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RESEARCH

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Extradural anterior clinoidectomy in surgical management of clinoidal meningiomas

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Abstract

Background: Despite the recent advances in skull base surgery, microsurgical techniques, and neuroimaging, yet surgical resection of clinoidal meningiomas is still a major challenge. In this study, we present our institution experience in the surgical treatment of anterior clinoidal meningiomas highlighting the role of extradural anterior clinoidectomy in improving the visual outcome and the extent of tumor resection. This is a prospective observational study conducted on 33 consecutive patients with clinoidal meningiomas. The surgical approach utilized consisted of extradural anterior clinoidectomy, optic canal deroofing with falciform ligament opening in all patients. The primary outcome assessment was visual improvement and secondary outcomes were extent of tumor resection, recurrence, and postoperative complications.

Results: The study included 5 males and 28 females with mean age 49.48 ± 11.41 years. Preoperative visual deficit was present in 30 (90.9%) patients. Optic canal involvement was present in 24 (72.7%) patients, ICA encasement was in 16 (48.5%), and cavernous sinus invasion in 8 (24.2%). Vision improved in 21 patients (70%), while 6 patients (20%) had stationary course and 1 patient (3%) suffered postoperative new visual deterioration. Gross total resection was achieved in 24 patients (72.7%). The main factors precluding total removal were cavernous sinus involvement and ICA encasement. Mortality rate was 6.1%; mean follow-up period was 27 ± 13 months.

Conclusions: In this series, the use of extradural anterior clinoidectomy provided a favorable visual outcome and improved the extent of resection in clinoidal meningioma patients.

Keywords: Anterior clinoidal meningioma, Medial sphenoid wing meningioma, Anterior clinoidectomy, Visual outcome, Extent of resection

Background

Sphenoid ridge meningiomas were first classified by Cushing and Eisenhardt in 1938 into en plaque and globoid tumors, the latter group was subdivided according to their location into lateral or pterional tumors, middle ridge tumors, and medial or inner ridge tumors which are commonly referred to as anterior clinoidal meningiomas [1].

Anterior clinoidal meningiomas arise from the meningeal covering of the anterior clinoid process (ACP) and characterized by its epicenter on the ACP with upward growing features, and hyperostosis of the ACP. Their incidence ranges from 34 to 43.9% of sphenoidal meningiomas [2, 3]. The important classification proposed by Al-Mefty described three different types based on its origin from the ACP, its relationship with the ICA, and the presence of arachnoid plane which are the most important determinant of surgical resectability. Tumor size was also an important factor for the surgical outcome as postulated in other studies [4].

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In 1985, extradural anterior clinoidectomy (EAC) was first introduced by Dolenc for surgical approach to the cavernous sinus [5]. This technique was subjected to various refinement by investigators to approach the parasellar and peri-clinoidal lesions [6–9]. It provides early localization, exposure, and mobilization of the optic nerve and the ICA, with early optic nerve decompression before tumor removal [10, 11]. In the present study, we present our surgical experience in treating patients with clinoidal meningiomas at our institute, to clarify the role of the EAC in improving the visual outcome and the extent of tumor resection. We also outline the significance of optic canal involvement to the preoperative visual status and analyze different factors that may affect the patient's overall outcome.

Methods

This is a prospective observational study, conducted between January 2017 and December 2020. Thirty-three consecutive patients (age > 18 years) with a confirmed radiological diagnosis of anterior clinoidal meningioma were included in this study. Anterior skull base meningioma with its epicenter on the ACP, upward growing features, and hyperostosis of the ACP were defined as a clinoidal meningioma. Tumors originating from the tuberculum sellae, olfactory groove, orbital roof, middle or lateral sphenoid ridge, or the cavernous sinus were excluded. All patients were primarily diagnosed and treated at our institute with no previous surgical intervention, catheter embolization, or previous radiation. All patients were informed about the benefits and the risks of the intended procedure; an informed written consent was signed at least 24 h before the operation.

All patients were subjected to thorough preoperative and postoperative neurological and ophthalmological assessments including visual acuity (using the Snellen metric chart and converted to Log MAR method), visual field perimetry, and ocular motility testing. Laterality of visual impairment associated with field defects or related to tumor location was considered tumor-related visual deficit.

Preoperative and postoperative investigations including CT scans and MRI contrasted studies were conducted on all our patients; cerebral CT angiography with digital subtraction was performed on all patients with encased ICA by tumor in the MRI.

The data of the enrolled patients were prospectively collected: clinical data such as sex, age, the presenting symptoms, pre- and postoperative ophthalmological assessments, immediate and permanent postoperative complications, and follow-up duration.

Preoperative contrasted MRI data included tumor site, size according to its maximal diameter in 3-dimensional contrasted T1-weighted imaging (cut of size 40 mm), tumor intensity (iso, hypo, or hyperintense), and peritumoral edema (< 5 mm or > 5 mm) in the T2-weighted imaging. CT scan findings including tumor calcifications, hypertrophy of the ACP, ACP variations, and pneumatization were also collected.

The relation of the tumor to the ICA was divided into four groups as previously described in the literature [12] (G1, displaced ICA; G2, encased not narrowed; G3, encased and narrowed; G4, extended contralateral or into the basilar arterial system) according to the MRI findings, DSA, and intraoperative confirmation. Tumor types were classified according to Al-Mefty's classification, CS invasion, and optic canal involvement were reported according to the intraoperative finding.

The extent of tumor resection was classified according to Simpson's grading system, based on the operative data and postoperative imaging within 3 months after surgery; grade I or II resection was defined as gross total resection and grade III was defined as subtotal resection, while grade IV was partial resection. Tumor histopathological grading was classified according to the WHO classification system.

Postoperative new neurological deficit or aggravation of the presenting symptoms was considered immediate complications; complications extended beyond 6 months during follow-up were considered permanent. The appearance of new enhanced lesions after GTR or regrowth of tumor after subtotal or partial resection in the follow-up MRI with enhancement was considered as tumor recurrence.

In our study, we aim to evaluate the role of extradural anterior clinoidectomy which was performed routinely in all our patients; FTOZ was performed except in small-sized lesions in which extended pterional craniotomy was used (6 patients). Extradural bone drilling was done using the egg-shell technique from the posterior orbital roof, sphenoid ridge, and lesser wing of the sphenoid bone till reaching the base of the ACP. Unlocking the superior orbital fissure and cutting the meningo-orbital band allowed better exposure to the anterolateral skull base and the lateral wall of the cavernous sinus.

Unroofing the optic canal, extradural anterior clinoidectomy, and opening of the falciform ligament were done using high-speed diamond-burr micro-drill; intradural drilling to the ACP was continued in cases presented with interclinoidal osseous bridges. Whenever possible, gross total resection was performed, careful dissection of the tumor from the neurovascular structures, and tumor extension into the optic canal was also removed as shown in Fig. 1. Tumor adherence to the lateral wall of the cavernous sinus was carefully pealed and removed. No aim to remove the intracavernous tumor extension to avoid major added morbidity. Closure was

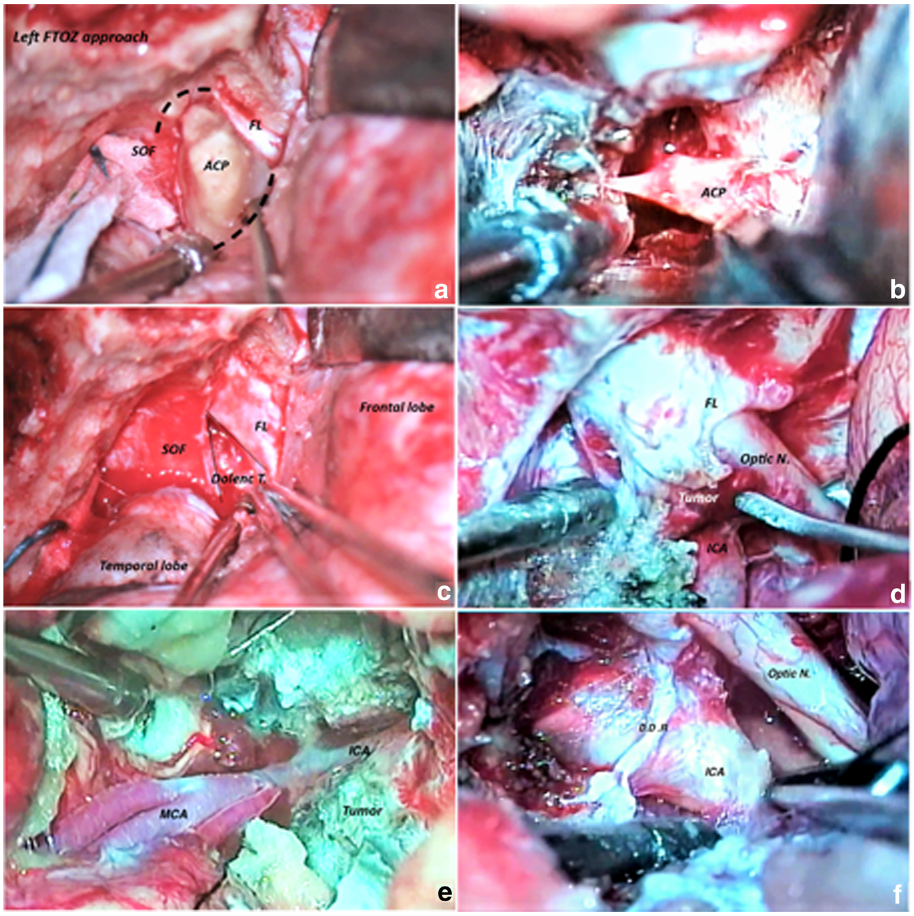

Fig. 1 **a**–**f** Sequential intraoperative view of the left ACM resection through a left FTOZ approach. **a** Extradural bone drilling of the sphenoid ridge, the posterior orbital roof, and the optic canal roof exposing the ACP between the superior orbital fissure (*SOF*) and the falciform ligament (*FL*) covering the optic nerve. **b** Removal of the ACP tip (shark tooth). **c** The optic strut is drilled out exposing the Dolenc triangle (*Dolenc T.*). **d** The tumor was extending in the optic canal beyond the falciform ligament; optic nerve decompression was done by releasing the falciform ligament and tumor debulking with care not to compromise any vascular supply to the undersurface of the optic nerve. **e**, **f** Encasement of the internal carotid artery (*ICA*) and middle cerebral artery (*MCA*) by the tumor, careful dissection of the tumor aided by mobilization of the ICA through releasing the distal dural ring (*DDR*)

done using a large vascularized pericranium flap, abdominal fat graft, and sometimes tensor fascial lata graft. Intraoperative lumber drain was not routinely used. Postoperative helical CT bone window scan was performed to visualize the extent of bone drilling as shown in Fig. 2.

All our patients were followed clinically and radiologically by contrasted MRI at interval 3 to 6 months postoperative and yearly after surgery. The follow-up period ranged from 6 to 48 months with a mean duration of 27 ± 13 months.

IBM SPSS statistics (V. 26.0, IBM Corp., USA, 2019) was used for data analysis. Comparison between two paired groups with quantitative data and parametric distribution was done using Paired t-test. Chi-square test was used to study the association between every 2 qualitative variables. The confidence interval was set to 95% and the probability of error at 0.05 was considered significant, while at 0.01 and 0.001 are highly significant.

Results

Our clinical study included 33 consecutive patients with ACMs; there were 5 males (15.2%) and 28 females (84.8%) with a male to female ratio of ≈ 1:6. The age range was 34–72 years with mean age of 49.48 ± 11.41 years. Preoperative visual deficit was the most common presenting symptom, found in 30 patients (90.9%); headache was present in 24 patients (72.7%). Three patients (9.1%) had preoperative oculomotor nerve palsy. A summary of the clinical data is shown in Table 1.

According to Al-Mefty's classification, type I group had 14 patients (42.4%), and 17 patients were included in type II group (51.5%), while type III had only 2

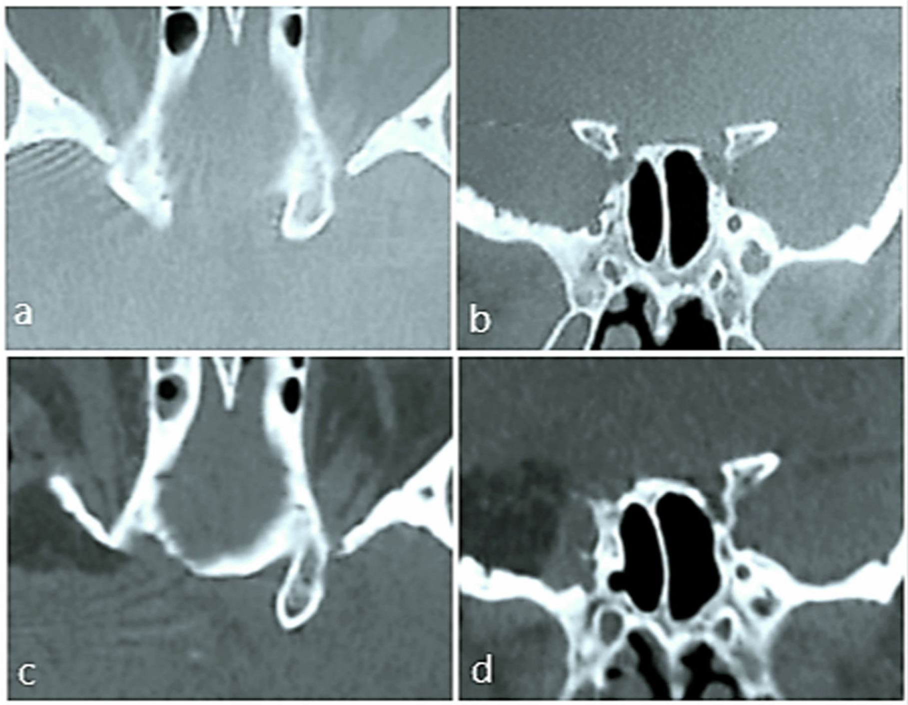

Fig. 2 a–d Preoperative and postoperative helical bone window CT scan after right extradural anterior clinoidectomy for ACM patient. **a**, **b** Preoperative axial and coronal view, respectively. **c**, **d** Postoperative axial and coronal view showing the extent of bone drilling involving the right ACP, the optic canal roof, and the optic strut

patients (6.1%). Its size ranged from 1.8 to 7.6 cm with a mean of 4.1 cm. On T2-weighted MRI, 14 patients (42.4%) showed tumor hypo-intensity, while significant peritumoral edema (> 5 mm thickness) was found in 20 patients (60.6%). On CT scans, tumor calcification was found in 14 patients (42.4%). Hyperostosis of the ACP was observed in 19 patients (57.6%). The ICA was encased by the tumor in 16 patients (48.5%). CS invasion was observed in 8 cases (24.2%). Incidental CCF was shown in 2 cases (6.1%) and IOB in another 3 cases (9.1%), ACP pneumatization was noticed in 5 patients (15.2%) as shown in Table 2.

FTOZ was performed in most cases (27/33), while an extended pterional approach was used in patients with small-sized lesions. Tumor extension beyond the falciform ligament (OCI) was observed in 24 patients (72.7%). Tumor characteristics, CS invasion, ICA encasement, and bony hyperostosis were confirmed intraoperatively. Intraoperative vascular complications were encountered in 6 patients (18.2%) due to excessive tumor adhesion to the ICA and its major branches. Intraoperative vascular spasm occurred in 3 patients and treated with topical application of vasodilator agents (papaverine soaked cottonoid); postoperative nimodipine infusion was used in patients with ischemic insult. Unfortunately, incidental vascular injury occurred in another 3 patients (ICA, MCA, and ACA were injured in each case, respectively). The first 2 cases passed away in the first postoperative week due to extensive postoperative cerebral edema and ischemic insult. Clinoidal ICA aneurysm was incidentally found intraoperative in one patient and was managed intraoperatively by clipping.

Among 30 patients with a preoperative visual deficit, visual acuity was improved in 21 patients (70%), while 6 patients (20%) had a stationary course and 1 patient suffered postoperative new visual deterioration (3%); however, no patient with an intact vision developed visual deficit after surgery. Among 4 patients who presented with poor vision (hand motion), 3 of them improved after surgery. The visual outcome was analyzed; the difference between pre- and postoperative visual status was highly significant (*P*-value < 0.001). OCI was strongly correlated to the preoperative visual impairment; this correlation was highly significant (*P*-value = 0.001). Preoperative oculomotor nerve palsy was strongly correlated to the tumor invasion into the CS, this relation was also highly significant (*P*-value = 0.001). Two out of 3 patients with preoperative oculomotor palsy improved after surgery.

GTR (Simpson grade I and II) was successfully achieved in 24 patients (72.7%), whereas subtotal

Table 1 Demographic and clinical data of 33 patients with ACMs

Patients characteristics	No. of patients	Percent
Age (years)		
Mean (range)	49.48 ± 11.41 (34–72) years	
Sex		
Male	5	(15.2%)
Female	28	(84.8%)
Presenting symptoms		
Visual impairment	30	(90.9%)
Headache	24	(72.7%)
Seizures	9	(27.3%)
Limb weakness	2	(6.1%)
Diplopia	3	(9.1%)
Proptosis	6	(18.2%)
Retroorbital pain	6	(18.2%)
Ptosis	3	(9.1%)
Eye redness	3	(9.1%)
Facial numbness	2	(6.1%)
Anosmia	1	(3.0%)
Ophthalmological assessment		
Visual acuity testing	30/33	(90.9%)
Log MAR (mean ± SD) (range)	1.15 ± 0.53 (0.2–2.0)	
Intact vision	3	(9.1%)
Mild impairment (≤ 1 Log MAR)	14	(42.4%)
Severe impairment (> 1– 2 Log MAR, HM)	16	(48.5%)
Visual field defects	26	(78.8%)
Intact	7	(21.2%)
Enlarged central scotoma	7	(21.2%)
Nasal field defect	2	(6.1%)
Temporal field defect	1	(3.0%)
Tubal field	12	(36.4%)
Dark field (HM)	4	(12.1%)
Ocular motility		
Oculomotor nerve palsy	3	(9.1%)

Patients had more than one symptom at clinical presentation
ACMs Anterior clinoidal meningiomas

resection (Simpson grade III) and partial resection were confirmed in 6 (18.2%) and 3 (9.1%) respectively. Extensive encasement and adhesion by the tumor to the neurovascular structures and cavernous sinus invasion were the main determinants of incomplete resection. GTR was achieved in 22/25 patients (88%) with no CS invasion. On the other hand, only 2/8 patients (25%) with CS invasion achieved GTR, with a highly significant difference (P-value = 0.002). As would be expected, there was a strong correlation between ICA encasement and the extent of resection. Eight out of nine patients (88.8%) with incomplete resection had ICA encasement (P-value = 0.011). Tumor size and peritumoral edema were not statistically significant factors affecting the extent of resection (P-value> 0.05).

Immediate postoperative complications occurred in 15/33 (45.5%) of our patients, most of them improved in 3 to 6 months postoperative, and only 6 patients had permanent complications (18.2%) as shown in Table 3. The most common immediate complications were oculomotor nerve palsy and CSF rhinorrhea which happened in 4 patients each (12.1%). Postoperative oculomotor nerve palsy was significantly correlated to CS invasion by using chi-square test (P-value = 0.012).

Table 2 Radiographic and surgical tumor characteristics of 33 patients

ACMs characteristics	No. of patients	Percentage
Al-Mefty's classification		
Type I	14	(42.4%)
Type II	17	(51.5%)
Type III	2	(6.1%)
Site (Rt/Lt)	11/22	33.3%/66.6%
Size		
Mean (range)	4.1 (1.8–7.6)	
< 4 cm	16	(48.5%)
> 4 cm	17	(51.5%)
T2-MRI tumor intensity		
Hypointense	14	(42.4%)
Isointense	7	(21.2%)
Hyperintense	12	(36.4%)
Peritumoral edema	20	(60.6 %)
Tumor calcifications	14	(42.4%)
Central or peripheral	7	(21.2%)
Marked	7	(21.2%)
ACP-Hypertrophy	19	(57.6%)
OCI	24	(72.7%)
CS invasion	8	(24.2%)
ICA relation		
Group A	17	(51.5%)
Group B	9	(27.3%)
Group C	6	(18.2%)
Group D	1	(3.0%)

ACMs anterior clinoidal meningiomas, *Rt* right, *Lt* left

Lumber drain was inserted in 1/4 patients with postoperative CSF rhinorrhea for 5 days; the others 3 resolved spontaneously within 3 days. Contralateral hemiparesis occurred in 3 patients (9.1%) due to operation-related ischemia, abducent nerve palsy was documented in 1 patient (3%), postoperative deterioration of conscious level occurred in 3 patients (9.1%), one of them developed secondary hydrocephalus and a ventriculoperitoneal shunt was inserted, this patient improved, and afterwards, the other 2 cases developed massive cerebral edema and ischemia due to intraoperative vascular injury and passed away resulting in a mortality rate of (6.1%). The most common long-term complication was oculomotor palsy 2/33 (6.1%). One patient who developed abducent palsy did not show improvement after 6 months. Despite intensive postoperative physiotherapy, one patient suffered residual hemiparesis. Enophthalmos was noticed in one patient who refused further management.

Most of the patient's histopathology was benign (WHO grade I, 97%), the most common histopathology was the meningothelial type 14/33 (42.4%), and MIB-1 labeling index was less than 5%. Atypical meningioma (WHO grade II) was diagnosed in 1 patient (3%) with MIB-1 labeling index of 9%. The recurrence rate was 9.1% (3 patients), recurrence occurred in 1 out of 24 cases with GTR (4.2%), and regrowth was observed in 2 of 9 cases (22.2%). Stereotactic radiosurgery (Gamma Knife) was introduced in the management of 7 patients with residual or recurrent lesions. Tumor control was achieved in those patients within 2 years after receiving SRS-GK.

Case 1

A 39-year-old lady presented with right visual impairment associated with diplopia because of preoperative oculomotor palsy. The preoperative vision was counting

Table 3 Immediate and permanent postoperative complications

Postoperative complications	Immediate	Percent	Permanent	Percent
Oculomotor nerve palsy	4	(12.2%)	2	(6.1%)
CSF rhinorrhea	4	(12.2%)	0	0
Altered consciousness	3	(9.1%)	0	0
Hemiparesis	3	(9.1%)	1	(3.0%)
Expressive dysphasia	2	(6.1%)	0	0
Abducent nerve palsy	1	(3.0%)	1	(3.0%)
Wound infection	1	(3.0%)	0	0
Hydrocephalus	1	(3.0%)	1	(3.0%)
Enophthalmos	1	(3.0%)	1	(3.0%)
Mortality	2	(6.1%)	2	(6.1%)

Some patients developed more than one postoperative complication
CSF cerebrospinal fluid

fingers at 3 m, she had tubal field by visual field perimetry, MRI brain with enhancement was done, and she was diagnosed with a right-sided anterior clinoidal meningioma (Fig. 3). The tumor encased the ICA and its major branches extending beyond the distal dural ring; true invasion of the cavernous sinus was observed. The optic canal was also involved. FTOZ and extradural anterior clinoidectomy were performed; tumor was invading the optic canal. Near-total resection was achieved except for a small adherent part at the level of the distal dural ring. Visual acuity was improved in the subsequent follow-up to 6/48 (0.9 Log MAR). The patient had an uneventful postoperative course. After 6 months, she was advised upfront SRS-GK for tumor control. No regrowth was observed till the last follow-up after 43 months of surgery.

Case 2

A 44-year-old lady presented with bilateral visual impairment for six months associated with persistent headache, retroorbital pain, and proptosis. She underwent an MRI brain with contrast and was diagnosed with a left-sided anterior clinoidal meningioma (Fig. 4). The tumor invaded the optic canal displaced the ICA and its bifurcation medially. Significant tumor calcifications, peritumoral edema, and midline shift were observed. FTOZ and extradural anterior clinoidectomy were performed, tumor was invading the optic canal. Gross total resection was achieved; visual acuity was improved from hand motion to counting fingers at a maximum distance of 2 m in the subsequent follow-up. The patient had an uneventful postoperative course till the last follow up after 22 months of surgery.

Discussion

Surgical resection of clinoidal meningiomas is still challenging, despite the recent advances in skull base surgery, microsurgical techniques, and neuroimaging [13, 14]. This is due to its close relationship to vital neurovascular structure such as the anterior optic apparatus, the adhesion to the internal carotid artery with its major branches, and its tendency to invade the cavernous sinus with the traversing cranial nerves [15].

Various surgical approaches were advocated in the management of clinoidal meningiomas; the optimum surgical approach to improve the visual outcome and the extent of resection is still debatable. Many studies reported the use of the extradural cranial base technique through pterional approach or FTOZ and anterior clinoidectomy [2, 11, 13, 16–21]. Pterional approach with intradural anterior clinoidectomy [4, 22–25], lateral supraorbital approach [25–27], and lateral sub-frontal approach [13] were also performed in many studies. In our series, the extradural cranial base approach was performed in all patients; our purpose is to localize and decompress the optic nerve before tumor removal, avoiding excessive manipulation on the optic nerve during tumor debulking. This approach facilitates the exposure and mobilization of the clinoidal ICA and lessens the risk of vascular injury during the operation. The extradural bone drilling allows extensive tumor devascularization; provides more access to the optic canal, cavernous sinus, sub and suprachiasmatic areas; and thus facilitates aggressive tumor resection.

According to a systematic review published in 2019 by L. Giammattei and colleagues, the visual impairment was the most common presentation reported in previous

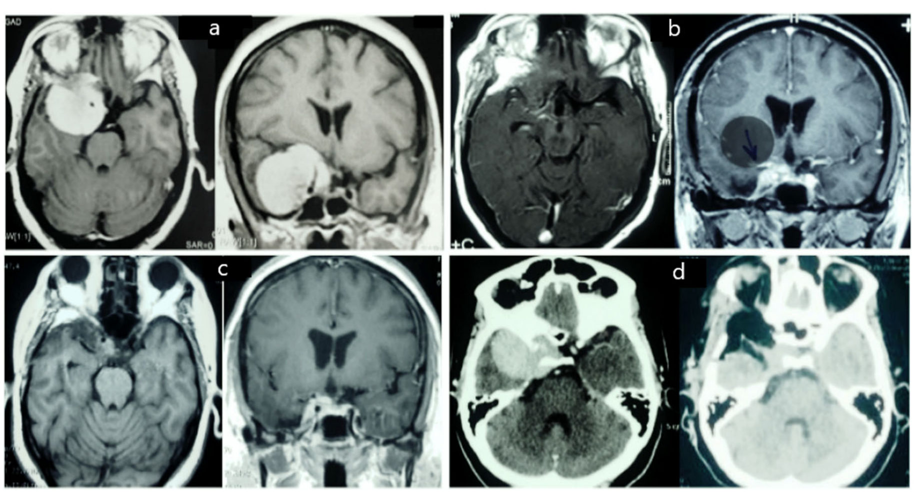

Fig. 3 a–**d** Preoperative and postoperative imaging of case 1 with right ACM (type I). **a** MRI brain with enhancement axial and coronal view showing right ICA encasement and CS invasion by the tumor. **b** Postoperative MRI with enhancement showed the extent of tumor resection. **c** Last follow-up MRI with enhancement after SRS-GK, tumor control with no regrowth was achieved. **d** Immediate postoperative CT scan showing the right anterior clinoid was removed

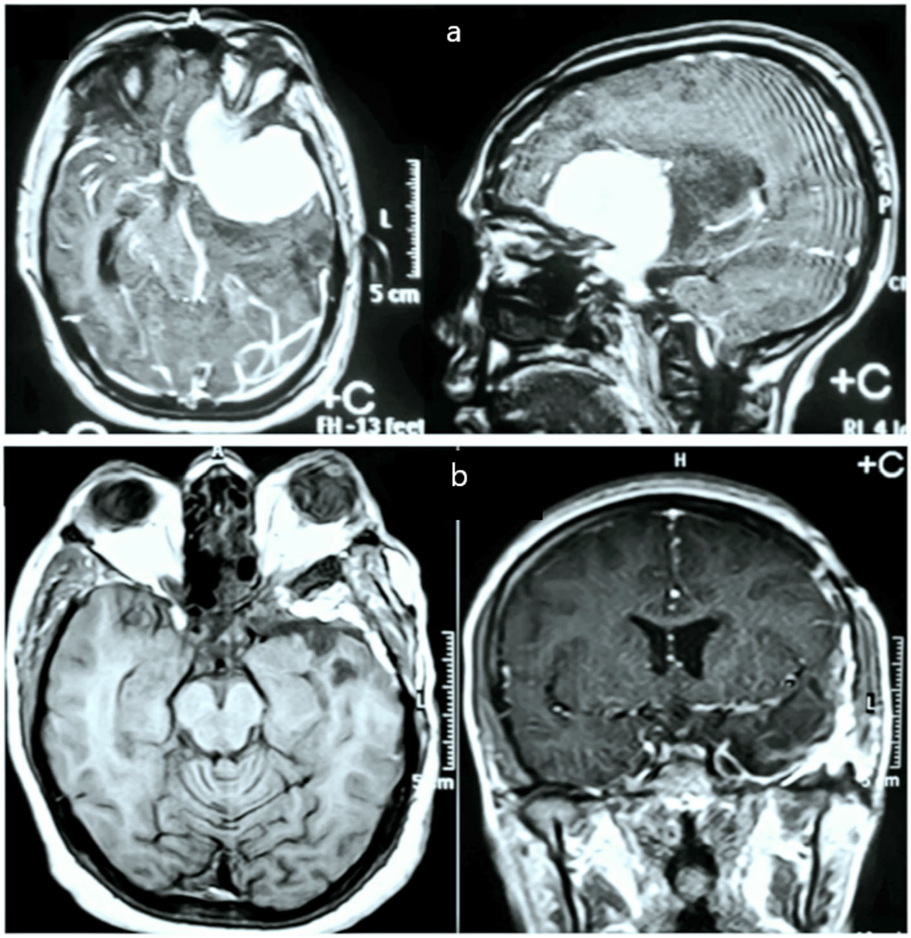

Fig. 4 a, **b** Preoperative and postoperative imaging of case 2 with left ACM (type II). **a** Preoperative MRI with enhancement axial and sagittal view showing the displacement of the ICA bifurcation. **b** Postoperative MRI T1-weighted non-enhanced axial view and T1-weighted coronal view after contrast showing gross total resection and a hyperintense signal at the temporal pole explained by the fat and fascia lata graft used for the dura and the skull base repair

studies (61.4% of patients), while the postoperative visual improvement was less satisfactory when compared to other anterior skull base lesions (48% of patients). The overall gross total resection rate was found in 64.2% of cases (95% CI, 57.3–71%) and the overall recurrence rate was 8.9% (95% CI, 6–11.8%), while the overall mortality rate was observed in 1.2% of pooled cases (95% CI, 0.6–1.8%) [20].

The incidence of visual impairment in patients with clinoidal meningiomas is variably high. Since its close relation to the inferolateral aspect of the optic nerve, ACMs interfere with the main vascular supply to the optic apparatus which make vascular preservation during surgery quite difficult [28]. Besides, ACMs tend to invade the optic canal. Long-standing mechanical compression, ischemia, and demyelination subsequently lead to optic nerve injury [29]. The visual outcome had been related to multiple factors including the preoperative visual status, duration of symptoms, tumor size, adherence to major vessels, optic canal invasion, and ACP hypertrophy [4, 11].

In our study, visual improvement was reported in 70% of our patients. In previously published case series in which extradural anterior clinoidectomy was used [2, 11, 13, 16–21, 29–31], visual improvement ranged from 10 to 77% as shown in Table 4. Preoperative visual status is an important prognostic factor affecting the visual outcome [4, 34]; Verma and colleagues reported a 20.7% improvement in visual outcome; however, this study had a higher percentage of patients with long-lasting severe visual deficit (32%) or patients who were already blind (15%) with a mean duration 21.5 months [19]. The lack of recent microscopic and technical advances in earlier studies reported by Al-Mefty and Risi and colleagues might be the reason behind the lower visual outcome reported [2, 31].

Pamir and colleagues reported a higher percentage of improved visual outcome (84.6%) without the need for

Table 4 Recent studies of outcome of patients surgically treated for ACMs using the EAC approach and tumor characteristics

Author (year)	Cases No.	Preop visual deficit (%)	EAC (%)	Al-Mefty's types I/II/III	Tumor size max diameter mean (cm)	OCI (%)	CSI (%)	ICA encasement (%)	Postop. visual improv. (%)	GTR (%)	Recurrence (%)	Mortality rate (%)
Al-Mefty 1990 [2]	24	20 (84)	24 (100)	03/19/02	NR	NR	9 (37.5)	14(58.3)	2 (10)	20(83)	2 (8.3)	1 (4.2)
Risi et al. 1994 [31]	34	20 (58.8)	34 (100)	NR	NR	NR	15 (44.1)	NR	6(31.6)	20(58.9)	4(11.7)	2(5.8)
Lee et al. 2001 [16]	15	8 (53.3)	13 (86.7)	NR	3.42	5 (33.3)	2 (13.3)	NR	6(75)	13(86.7)	0	0
Tobias et al. 2003 [29]	26	14 (53.8)	24 (92.3)	03/19/02	3.7	NR	6 (23)	NR	10(71.4)	20(77)	0	0
Cui et al. 2007 [30]	26	22 (84.6)	26 (100)	04/22/00	3.5	NR	4 (17.4)	NR	16 (72.7)	16(61.5)	0	0
Sade and Lee 2008 [11]	52	24 (46)	47 (90.4)	NR	3.4	19 (36)	NR	NR	17 (77)	37(71.2)	0	1(1.9)
Attia et al. 2012 [17]	22	19 (86.4)	19 (86.3)	NR	5.9	17 (77.3)	13 (59.1)	20(90)	12 (66.7)	7(31.8)	3 (13.6)	0
Czernicki et al. 2015 [18]	30	18 (60)	30 (100)	06/20/04	3.73	NR	6 (20)	5(16.6)	6 (33.3)	19(63.3)	4/25(16)	2(6.7)
Verma et al. 2016 [19]	78	58 (74.3)	78 (100)	NR	4.4	NR	21 (26.9)	43(55.1)	12(20.7)	52(66.7)	16 (20.5)	2(2.6)
Kim et al. 2017 [13]	59	17 (28.8)	59 (100)	NR	4	2 (3.4)	8 (13.6)	45(76.3)	NR	38(64.4)	11 (18.6)	0
Alam et al. 2018 [21]	10	10 (100)	10 (100)	NR	5.1	NR	NR	NR	7 (70)	5(50)	1 (10)	0
Giammattei et al. 2019 [20]	18	12 (66.6)	18 (100)	06/10/02	2.7	8 (44.4)	6(33.3)	9 (50)	5 (41.6)	12(67)	0	0
Current study 2021	33	30 (90.9)	33 (100)	14/17/02	4.1	24 (72.7)	8 (24.2)	16 (48.5)	21 (70)	24(72.7)	3 (9.1)	2 (6.1)

Mariniello and colleagues in 2013 [32] and Liu and colleagues in 2012 [33] reported visual improvement in 56.7% and 56.8%, respectively, while GTR was reported in 84.8% and 81.8%, respectively. However, extradural anterior clinoidectomy was not performed in most of their included patients

ACMs anterior clinoidal meningiomas, *CSI* cavernous sinus invasion, *EAC* extradural anterior clinoidectomy, *GTR* gross total resection, *ICA* internal carotid artery, *Improv* improvement, *Max* maximum, *NR* not recorded, *OCI* optic canal invasion, *Postop* postoperative, *Preop* preoperative

extradural anterior clinoidectomy; their study population composed mainly of type II ACMs (88.4%) and the rate of OCI was not reported; however, they performed intradural anterior clinoidectomy and opening of the optic canal in 40/43 patients (93%). They reported a limitation with their approach that it did not allow exploration of the cavernous sinus in case there is CS invasion by the tumor [4]. In literature, other studies reported the use of standard pterional approach [14, 22–25, 27] and lateral supraorbital approach [25–27] with intradural anterior clinoidectomy when needed for the surgical management of ACMs. They reported visual improvement ranged from 15.4 to 73% with 5 out of 7 studies had visual outcome below 50%.

There is a potential risk of optic nerve injury when performing EAC due to the additional pressure and stretch on the optic nerve as the dura and the tumor must be retracted extradural during the procedure [4]. Some investigators stated that EAC does not increase the risk of damage to the optic nerve [20]; a previous case series by Mariniello and colleagues reported a significantly lower rate of postoperative visual deterioration when the extradural skull base approach was routinely used [32]. In our series, we did not use fixed brain retractors during EAC to avoid excessive pressure on the optic nerve; continuous irrigation was used to avoid heat injury during the stage of extradural drilling. Despite that, EAC offers us a wider operative field to access the inter-optic, optic-carotid, and carotid-oculomotor spaces and reduce the possibility of injury to these structures.

The relation of the tumor to the ICA and the cavernous sinus invasion are the critical points in achieving GTR [19, 25]. In our study, the rate of GTR was 72.7%, which was found to be 42.9% in type I ACMs and 94.1% in type II ACMs; this difference was statistically significant (*P* value = 0.002). In the previous studies listed in Table 4, the GTR rate ranged from 31.8 to 86.7%. In a series published by Attia and colleagues, the rate of GTR was 31.8%; the reason behind that was the larger tumor size (mean 5.9 cm) with a higher percentage of ICA encasement (90%), and a higher rate of CS invasion (59.1%) [17].

The morbidity and mortality rates of patients with ACMs remain high in comparison to another skull base meningiomas. The strategy of achieving gross total resection, if technically possible, had been changed in the recent decade primarily due to the wide use of stereotactic radiosurgery to cases with residual tumor in the cavernous sinus, to limit morbidity and mortality as much as possible [35, 36]. In our series, intracavernous tumor invasion carried high risk of intraoperative blood loss and postoperative neurological deficit. Postoperative oculomotor palsy was found to be directly related to the tumor invasion into the cavernous sinus. Residual intracavernous portion of the tumor was left for further postoperative follow-up and intervention using SRS to achieve tumor control.

Encasement and adherence of the tumor to the ICA adventitia was a critical point in operation related vascular injury. Intraoperative vasospasm was observed during tumor dissection around the ICA and its major branches; intraoperative topical application of vasodilator agents and postoperative nimodipine infusion was used to protect against postoperative ischemic neurological deficit. Early localization of the clinoidal ICA after extradural anterior clinoidectomy and the use of intraoperative Doppler allowed better visualization of the ICA and its major branches. Despite that vascular injury was encountered in 3 cases, such complication would increase operation-related morbidity and mortality. The use of intraoperative micro-Doppler [30] or intraoperative indocyanine green angiography [14] would help to limit this risk.

In clinoidal meningiomas, the higher rate of subtotal resection leads to an increased risk of tumor recurrence. Cavernous sinus invasion is one of the main factors limiting total resection, while aggressive surgical management of meningiomas involving predominantly the cavernous sinus had an increased risk of cranial nerve deficit and mortality [37]. The recent advances in radiosurgery offered excellent results in tumor control rate in patients with subtotal resection; however, it carries some risk of visual affection due to radiation-induced optic neuropathy [38]. In our series, Gamma Knife offered good tumor control for 7 patients (21.2%), with no increase in tumor size within 2 years after SRS-GK.

Conclusions

The use of the skull base technique with extradural anterior clinoidectomy allowed early exposure and decompression of the optic nerve, facilitates resection of the tumor extending into the optic canal with preservation of the pial supply of the optic nerve at its inferior aspect. Without optic nerve decompression first, indirect manipulation of the tumor within the canal can add more trauma to the optic nerve or interfere with its pial blood supply. ICA encasement and CS invasion were the main factors correlated to the extent of resection. The use of the skull base approach allowed early identification of the ICA and allowed greater access to the cavernous sinus and thus enhances the extent of tumor resection. Stereotactic radiosurgery was a favorable option in residual and recurrent cases.

Study limitations

This is a prospective observational case series representing one institution experience in the surgical management of clinoidal meningiomas; there is no control group to analyze and compare variable outcomes of different surgical approaches. The mean follow-up period was relatively short to detect recurrence-free survival rate in patients with clinoidal meningioma.

Abbreviations

ACP: Anterior clinoid process; ACA: Anterior cerebral artery; CCF: Carotico-clinoid foramen; CS: Cavernous sinus; CT: Computed tomography; DDR: Distal dural ring; EAC: Extradural anterior clinoidectomy; FL: Falciform ligament; FTOZ: Fronto-temporal craniotomy with orbito-zygomatic osteotomy; GK: Gamma Knife; GTR: Gross total resection; HM: Hand motion; ICA: Internal carotid artery; IOB: Interclinoidal osseous bridges; MCA: Middle cerebral artery; MRI: Magnetic resonance imaging; OCI: Optic canal involvement; SOF: Superior orbital fissure; SRS: Stereotactic radiosurgery; WHO: World Health Organization

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Authors' contributions

AI: conceptualization, data curation, formal analysis, project administration, software, writing—original draft. *IA:* data curation, investigation, supervision. *HS:* validation, visualization, writing—review and editing. *KB:* methodology, intervention, supervision, resources, final review and editing. All authors have read and approved the final manuscript.

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Availability of data and materials

All the forementioned data and results of the statistical analysis are available with the authors and ready to be shared with approved personnel upon request.

Declarations

Ethics approval and consent to participate

All patients were informed about the benefits and the risks of the intended procedure; an informed written consent was signed at least 24 h before the operation. The study was conducted with the approval of the Research Ethics Committee, Faculty of Medicine, Ain-Shams University (FMASU REC). Institutional Review Board No. is FWA 000017585.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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