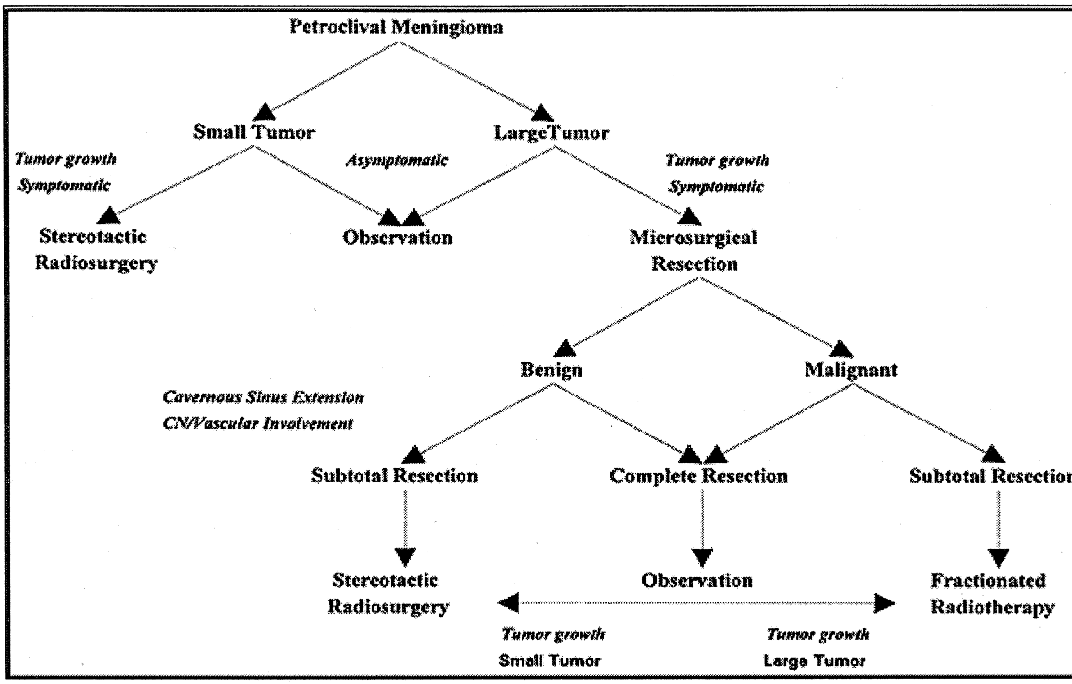

Fig. 5: Treatment algorithm for petroclival meningiomas as proposed by Kondziolka et al [83] for the management of petroclival meningiomas.

Regardless of tumor size, treatment should be reserved for patients with related symptoms. Based on the indolent nature of some petroclival meningiomas, serial neurodiagnostic imaging is indicated for asymptomatic or incidentally discovered tumors. Once symptoms develop or growth is documented, appropriate management should be initiated based on tumor size. For patients with tumors smaller than or equal to 30 mm in average diameter, they think that stereotactic radiosurgery is the best primary treatment. In their experience, all patients managed with this strategy had subsequent tumor control and low accompanying morbidity. For patients with larger tumors (e.g., average diameter > 30 mm), surgical resection should be considered. Although the goal of surgery should be complete resection, this must be tempered by the need to prevent serious postoperative neurological injury. For patients with tumors engulfing critical vascular structures or invading the cavernous sinus, a strategy of subtotal resection plus radiosurgery should be used. Patients with atypical or malignant meningiomas should receive fractionated radiation therapy plus "boost" radiosurgery. Individual patient characteristics, such as age, functional status, and general medical condition, also influence the decision-making process.

Paradoxically, ionizing radiation is an unequivocal risk factor for the development of meningeal and glial neoplasms, even at low doses.[20,34,40,80,88] In fact, development of malignant tumors secondary to radiosurgery for benign lesions has been described in the literature.[47,53,57,58,78,79,91] The comparison between radiosurgical and surgical series contains much bias because in the latter group, majority of the patients have larger tumors.

OPTIMAL TREATMENT

The ideal treatment for these tumors is continuously under discussion, because of their low incidence, their variable biological behavior and their specific location near the brainstem and cranial nerves which makes surgery hazardous, even with the latest techniques and approaches. It is clear that complete resection is theoretically the optimal treatment, especially if surgery could be performed with negligible morbidity and no risk of death. Hakuba et al[32] presented a series of six patients who underwent a total tumor removal with an operative mortality rate of 17%. Yasargil et al[90] reported total resection in 35% cases with a mortality rate of 15%. Sekhar et al[76] observed that cranial nerve palsy, prior treatment and radiological features (tumor size, vessel encasement and multiple fossae involvement) were significant factors influencing postoperative outcomes

Park et al[64], after dividing a population of petroclival meningiomas into microsurgery group, radiosurgery group, radiation group and radiosurgery group made observations that the incidence of favorable outcomes for cranial neuropathies was better in the incomplete resection group (69.2%) than for patients in the complete resection group (20%, p value = .032). Also, favorable functional outcome predominated in the incomplete resection group (76.9%) compared with the complete resection group (30%, p value = .049). The disease was stable in both the radiation therapy and the radiosurgery groups during the follow-up period, with functional status and cranial nerve function perfectly preserved in these patients. They concluded that intended incomplete resection should be considered as an acceptable treatment option and that adjuvant treatment after surgery is useful in the control of residual tumors.

In a recent analysis of a series of 18 patients with small petroclival meningiomas (diameter ≤ 2.8 cm) treated with radical surgical removal, Ramina et al[66] achieved total resection (Simpson's Grade 1) in all patients with minimal morbidity and no mortality. Transient abducent nerve palsy was the only post-operative complication. The pre-operative cranial nerves deficits improved after surgery. Only one patient had persistent diplopia postoperatively

The present data on the natural history of petroclival meningiomas suggest that most of these tumors are growing incessantly. Small and medium size tumors seem especially prone to more growth. Therefore active treatment for symptomatic patients with small or medium sized tumors is mandatory. For younger patients, surgery is the treatment of choice; for elderly patients or patients who cannot undergo surgery, stereotactic radiosurgery should be proposed. It is also noticed that, for 50 percent of the growing tumors, a clear change in the growth rate preceded clinical deterioration. On the basis of these findings, observation (with meticulous radiological follow up monitoring) could be considered for asymptomatic patients with small petroclival meningiomas. An increase in growth rate should lead to active treatment without delay. For large symptomatic tumors, the treatment should be safe microsurgical resection, especially of the infratentorial part, followed by stereotactic radiosurgery as an adjuvant treatment, if possible.[88]

MATERIALS & METHODS..

A retrospective analysis of records of patients operated for petroclival meningiomas at our institute from 1990 to 2007 was done. Petroclival meningiomas were defined as tumors, where the primary dural attachment was to the upper two thirds of the clivus and posterior petrous pyramid anteromedial to the internal auditory meatus. There were a total of 72 petroclival meningiomas out of which 67 patients underwent surgery. Two patients in poor general condition underwent ventriculoperitoneal shunt and two had endoscopic third ventriculostomy as the only procedure. One patient with a small lesion was referred for gamma knife treatment. The medical records of three patients who underwent surgery in 1990 could not be retrieved and hence were excluded. This study analyzed 64 patients who underwent surgery in the past 18 years.

Clinical and neuroradiological evaluation

The clinical data of all patients were obtained from the medical records available. All except 3 patients had preoperative CT scans with contrast; MRI scans with contrast were available in 53. Four vessel DSA was performed in 37 patients and one underwent embolisation of ECA feeders prior to surgery.

Selection of surgical approach

The various approaches included transsylvian / subtemporal approach, combined supra / infra tentorial approach and retrosigmoid approach. Surgical approach was planned on the location of the epicenter of the tumor, size and extent of the tumor, and the surgeon's experience with various approaches.

Extent of resection and residual/recurrence

The extent of resection (EOR) was decided by the intraoperative impression and the postoperative scans. Radical decompression was defined as no gross tumor being left behind in the surgeon's impression and with minimal or no enhancing component seen in the postoperative scan. More than 90 percent of tumor resected was termed subtotal and less than 90 percent resection was termed partial.

Tumor recurrence was defined as any newly identified enhancement after radical decompression or any increase in the enhancing tumor volume after subtotal resection (STR).

Patients with significant residual lesion underwent second stage surgery, most often during the same admission; those with small residual tumors especially in the region of the cavernous sinus and near the brain stem were followed up with serial imaging. Patients who underwent surgery over the last 5 years were given the option of stereotactic radiosurgery, but many preferred to be on regular follow up. Patients in good general health with evidence of significant growth of residual/recurrent lesion on serial imaging were offered re exploration.

Outcome assessment

The primary outcome variables assessed were

1. Extent of resection (EOR)

2. Post operative neurological deficits, both at immediate postoperative period and assessed at last follow-up

3. Radiographic tumor recurrence or progression based on the last available radiographic evaluation

4. Quality of life as assessed at the last follow up

New deficits which developed after surgery or those exacerbated beyond the preoperative baseline were combined for analysis of morbidity. Surgery related complications were also accounted into morbidity in the immediate postoperative period. To obtain follow-up data, patients were called to attend out patient department. In those who could not attend, outpatient charts containing details of latest follow up, a written questionnaire or telephonic interview was used to assess the functional status.

Statistical Analysis

The primary outcome variables assessed were EOR, postoperative neurological deficits assessed at last follow-up, and radiographic tumor recurrence or progression based on the last available radiographic evaluation. New deficits or those exacerbated beyond the preoperative baseline were combined for analysis. For each outcome variable, univariate analysis was performed on all potential prognostic factors using the χ^2 test. Differences associated with an error probability of <0.05 were considered significant.

RESULTS..

Demographic profile

There were 72 cases of petroclival meningiomas, out of which 67 were planned for definitive surgery. One patient with a small tumor was referred for stereotactic radiosurgery, four of them were in poor general condition and underwent only endoscopic third ventriculostomy (2 patients) or ventriculoperitoneal shunt (2 patients) as the only procedure. The medical records of three patients who underwent surgery in 1990 could not be retrieved and hence were excluded. We analyzed the data of 64 patients who underwent surgery for the tumor. There were 47 females and 17 males (M:F:1:2.77) (Fig. 6) The mean age at presentation was 47 ± 10 years (range 17-66 years)(Fig. 7)

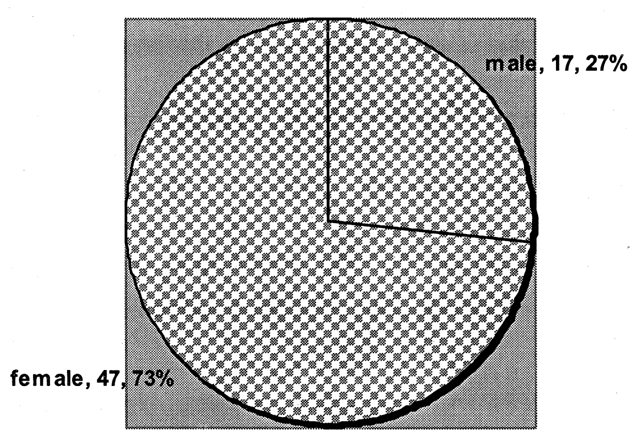

Fig. 6: Sex distribution

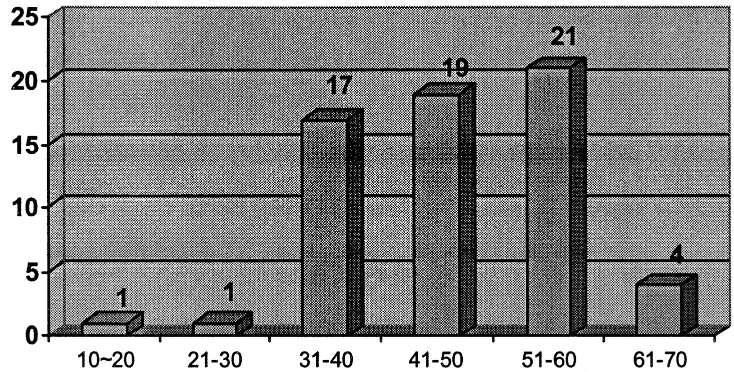

Fig. 7: Age distribution

Clinical profile :

The most common initial presenting symptoms were headache in 26 (41%) patients, imbalance of gait in 12 (19%) and facial pain in 10 (16%) (Table 2) whereas cranial nerve palsy represented the most common presenting sign (86%) (Fig. 8). The most common cranial nerve involved was VIII nerve in 27 (40%) patients, followed by trigeminal in 26 (38%), facial nerve in 21(31%) and lower cranial nerves in 15 (22%). Fourteen (21%) had evidence of pyramidal signs in the form of hemiparesis (9 patients) or exaggerated reflexes. Twenty four (36%) patients had evidence of raised intracranial pressure as evidenced by papilledema. Thirty (45%) patients had cerebellar signs. Six (9%) patients were dependent for activities of daily living.

Headache	**41% (26)**
Facial pain	**16% (10)**
Vertigo	**3% (2)**
Facial Numbness	**4% (3)**
Seizures	**1.5% (1)**
Behavioral disturbances	**1.5% (1)**
Syncope	**1.5% (1)**
Gait ataxia	**19% (12)**
Tinnitus	**1.5% (1)**
Deafness	**3% (2)**
Visual blurring	**3% (2)**
Facial paresthesias	**1.5% (1)**
Incidental	**3%(2)**

Table 2: Initial presenting symptoms (n=64)

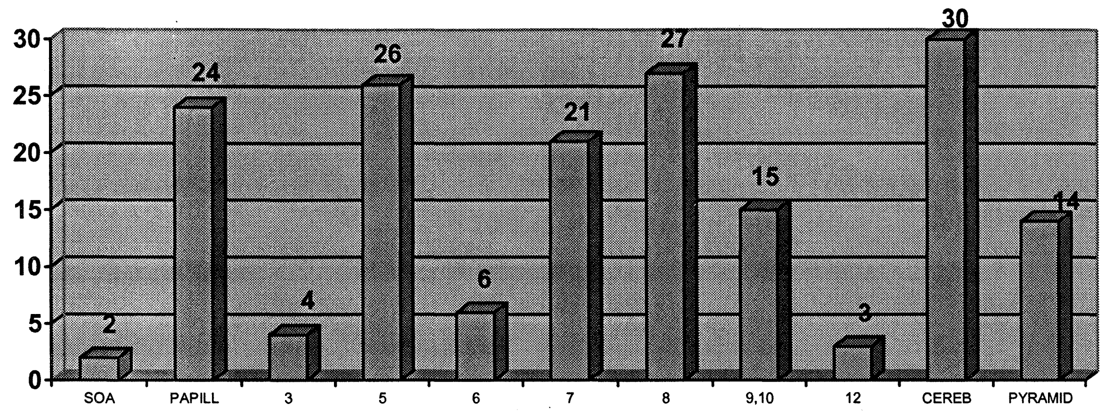

Fig. 8: Neurological deficits at presentation

SOA:secondary optic atrophy, P:papilledema,CEREB: cerebellar signs, PYRAMID: pyramidal signs, numbers represent corresponding cranial nerves

Radiology:

CT scan head with contrast was available in 61 patients. Most of the tumors were isodense or hyperdense on plain scan, and enhancing on contrast. Twenty six (39%) patients had evidence of hydrocephalus. MRI was not available in patients operated before 1993. Fifty three patients had MRI with contrast study (Table 3). Majority of the lesions were iso to hypointense on T1 and hyperintense on T2, with contrast enhancement. Eleven (17%) tumors were confined to the petroclival region whereas 53 (83%) tumors extended to other regions, most commonly cerebellopontine angle and cavernous sinus. (Table 4) Four vessel cerebral angiography was performed in 37 patients and one underwent embolisation of ECA feeders prior to surgery.

CT scan	**95% (61)**
MRI	**83% (53)**
CT+ MRI	**78%(50)**
DSA	**58% (37)**

Table 3: Investigations

Regions involved	**n=64**
Petroclival only	**11**
Other regions involved	**53**
• **Cerebellopontine angle**	**26**
• **Cavernous sinus**	**20**
• **Middle fossa**	**18**
• **Tentorium**	**13**
• **Meckel's cave**	**8**
• **Sphenoid**	**6**
• **Foramen magnum**	**3**
• **Jugular foramen**	**2**

Table 4 :Extent of the lesion

Surgical approach and extent of resection :

Three patients had undergone surgery at local hospitals and were referred for residual lesion. Sixty three patients (n=64) underwent primary tumor decompression. In one patient who developed disseminated intravascular coagulation after removal of the bone flap, surgery was abandoned.

While a transsylvian / subtemporal approach was carried out in 20 (31%) patients, the tumor was approached through a combined supra / infra tentorial approach in 24 (38%) and through a retrosigmoid route in 20 (31%).(Fig. 9) The tumor was radically removed in 41 (64%) patients, subtotally excised in 16 (25%) and a partial excision done in 6 (9%)(Fig. 20). Four patients after partial removal of the tumor, underwent a second stage procedure of which 3 were operated by the same approach. One patient who earlier underwent a combined approach was re explored by extending the craniotomy frontally for removal of middle fossa/cavernous sinus component. Radical excision was achieved in one patient and subtotal excision in the remaining three.

The other two patients who underwent partial excision are on follow up with serial imaging.

Figures 10-19 shows representative images of patients operated by various approaches.

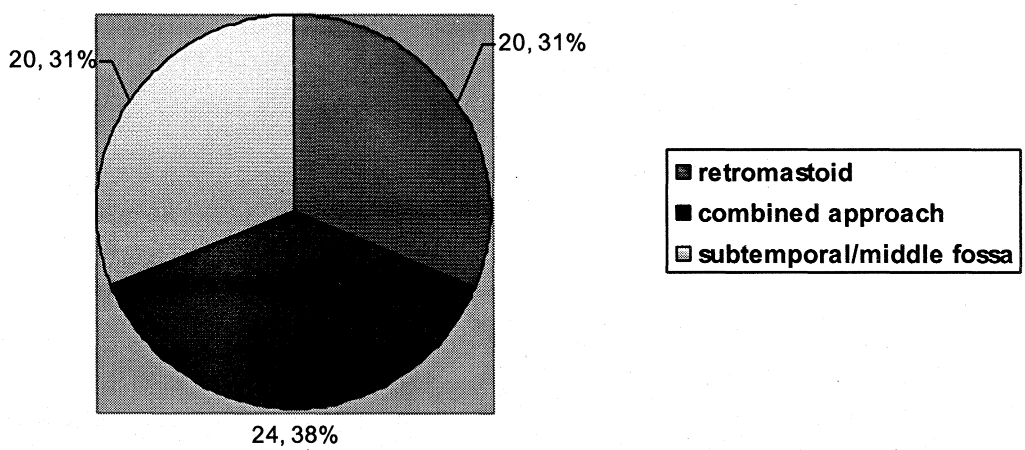

Fig. 9: Surgical approaches used

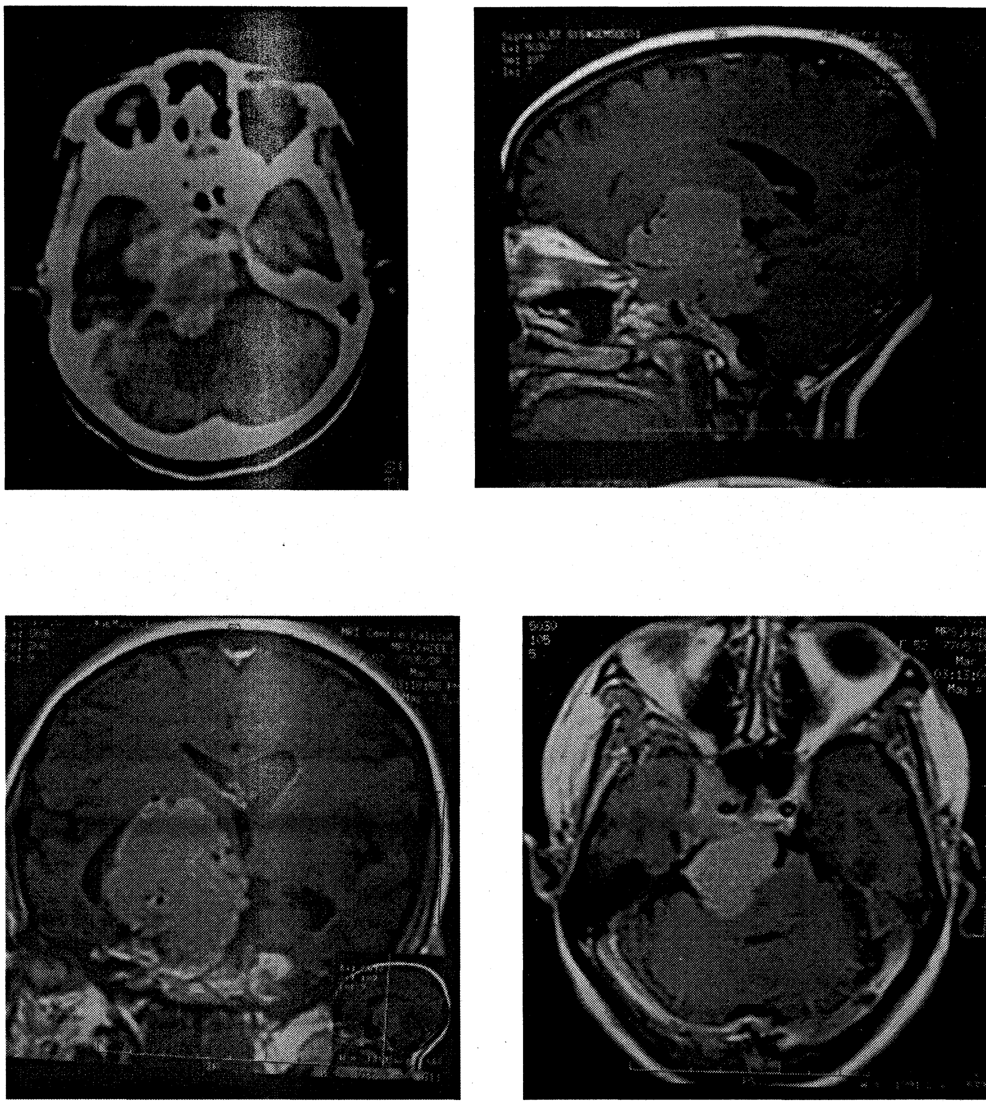

Fig. 10: Pre operative CT and MRI scans of a patient with right petroclival meningioma operated by fronto-temporal orbito zygomatic osteotomy, trans-sylvian/anterior subtemporal approach

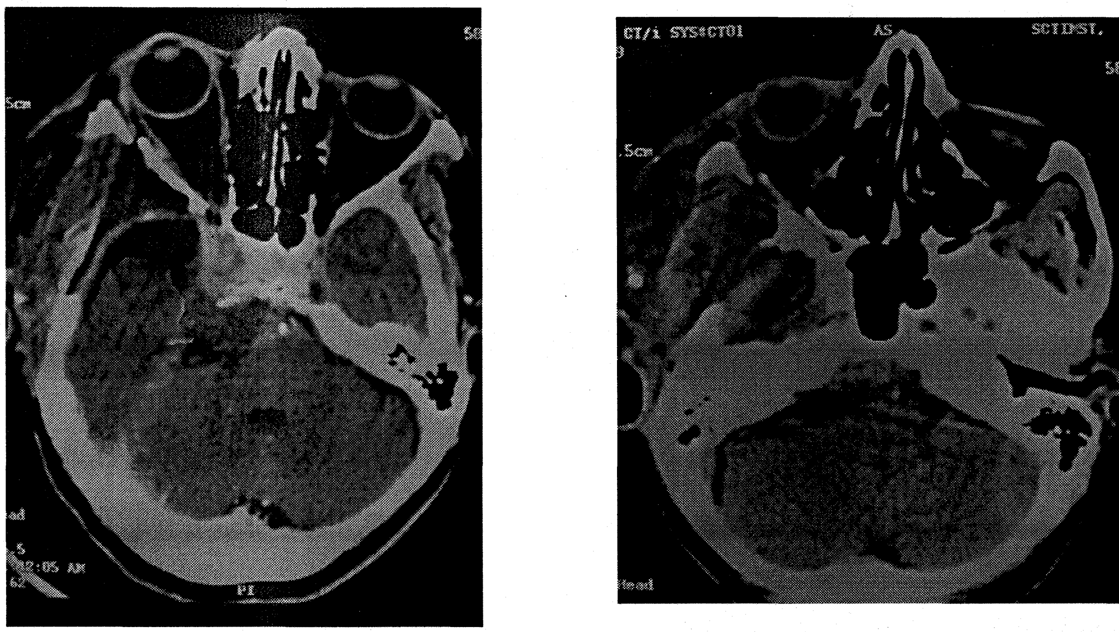

Fig. 11: Post operative CECT scan of the patient in Fig. 10

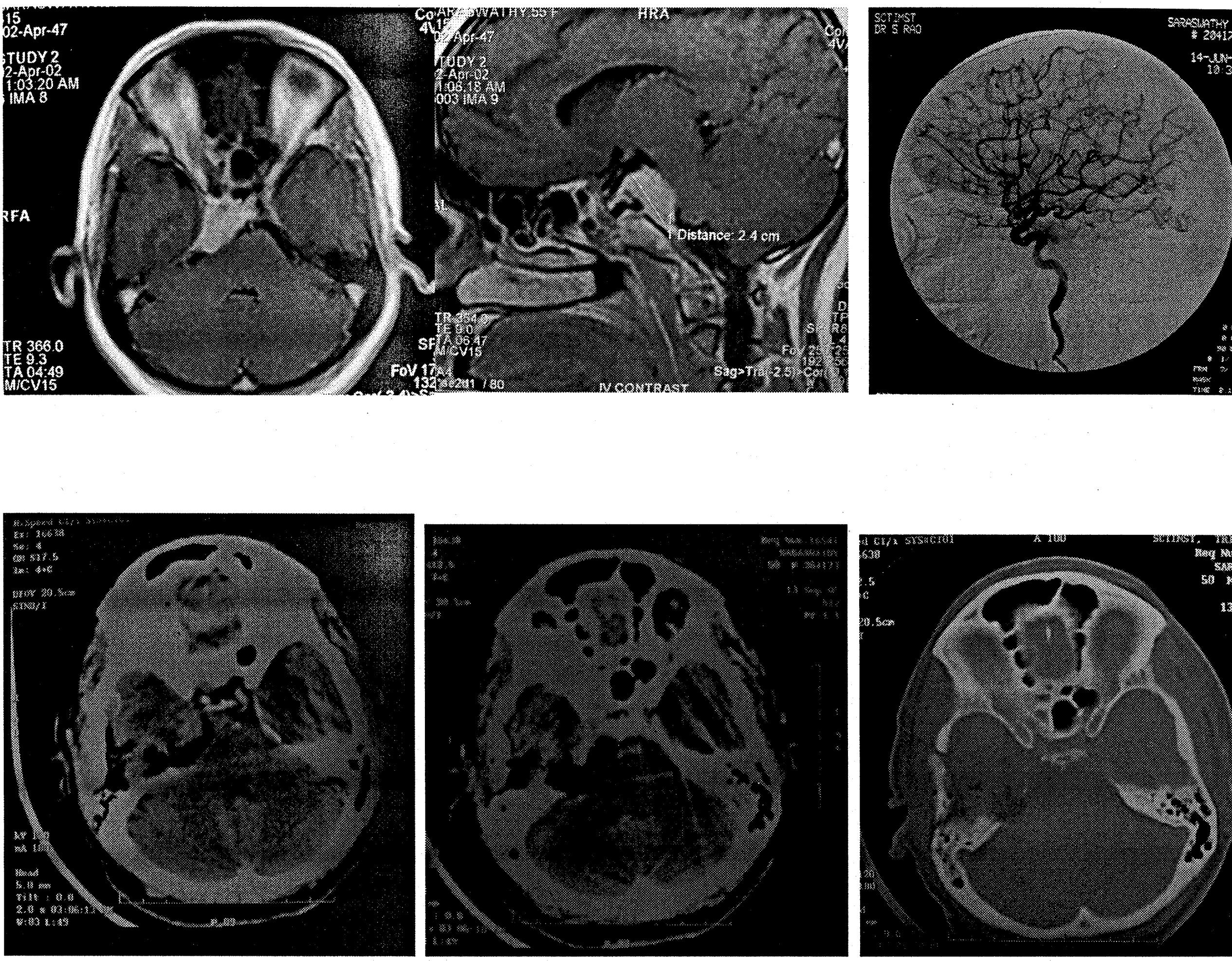

Fig. 12: Pre operative contrast MRI and right carotid angiogram (above) and post operative CECT (below) of a patient operated by Kawase's approach

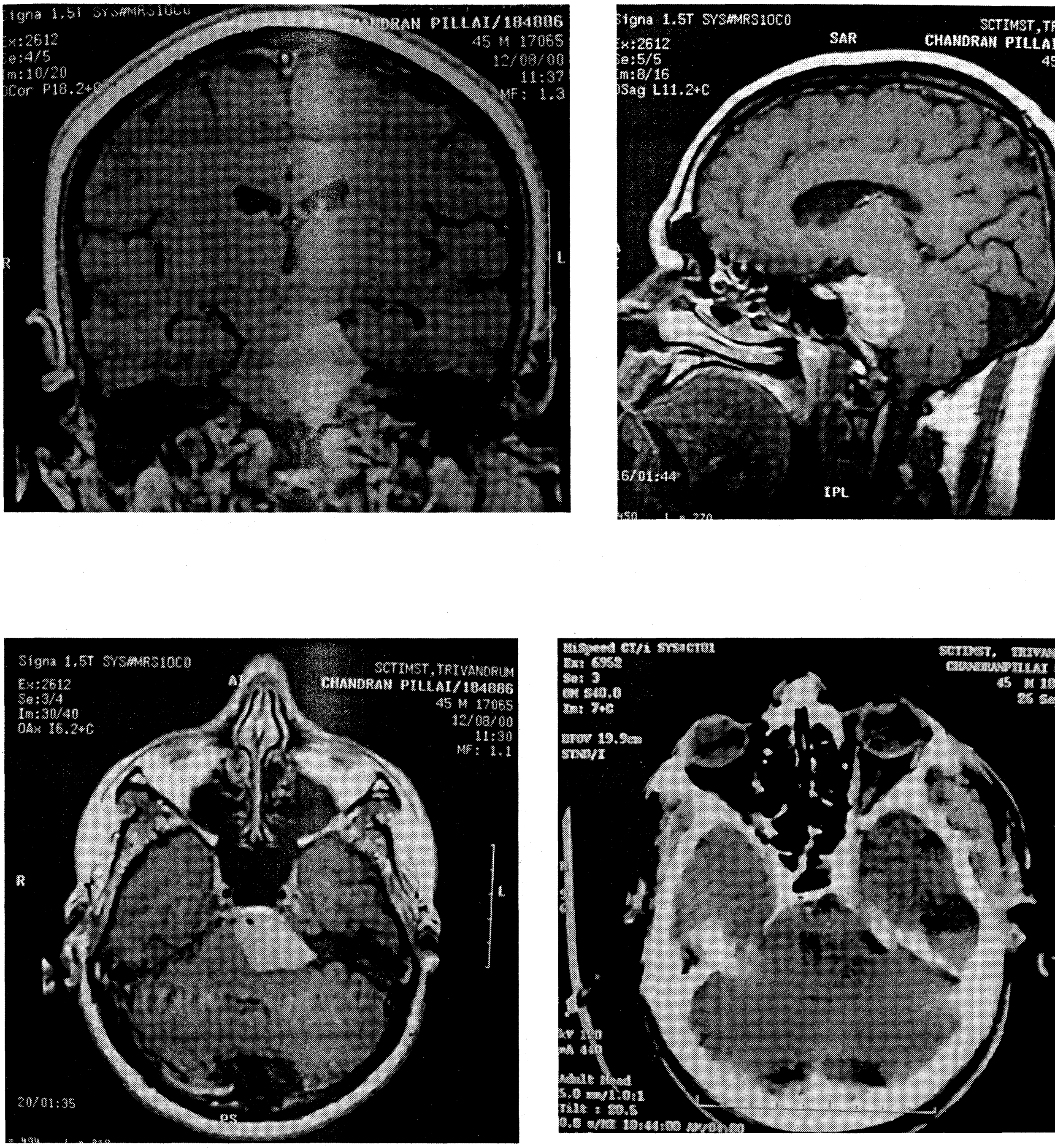

Fig. 13: Preoperative contrast MRI scans and post operative CECT scan (bottom right) of a patient operated by subtemporal approach

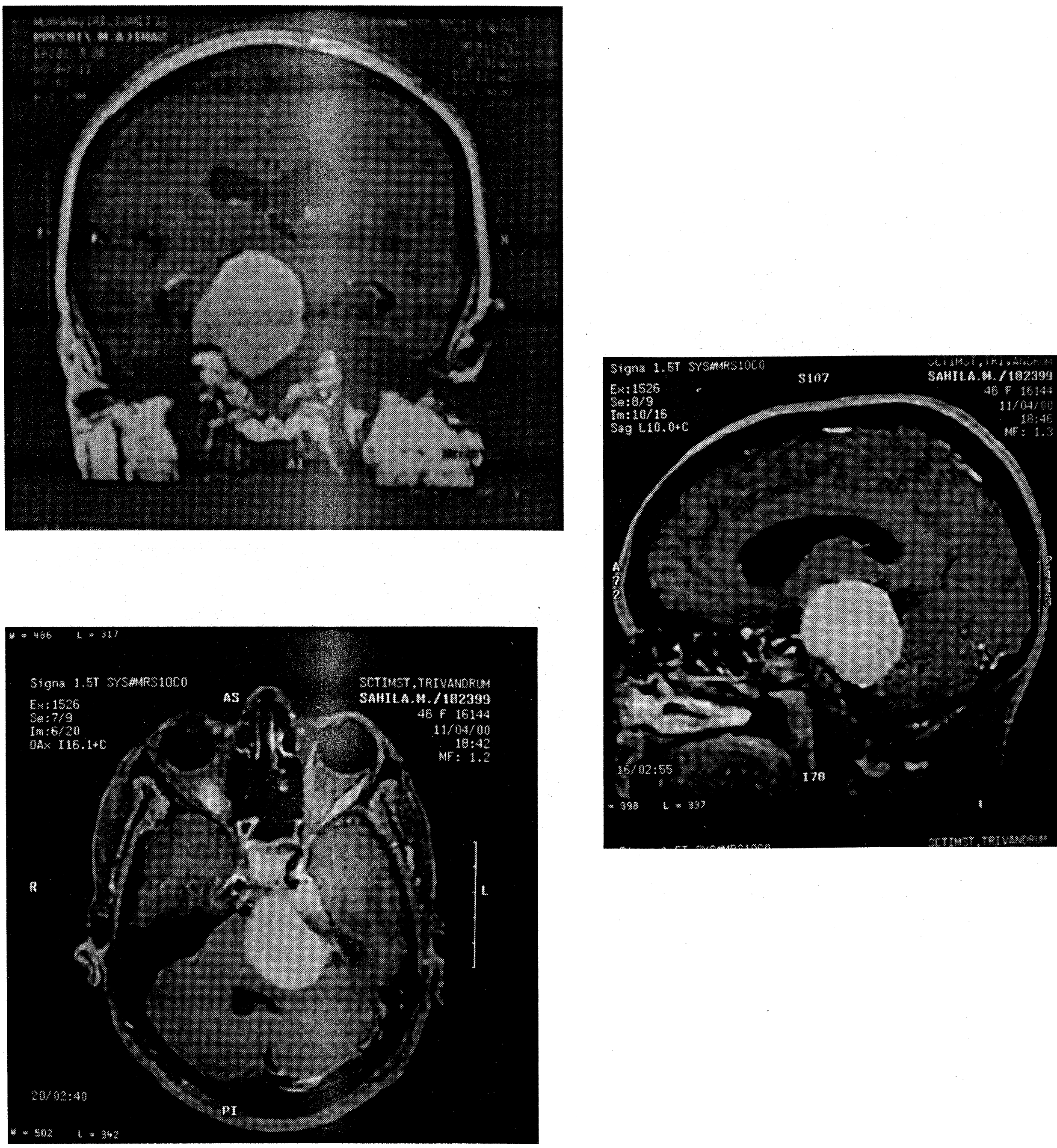

Fig. 14: Preoperative contrast MRI scan of a patient operated by fronto-temporal anterior sub-temporal approach with zygomatic osteotomy

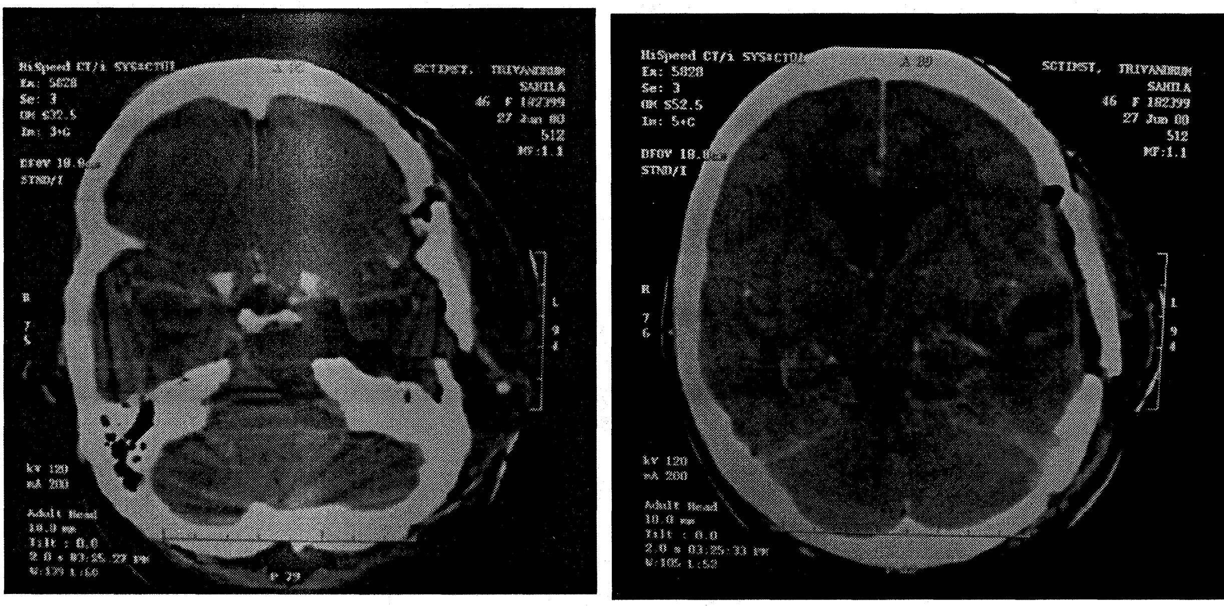

Fig. 15: Post operative CECT scan of the patient shown in Fig. 14

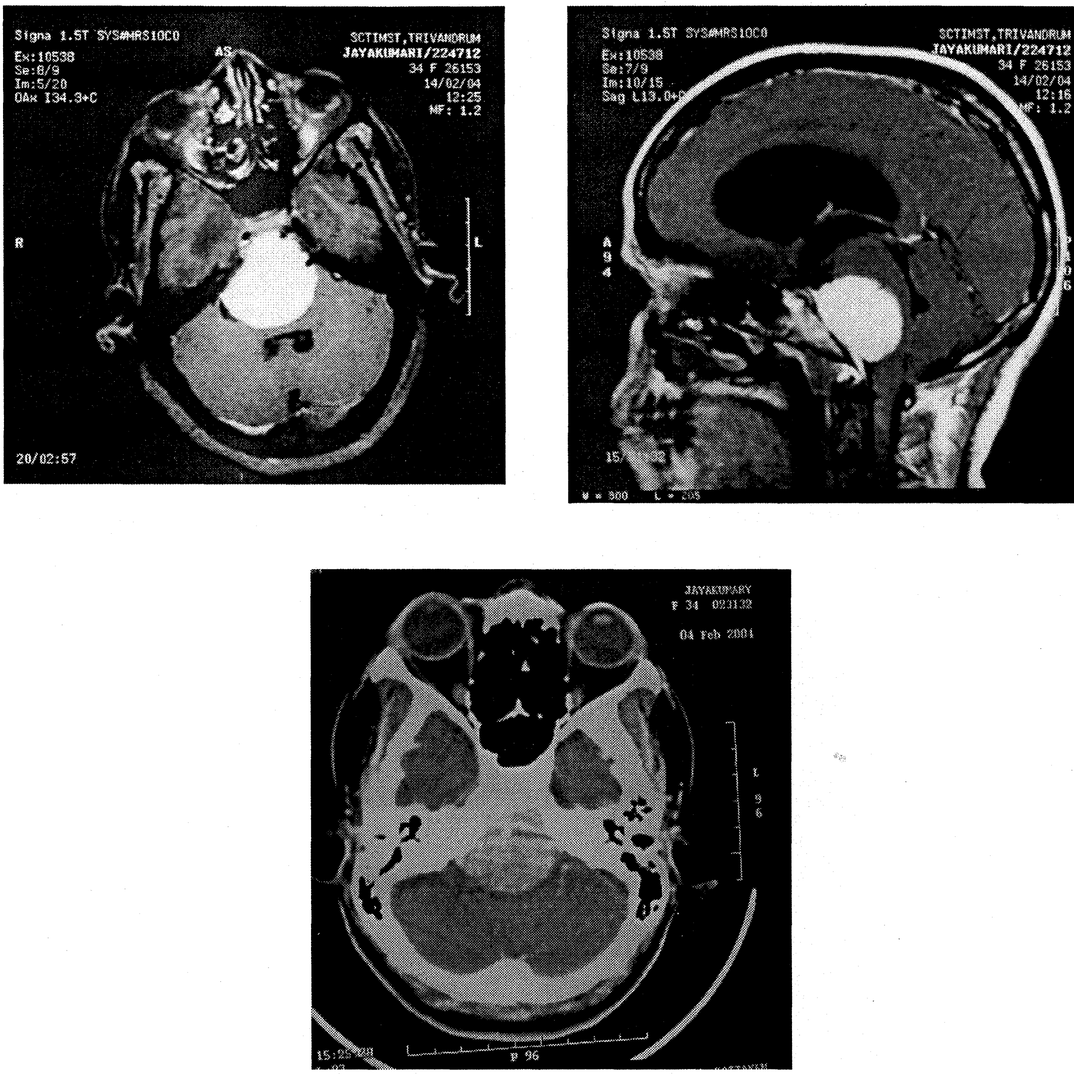

Fig. 16: Preoperative contrast MRI and CT scans of a patient operated by retrosigmoid approach

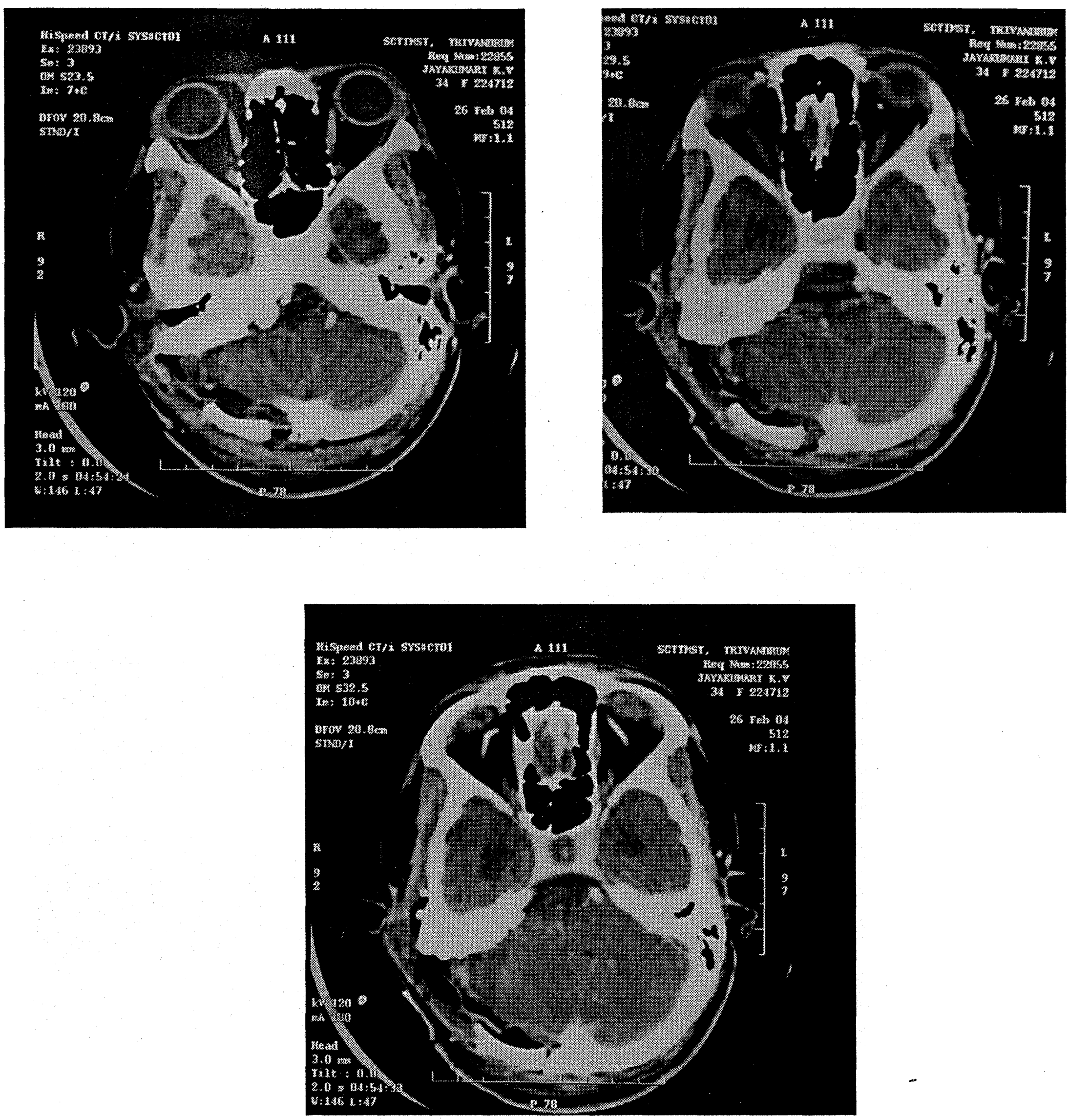

Fig. 17: Post operative CECT of the patient in Fig. 16

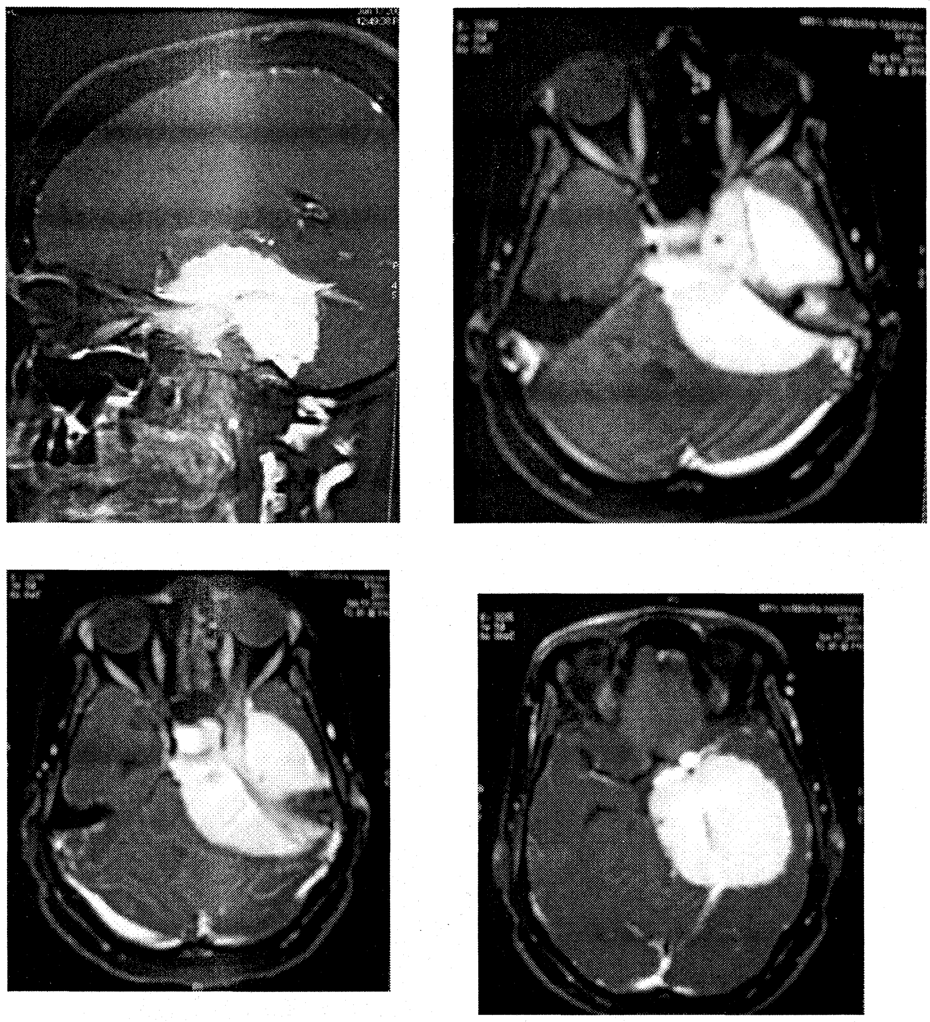

Fig. 18: Sagittal and axial contrast MRI of a patient operated by a combined approach.

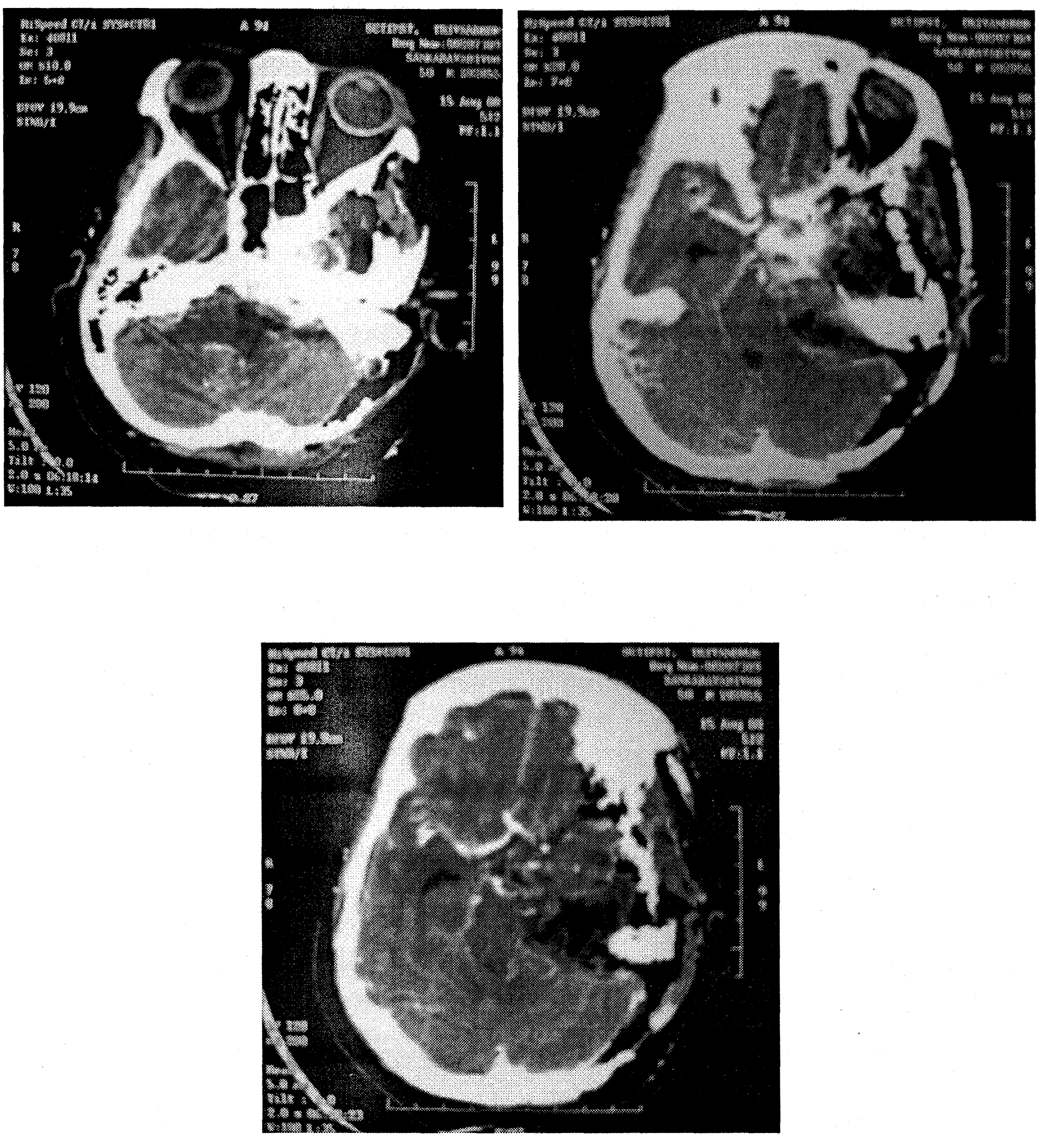

Fig. 19: Post operative CECT scan of the patient in Fig. 18

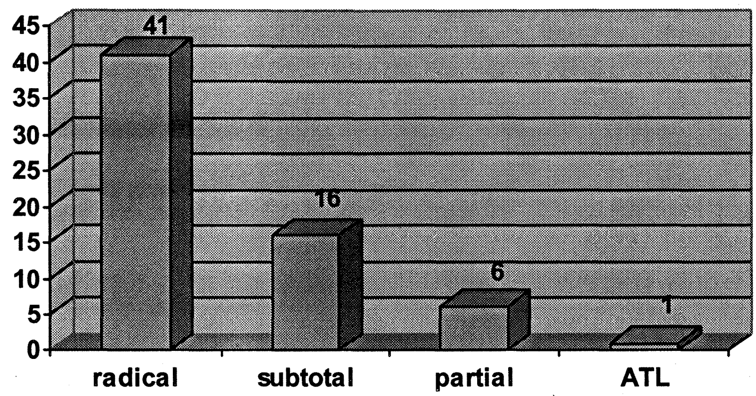

Fig. 20: Extent of resection

ATL: anterior temporal lobectomy only

Hydrocephalus:

Twenty six (39%) patients had evidence of hydrocephalus of which 4 underwent ventriculoperitoneal (VP) shunt and one endoscopic third ventriculostomy pre operatively; 6 patients underwent VP shunt in the post operative period due to persistent hydrocephalus.

Complications:

In our series, there was an operative morbidity of 52%. The surgery related complications included cranial nerve deficits, hemiparesis or hemiplegia, CSF leak from the wound, CSF otorrhea/rhinorrhea, meningitis, cerebellar/temporal hematoma, pseudomeningocele, graft wound infection and deep venous thrombosis. (Fig. 21 and Table 5). Twenty three patients developed either fresh cranial nerve deficits or worsening of pre existing cranial nerve deficits after surgery. Most of them had involvement of VII nerve (14 patients), followed by lower cranial nerves (13 patients) and V nerve (12 patients). At last follow up, these deficits are improving in 16 patients. Twenty one patients developed post operative limb weakness, including 3 who developed worsening of pre existing hemiparesis. At last follow up, it was improving in 9 patients. Eight patients developed CSF leak, either from the wound or from ear/nostril. One patient had CSF leak from the wound and one had CSF rhinorrhea. It settled with serial lumbar CSF drainage in both of them, but developed meningitis requiring prolonged antibiotic administration. Six patients developed CSF otorrhea, managed conservatively with serial lumbar drainage in five patients. One patient with CSF otorrhea underwent re exploration and repair. One patient with CSF otorrhea had fulminant sepsis and expired in the post operative period.

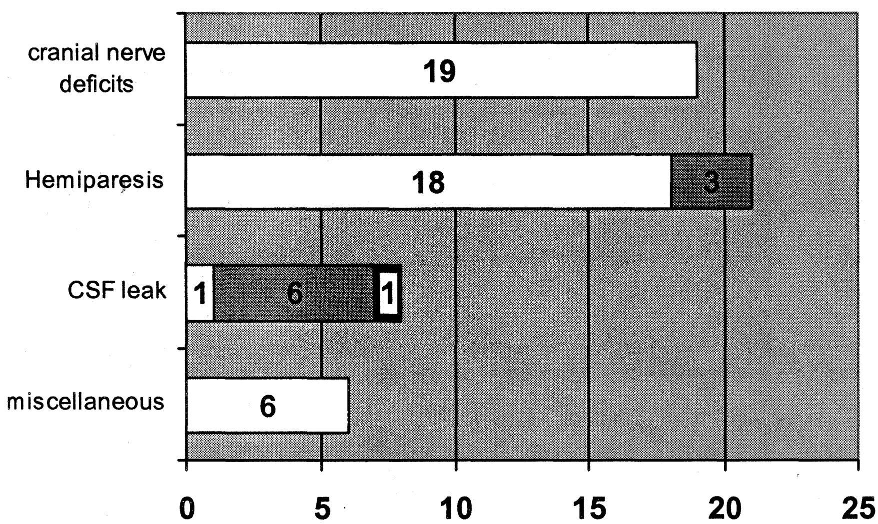

Fig. 21: Post operative complications (n=64)

CSF leak: one each had CSF rhinorrhea and wound leak, 6 had CSF otorrhea

Hemiparesis: Eighteen patients developed new onset limb weakness, three had worsening of pre existing weakness; Miscellaneous: See text

One patient who underwent surgery by combined approach developed temporal lobe contusion following which temporal lobectomy was done. She had fresh cranial nerve deficits which were resolving at last follow up. Three patients developed DVT of the lower extremities and were successfully managed with anticoagulants. One patient developed operative site pseudomeningocele, which resolved after cystoperitoneal shunt. One patient developed bone flap osteomyelitis and expired due to sepsis in the post operative period.

Deficit	**Pre op**	**Recovery**	**New onset or progression**
Cranial nerve III	4	1	12
V	26	3	12
Trigeminal neuralgia	12	8	5
VI	6	2	8
VII	21	1	14
VIII	27	0	10
IX,X	15	1	13
XII	3	1	3
Motor	9	2	21

Table 5: Pre and post operative neurological dysfunction

Operative mortality:

There was an operative mortality of 8% (5 patients).

1. Fifty year old female with tumor in the middle and posterior fossae, underwent combined approach and subtotal excision of the tumor. Post operatively she developed pupillary asymmetry and hemiplegia, CT scan showed large PCA infarct and cerebral edema. She was electively ventilated under barbiturate coma, but expired on post operative day 8.
2. Fifty one year old female underwent subtotal excision of tumor in middle and posterior fossae through combined approach. She recovered with lower cranial nerve deficits and post operative scan was normal. She developed CSF otorrhea, meningitis and respiratory infection and finally died of sepsis two months after surgery
3. Thirty five year old male with incidentally detected middle fossa meningioma following imaging for trauma was planned for middle fossa approach. While performing craniotomy, he developed features of disseminated intravascular coagulation and the procedure was abandoned after a temporal lobectomy. He died in the immediate post operative period.
4. Fifty year old female with a middle fossa meningioma underwent subtemporal transtentorial total excision. She had sustained vein of

Labbe injury intraoperatively. She had malignant cerebral edema post operatively, underwent emergency temporal lobectomy but developed fulminant sepsis, bone flap osteomyelitis and sigmoid sinus thrombosis and expired 6 weeks after the procedure.

5. Fifty five year old female with predominant posterior fossa tumor underwent retromastoid craniectomy and subtotal excision following which she developed hydrocephalus for which VP shunt was done. She was neurologically stable, but five months after surgery, she died of respiratory infection and sepsis.

Follow up:

The mean follow up period was 4.36 years (range: 1-15 years)

Of the 64 patients, we had a peri operative mortality of 5 (8%). Two patients died in the follow up period, one 14 years after and the other 6 months after surgery, due to unrelated causes. Eight patients did not come for follow up. Of the 49 patients on follow up, 36 patients were functionally independent at last visit.

Recurrent/residual tumor:

Four patients underwent re exploration at 11, 7, 1.5 and 0.5 years after the initial surgery for symptomatic residual/recurrent tumor. One of them had undergone stereotactic radiosurgery for symptomatic recurrence, 7 years after the first surgery. Five years post radiosurgery, there was significant growth of the residual necessitating re-exploration. In this patient, histopathological examination after first surgery was suggestive of meningothelial meningioma. After radiosurgery and re-exploration, the lesion showed evidence of atypical changes. Two patients were functionally independent after re exploration with no fresh neurological deficits. One patient developed worsening of hemiplegia after re exploration and the other patient who was in a poor general condition prior to surgery remained functionally dependent after surgery.

Ten patients on follow up had slowly growing residual lesions, mostly in the region of the cavernous sinus and Meckel's cave. Seven of them were asymptomatic and independent functionally at last follow up. One of them was referred for radiosurgery, she had stable residual lesion at last follow up. Three patients were symptomatic and functionally dependent of which one was referred for radiotherapy, one was advised surgery but patient opted for follow up and in the third patient who had a large residual, surgery was deferred because of poor general condition.

DISCUSSION..

Petroclival meningioma is one of the most difficult tumors of the cranial base. During the past 15 years, the field of cranial base surgery has been revolutionized by improvements in anesthetic and surgical techniques, as well as the use of multidisciplinary approaches. These lesions were initially considered inoperable[69], and the first surgical resections were associated with significant morbidity and mortality rates.[32] In recent years, several reports have demonstrated marked evolution in the microsurgical management of petroclival meningiomas.[17,52,70,71] Although Simpson's Grade 1 resection is possible in many cases, in most of the patients, subtotal resection with or without radiosurgery has become the preferred treatment to reduce the postoperative morbidity[36,60,83]. The results of surgery are encouraging regarding tumor growth control and patient outcomes, although follow-up periods were short in most studies. For selection of the ideal treatment modality in each case, understanding of the natural history, determination of preoperative predictors[76], and a knowledge of the results after treatment using different strategies[36,38,60,83] are useful. Modern cranial base exposure, resection techniques, and cranial base repair techniques have allowed the safe resection of many complex cranial base meningiomas. However, nuances of the surgical technique of resection, including minimal brain retraction, improved handling of cranial nerves, intracranial arteries, and veins; knowing when to remove tumor completely and when and where to leave tumor behind are based on the surgeon's experience and expertise, as well as the patient's wishes and goals. The preliminary results of radiosurgical treatment of small meningioma remnants or small non-operated tumors have had a definite impact on the management of the tumors and therapy must be tailored to the needs of the individual patient.[59]

Comparison with other series:

The male: female ratio in patients operated for petroclival meningiomas was 1:1.75 in Bricolo's series[11] of 33 patients, 1:2.42 in Samii's series[70] of 24 patients, 1:2.6 in Little's series[46] of 137 patients and 1:4.2 in Natarajan/Sekhar's[59] series of 150 patients. In our series also we found a female preponderance of 1:2.77, in agreement with the data from other series. Mean age of patients was 52, 45, 53 and 51 years respectively in the above studies; in our study the mean age of presentation was 47 years. Gait ataxia was the commonest initial presenting symptom in Bricolo's and Samii's series; in our series headache was the commonest initial manifestation, followed by gait ataxia. The commonest signs at presentation were involvement of cranial nerves 7 and 8 in Samii's series, trigeminal nerve in the series by Bricolo and Natarajan, and facial paresthesias and dysesthesias in Little's series. Cerebellar signs were the commonest neurological manifestation in our patients. The commonest cranial nerve involved was 8^{th} nerve, followed closely by the trigeminal nerve. The tumor was limited to the petroclival region in 43% of patients in Natarajan's series, it extended to the cavernous sinus in 50%, other common sites of extension were the sphenoid (7%), middle fossa (5%) and the tentorium (5%). In Little's series, 31% had evidence of cavernous sinus invasion. We had 11 (17%) patients with tumors limited to the petroclival region. Most commonly the tumor extended into the cerebellopontine angle (41%), cavernous sinus (31%) and middle fossa (28%). In Bricolo's series, the tumor was approached through a retromastoid craniectomy in 70% of patients, 15% each underwent middle fossa and combined approach. In the series by Little, 39% underwent excision by a combined approach, 22% by retromastoid route, 36% by middle fossa approach and the rest (6%) by total petrosectomy and transmastoid approaches. In the series by Natarajan and Sekhar, combined approach was used in 33% of patients. In our series, transsylvian / subtemporal approach was carried out in 31%, the tumor was approached through a combined supra / infra tentorial approach in 38% and through a retrosigmoid route in 31%.

Surgical outcome:

Before 1970 the operative mortality was more than fifty percent and total resection was reported only in one of the 26 cases operated upon.[12,90] A review of major operative series for total excision of petroclival meningiomas in the microsurgical era (Table 6) shows that rates of total excision vary from 25-100%. Gross-total excision is obtained in approximately 60% of all reported cases. Reported mortality rates in the series ranges from 0-17% and this low rate demonstrates the progress achieved in the surgical technique of tumor removal. The risk of hemiparesis varies from 7 to 45%, and persistent coma has been reported in 12 to 27%

of surgical patients. Permanent cranial nerve deficits resulting from surgery were noted in 22 to 91% of patients. On average, 54% of patients will develop new neurological deficits as a result of surgery.[5,11,17,52,63,71,77] We could achieve radical decompression in 64% of the patients operated with

Author	Year	No of patients	Total removal %	Operative morbidity %	Mortality %
Hakuba[32]	1977	6	100	-	17
Yasargil [90]	1980	20	35	50	15
Mayberg[52]	1986	35	26	54	9
Al-Mefty[4]	1988	13	85	31	0
Nishimura[61]	1989	24	-	91	8
Samii[70]	1989	24	71	46	0
Sekhar[75]	1990	41	78	22	2
Al-Mefty and Smith [3]	1991	18	83	-	0
Briccolo[11]	1992	33	79	76	9
Samii & Tatagiba[71]	1992	36	75	42	-
Spetzler[82]	1992	46	91	56	0
Sekhar[76]	1994	75	60	60	0
Cantore[13]	1994	16	80	38	0
Couldwell[17]	1996	109	69	51	4
Thomas & King[86]	1996	16	44	-	0
Zentner[92]	1997	19	68	58	5
Bricolo[9] et al	1999	110	66	47	4
Jung et al[38]	2000	38	0*	-	-
Seifert et al[73]	2003	22	68	-	0
Little et al[46]	2005	137	40	26	1
Natarajan & Sekhar[59]	2007	150	32	22	0
Our series	2008	64	64	52	8

* study on subtotally resected meningiomas

Table 6: showing various operative series on petroclival meningiomas

a post operative morbidity of 52% which included fresh cranial nerve deficits and hemiparesis as well as worsening of pre existing cranial nerve and motor deficits. We had a mortality rate of 8% (5 patients).

Recurrence

Recurrence rate after resection of petroclival meningiomas ranges from 0 to 42%.[17,27,38,59,92] (Table 7) The broad dural base of most petroclival meningiomas and their tendency to grow en plaque with extensive bone and dural involvement account for the high recurrence rate. Sekhar[76] reported only 20% of patients with residual tumor required re operation . Mayberg and Symon[52] reported that 15% of patients with subtotal removal had clinical progression and died.

Series	**Year**	**n**	**Mean FU (months)**	**Extent of resection**	**Recurrence/ progression**
Bricolo[11] et al	1992	33	52	GTR, 79%	26%
Couldwell[17] et al	1996	109	73	GTR, 69%	13%
Zentner[92] et al	1997	19	18	Total, 68%	0
Jung[38] et al	2000	38	47.5	STR, 100%	42%
Little[46] et al	2005	85	29.8	Near total, 40%	17.6%
Natarajan[59] et al	2007	150	100.8	GTR 48%	5%
This series	2008	64	52	Radical, 64%	22%

Table 7: showing recurrence rates in various series

Recently, Natarajan et al[59] reported a recurrence rate of only 5% in their series of 150 patients with a mean follow up of 100 months. They opined that it may be the result of aggressive surgical and radiosurgical management of most patients. In our series, radical decompression was achieved in 64% of patients, and there was a recurrence/progression rate of 22%, which is within the range described in various studies with long term follow up.

Follow up

Of the patients in whom long term follow up data were available, tumor recurrence or progression was seen in 14 patients (22%), of which 2 patients had undergone radical decompression earlier. Remaining 12 patients had undergone either a partial or subtotal resection. Radical resection was significantly associated with a better progression free survival than subtotal or partial resection ($p<0.05$). This is in accordance with various published reports on surgical management of petroclival meningiomas.[38,59]

CONCLUSIONS..

- **Petroclival meningiomas are rare tumors of the skull base and remain a surgical challenge.**
- **They are relatively more common in females in the fourth to sixth decades.**
- **Petroclival meningiomas are multi-compartmental tumors that involve critical neurovascular structures making curative resection difficult.**
- **Patients with asymptomatic residual lesions in the cavernous sinus or adjacent to brainstem can be followed up with serial imaging.**
- **Radical resection significantly improves progression-free survival rates at long term follow up ($p < 0.05$). However a larger study group is needed to assess difference in outcome of various surgical approaches.**

BIBLIOGRAPHY..

1. Abdel Aziz KM, Sanan A, van Loveren HR, Tew JM Jr, Keller JT, Pensak ML. Petroclival meningiomas: predictive parameters for transpetrosal approaches. Neurosurgery. 2000; 47:139-50.
2. Abramovich CM, Prayson RA. MIB-1 labeling indices in benign, aggressive, and malignant meningiomas: a study of 90 tumors.Hum Pathol. 1998; 29:1420-7.
3. Al-Mefty O, Smith RR. Clival and petroclival meningiomas. In: Al-Mefty O (ed) Meningiomas. New York: Raven Press,1991; 517-538.
4. Al-Mefty O, Fox JL, Smith RR. Petrosal approach for petroclival meningiomas. Neurosurgery 1988; 22: 510–517.
5. Al-Mefty O, Kersch JE, Routh A, Smith RR. The long term side effects of radiation therapy for benign brain tumors in adults. J Neurosurg 1990; 73: 502-512.
6. Bambakidis NC, Kakarla UK, Kim LJ, Nakaji P, Porter RW, Daspit CP, Spetzler RF. Evolution of surgical approaches in the treatment of petroclival meningiomas: a retrospective review. Neurosurgery. 2008; 62(6 Suppl 3): 1182-91.
7. Barbaro NM, Gutin PM, Wilson CB, Sheline GE, Boldrey EB, Wara WM. Radiation therapy in the treatment of partially resected meningiomas. Neurosurgery 1987; 20: 525-528.
8. Blond S, Coche-Dequeant B, Castelain B. Stereotactically guided radiosurgery using the linear accelerator. Acta Neurochir(Wien) 1993; 124: 40-43.

9. Bricolo A, Turazzi S: Surgical management of petroclival meningiomas: Experience on 110 cases (abstract). Presented at XLVIII Congress of the Italian Neurosurgical Society, Catanzaro, September 12-15, 1999.
10. Bricolo A, Turazzi S. Petroclival meningiomas. In: Henry H Schmidek (ed) Operative Neurosurgical Techniques: Indications, Methods, and Results. Philadelphia: WB Saunders 2006; 992-1013.
11. Bricolo AP, Turazzi S, Talacchi A, Cristofori L. Microsurgical removal of petroclival meningiomas: A report of 33 patients. Neurosurgery 1992; 31: 813–828.
12. Campbell E, Whitfield RD. Posterior fossa meningiomas. J Neurosurg 1948; 5:131–153.
13. Cantore G, Delfini R, Ciappetta. Surgical treatment of petroclival meningiomas: Experience with 16 cases. Surg Neurol 1994, 42:105-111.
14. Carella RJ, Ransohoff J, Newall J. Role of radiation therapy in the management of meningioma. Neurosurgery 1982; 10: 332-339.
15. Castellano F, Ruggiero G. Meningiomas of the posterior fossa. Acta Radiol. 1953; 104: 3-157.
16. Couldwell WT, Weiss MH. Surgical approaches to petroclival meningiomas. Upper and midclival approaches. Contemp Neurosurg 1994; 16: 1-6.

17. Couldwell WT, Fukushima T, Giannotta SL, Weis MH. Petroclival meningiomas: Surgical experience in 109 cases. J Neurosurg 1996; 84: 20–28.

18. Cushing HW, Eisenhardt L. Meningiomas; Their Classification, Regional Behavior, Life History, and Surgical End Results. Springfield, Ill: Charles C Thomas, 1938: 3–387.

19. Dany A, Delcour J, Laine E. Les meningiomes du clivus: Etude clinique, radiologique et thérapeutique. Neurochirurgie 1963; 9: 249–277.

20. De Angelis LM. Brain tumors, N Eng J of Med, 2001; 344(2): 114-123.

21. DeMonte F, Smith HK, Al-Mefty O. Outcome of aggressive removal of cavernous sinus meningiomas. J Neurosurg 1994; 81: 245-251.

22. Elia AE, Shih HA, Loeffler JS. Stereotactic radiation treatment for benign meningiomas. Neurosurg Focus. 2007; 23(4): E5.

23. Erkmen K, Pravdenkova S, Al-Mefty O. Surgical management of petroclival meningiomas: Factors determining the choice of approach. Neurosurg Focus. 2005; 19: E7.

24. Ernst J. Delwel. The Anterior Transpetrosal-Transtentorial Approach (Kawase Approach) An Anatomic Description and Clinical Applications. Contemporary Neurosurgery 2008; 30(6): 1-6.

25. Ganz JC, Backlund EO, Thorsen FA. The results of gamma knife surgery of meningiomas, related to size of tumor and dose.Stereotact Funct Neurosurg. 1993; 61: 23-29.
26. Glaholm J, Bloom HJG, Crow JH. The role of radiotherapy in the management of intracranial meningiomas: The Royal Marsden Hospital experience with 186 patients. Int J Radiat Onc Biol Phys 1990; 18: 755-761.
27. Goel A. Extended lateral subtemporal approach for petroclival meningiomas:Report of experience with 24 cases. Br J Neurosurg 1999; 13: 270–275.
28. Goel A, Muzumdar D. Conventional posterior fossa approach for surgery on petroclival meningiomas: A report on an experience with 28 cases. Surg Neurol 2004; 62: 332–340.
29. Goldsmith BJ, Wara WM, Wilson CB, Larson DA. Postoperative irradiation for subtotally resected meningiomas. J Neurosurg 1994; 80:195-201.
30. Gustavo A. Carvalho, Cordula Matthies, Marcos Tatagiba, Rama Eghbal, Madjid Samii. Impact of Computed Tomographic and Magnetic Resonance Imaging Findings on Surgical Outcome in Petroclival Meningiomas. Neurosurgery 2000; 47: 1287–1295.
31. Hakuba A, Nishimura S, Jang BJ. A combined retroauricular and preauricular tanspetrosal-transtentorial approach to clivus meningiomas. Surg Neurol 1988; 30: 108-116.

32. Hakuba A, Nishimura S, Tanaka K, Kishi H, Nakamura T. Clivus meningioma: Six cases of total removal. Neurol Med Chir (Tokyo) 1977; 17: 63–77.

33. Horgan MA, Anderson GJ, Kellogg JX, Schwartz MS, Spektor S, McMenomey SO, Delashaw JB. Classification and quantification of the petrosal approach to the petroclival region. J Neurosurg 2000; 93(1):108-12.

34. Huang CI, Chiou WH, Ho DM. Oligodendroglioma occurring after radiation therapy for pituitary adenoma. J Neurol Neurosurg Psychiatry 1987; 50(12):1619-24.

35. Ichimura S, Kawase T, Onozuka S, Yoshida K, Ohira T. Four subtypes of petroclival meningiomas: differences in symptoms and operative findings using the anterior transpetrosal approach. Acta Neurochir (Wien) 2008;150(7): 637-45.

36. Iwai Y, Yamanaka K, Yasui T, Komiyama M, Nishikawa M, Nakajima H, Kishi H. Gamma knife surgery for skull base meningiomas. The effectiveness of low-dose treatment. Surg Neurol. 1999; 52(1): 40-4.

37. Jääskeläinen J, Haltia M, Laasonen E, Wahlstrom T, Valtonen S. The growth rate of intracranial meningiomas and its relation to histology: An analysis of 43 patients. Surg Neurol 1985; 24:165–172.

38. Jung HW, Yoo H, Paek SH, Choi KS. Long-term outcome and growth rate of subtotally resected petroclival meningiomas: Experience with 38 cases. Neurosurgery 2000; 46: 567–575.

39. Kallio M, Sankila R, Hakulinen T, Jääskeläinen J. Factors affecting operative and excess long-term mortality in 935 patients with intracranial meningioma. Neurosurgery 1992; 31(1): 2-12.
40. Kato N, Kayama T, Sakurada K, Saino M, Kuroki A.[Radiation induced glioblastoma: a case report] No To Shinkei. 2000; 52(5): 413-8.
41. Kawase T, Shiobara R, Ohira T et al. Developmental patterns and characteristic symptoms of petroclival meningiomas. Neurologia medico-chirurgica 1996; 36:1-6.
42. Kawase T, Shiobara R, Toya S. Anterior transpetrosal-transtentorial approach for sphenopetroclival meningiomas: surgical method and results in 10 patients. Neurosurgery 1991; 6: 869-876.
43. Kondziolka D, Flickinger JC, Lunsford LD. The principles of skull base radiosurgery. Neurosurg Focus. 2008; 24(5): E11.
44. Kondziolka DS, Lunsford LD, Flickinger JC: Stereotactic radiosurgery for benign intracranial meningiomas. Clin Neurosurg 1993; 40: 475-497.
45. Lippman C, Sen C. Petroclival meningiomas. In: Batjer HH, Loftus CM. Text Book of Neurological Surgery: Principles and Practice, Philadelphia: Lippincott William & Wilkins, 2003;1456-1471.
46. Little KM, Friedman AH, Sampson JH, Wanibuchi M, Fukushima T. Surgical management of petroclival meningiomas: Defining resection

goals based on risk of neurological morbidity and tumor recurrence rates in 137 patients. Neurosurgery 2005; 56: 546–559.

47. Loeffler JS, Niemierko A, Chapman PH. Second tumors after radiosurgery: tip of the iceberg or a bump in the road? Neurosurgery 2003; 52(6): 1436-4.

48. Longstreth WT Jr, Dennis LK, McGuire VM, et al. Epidemiology of meningioma. Cancer 1993; 72: 639-648.

49. Luyendijk W: The operative approach to the posterior fossa, in Krayenbühl H (ed): Advances and Technical Standards in Neurosurgery. Wien, Springer Verlag, 1976, vol 3, 81–101.

50. Marks SM, Whitwell HL, Lye RH. Recurrence of meningiomas after operation. Surg Neurol 1986; 25(5): 436-40.

51. Matsuno A, Fujimaki T, Sasaki T, Nagashima T, Ide T, Asai A, Matsuura R, Utsunomiya H, Kirino T. Clinical and histopathological analysis of proliferative potentials of recurrent and non-recurrent meningiomas. Acta Neuropathol 1996; 91(5): 504-10.

52. Mayberg MR, Symon L. Meningiomas of the clivus and apical petrous bone: Report of 35 cases. J Neurosurg 1986; 65:160–167.

53. McIver JI, Pollock BE. Radiation-induced tumor after stereotactic radiosurgery and whole brain radiotherapy: case report and literature review. J Neurooncol. 2004; 66(3): 301-5.

54. Miller CG, van Loveren HR, Keller JT, et al. Transpetrosal approach: surgical anatomy and technique. Neurosurgery 1993; 33: 461–469.

55. Miralbell R, Linggood RM, de la Monte S, Convery K, Munzenrider JE, Mirimanoff RO. The role of radiotherapy in the treatment of subtotally resected benign meningiomas. J Neurooncol. 1992 ;13(2):157-64.

56. Mirimanoff RO, Dosoretz DE, Linggood RM, Ojemann RG, Martuza RL. Meningioma: Analysis of recurrence and progression following neurosurgical resection. J Neurosurg 1985; 62: 18-24.

57. Monzen Y. [Natural history of intracranial meningioma after radiotherapy] Nippon Igaku Hoshasen Gakkai Zasshi. 1999; 59(6): 256-60. Japanese

58. Muracciole X, Cowen D, Régis J. [Radiosurgery and brain radio-induced carcinogenesis: update] Neurochirurgie. 2004 ;50(2-3 Pt 2): 414-20. French

59. Natarajan S K, Sekhar L N, Schessel D, Morita A: Petroclival meningiomas. multimodality treatment and outcomes at long-term follow-up: Neurosurgery. 2007; 60(6): 965-981.

60. Nicolato A, Foroni R, Pellegrino M, Ferraresi P, Alessandrini F, Gerosa M, Bricolo A. Gamma knife radiosurgery in meningiomas of the posterior fossa. Experience with 62 treated lesions. Minim Invasive Neurosurg 2001; 44(4): 211-7

61. Nishimura S, Hakuba A, Jang BJ, Inoue Y. Clivus and apicopetroclivus meningiomas: Report of 24 cases. Neurol Med Chir (Tokyo) 1989; 29: 1004–1011.

62. Olivecrona H: The surgical treatment of intracranial tumors, in Olivecrona H, Tonnis W (eds): Handbuch der Neurochirurgie. Berlin, Springer-Verlag, 1967.
63. Olivero WC, Lister JR, Elwood PW. The natural history and growth rate of asymptomatic meningiomas: A review of 60 patients. J Neurosurg 1995; 83: 222-224.
64. Park CK, Jung HW, Kim JE, Paek SH, Kim DG. The selection of the optimal therapeutic strategy for petroclival meningiomas. Surg Neurol. 2006; 66(2):160-5.
65. Petty AM, Kun LE, Meyer GA. Radiation therapy for incompletely resected meningiomas. J Neurosurg 1985; 62: 502-507.
66. Ramina R, Neto MC, Fernandes YB, Silva EB, Mattei TA, Aguiar PH. Surgical removal of small petroclival meningiomas. Acta Neurochir (Wien) 2008; 150(5): 431-8.
67. Rhoton AL. The temporal bone and transtemporal approaches, In Rhoton AL (ed) : Cranial anatomy and surgical approaches; 2003: 662-663.
68. Roche PH, Pellet W, Fuentes S, Thomassin JM, Régis J. Gamma knife radiosurgical management of petroclival meningiomas results and indications. Acta Neurochir (Wien) 2003;145(10): 883-8.
69. Russell JR, Bucy PC. Meningiomas of the posterior fossa. Surg Gynecol Obstet 1953; 96:183–192.

70. Samii M, Ammirati M, Mahran A, Bini W, Sepehrnia A. Surgery of petroclival meningiomas: Report of 24 cases. Neurosurgery 1989; 24:12–17.

71. Samii M, Tatagiba M. Experience with 36 surgical cases of petroclival meningiomas. Acta Neurochir (Wien) 1992; 118: 27–32.

72. Samii M, Ammirati M. The Combined Supratentorial presigmoid sinus avenue to the petroclival region. Surgical technique and clinical applications. Acta Neurochir 1988; 95: 6–12.

73. Seifert V, Raabe A, Zimmermann M. Conservative (labyrinth-preserving) transpetrosal approach to the clivus and petroclival region—Indications, complications, results and lessons learned. Acta Neurochir (Wien) 2003; 145: 631–642.

74. Sekhar LN, Samii M. Petroclival and medial tentorial meningiomas, in Scheuneman H, Schurmann K, Helms J (eds): Tumors of the Skull Base: Extra and Intracranial Surgery of Skull Base Tumors. Berlin, Walter de Gruyter, 1986, 141–158.

75. Sekhar LN, Jannetta PJ, Burkhart LE, Janosky JE. Meningiomas involving the clivus: Asix-year experience with 41 patients. Neurosurgery 1990; 27: 764–781.

76. Sekhar LN, Swamy NK, Jaiswal V, Rubinstein E, Hirsch WE Jr, Wright DC. Surgical excision of meningiomas involving the clivus: Preoperative and intraoperative features as predictors of

postoperative functional deterioration. J Neurosurg 1994; 81: 860–868.

77. Sekhar LN, Jannetta PJ. Cerebellopontine angle meningiomas: Microsurgical excision and follow-up results. J Neurosurg 1984; 69: 500- 505.

78. Shamisa A, Bance M, Nag S, Tator C, Wong S, Norén G, Guha A. Glioblastoma multiforme occurring in a patient treated with gamma knife surgery. Case report and review of the literature. J Neurosurg 2001; 94(5): 816-21.

79. Sheehan J, Yen CP, Steiner L. Gamma knife surgery-induced meningioma. Report of two cases and review of the literature. J Neurosurg 2006;105(2): 325-9.

80. Simpson D. The recurrence of intracranial meningiomas after surgical treatment. J Neurol Neurosurg Psychiatry 1957; 20(1): 22-39.

81. Siwanuwatn R, Deshmukh P, Figueiredo EG, Crawford NR, Spetzler RF, Preul MC. Quantitative analysis of the working area and angle of attack for the retrosigmoid, combined petrosal, and transcochlear approaches to the petroclival region. J Neurosurg 2006; 104:137–142.

82. Spetzler RF, Daspit CP, Pappas CTE. The combined supra- and infratentorial approach for lesions of the petrous and clival regions: Experience with 46 cases. J Neurosurg 1992; 76: 588–599.

83. Subach BR, Lunsford LD, Kondziolka D, Maitz AH, Flickinger JC. Management of petroclival meningiomas by stereotactic radiosurgery. Neurosurgery 1998; 42: 437–443.

84. Tatagiba M, Samii M, Matthies C, Vorkapic P. Management of petroclival meningiomas: A critical analysis of surgical treatment. Acta Neurochir Suppl 1996; 65: 92–94.

85. Taylor BW Jr, Marcus RB Jr, Friedman WA, Ballinger WE Jr, Million RR. The meningioma controversy: Postoperative radiation therapy.Int J Radiat Oncol Biol Phys 1988;15: 299-304.

86. Thomas NWM, King TT. Meningiomas of the cerebellopontine angle: A report of 41 cases. Br J Neurosurg 1996;10:59-68.

87. Valentino V, Schinaia G, Raimondi AJ. The results of radiosurgical management of 72 middle fossa meningiomas. Acta Neurochir (Wien) 1993;122: 260-270.

88. Van Havenbergh T, Carvalho G, Tatagiba M, Plets C, Samii M. Natural history of petroclival meningiomas. Neurosurgery 2003; 52: 55–64.

89. Yamashita J, Handa H, Iwaki K, Abe M. Recurrence of intracranial meningiomas, with special reference to radiotherapy. Surg Neurol 1980; 14: 33-40.

90. Yasargil MG, Mortara RW, Curcic M. Meningiomas of basal posterior cranial fossa. Adv Tech Stand Neurosurg 1980; 7: 3-115.

91. Yu JS, Yong WH, Wilson D, Black KL. Glioblastoma induction after radiosurgery for meningioma. Lancet 2000; 4: 356(9241):1576-7.
92. Zentner J, Meyer B, Vieweg U, et a.l. Petroclival meningiomas: Is radical resection always the best option? J Neurol Neurosurg Psychiatry 1997; 62: 341-345.