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ORIGINAL ARTICLE - TUMOR - MENINGIOMA

A single centre's experience of managing spheno-orbital meningiomas: lessons for recurrent tumour surgery

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Abstract

Background Spheno-orbital meningiomas are complex tumours involving the sphenoid wing and orbit. Various surgical strategies are available but treatment remains challenging and patients often require more than one surgical procedure. This study evaluated whether smaller surgical approaches and newer reconstructive methods impacted the surgical and clinical outcomes of patients undergoing repeat surgery.

Methods We retrospectively analysed the medical records of consecutive patients who underwent surgery for a spheno-orbital meningioma at a single tertiary centre between 2005 and 2016. We recorded procedural details and analysed complications, postoperative visual status and patient-reported cosmetic outcome.

Results Thirty-four procedures were performed in 31 patients (M:F 12:22, median age 49 years) including 19 (56%) primary operations and 15 (44%) repeat procedures. Seven patients (20.5%) had a pterional craniotomy, 19 (56%) had a standard orbitozygomatic craniotomy and 8 (23.5%) underwent a modified mini-orbitozygomatic craniotomy. Calvarial reconstruction was required in 19 cases with a variety of techniques used including titanium mesh (63%), PEEK (26%) and split calvarial bone graft (5%). Total tumour resection (Simpson grade I–II) was significantly higher in patients undergoing primary surgery compared with those having repeat surgery (41% and 0%, respectively; $p = 0.0036$). Complications occurred in 14 cases (41%). Proptosis improved in all patients and visual acuity improved or remained stable in 93% of patients. Cosmetic outcome measures were obtained for 18 patients (1 = very poor; 5 = excellent): 1–2, 0%; 3, 33%; 4, 28%; 5, 39%. Tumour recurrence requiring further surgery occurred in four patients (12%). There was no significant difference in clinical outcomes between patients undergoing primary or repeat surgery.

Conclusion Spheno-orbital meningiomas are highly complex tumours. Surgical approaches should be tailored to the patient but good clinical and cosmetic outcomes may be achieved with a smaller craniotomy and custom-made implants, irrespective of whether the operation is the patient's first procedure.

Keywords Meningioma · Spheno-orbital meningioma · Orbitozygomatic craniotomy · Visual outcome · Cosmetic outcome

Introduction

Spheno-orbital meningiomas arise from the greater sphenoid wing with infiltrative tumour growth into the orbital bone. Reactive hyperostosis may also occur in the greater or lesser sphenoid wing, destroying the orbital wall and roof, implicating the middle cranial fossa, the optic canal and the clinoid process. As a result, patients typically present with visual symptoms and/or unilateral proptosis as a result of compression from the tumour or growth [1–4].

Due to the extensive tumour infiltration and bony destruction associated with these tumours, considerable drilling of the skull base is often required to accomplish entire resection of the tumour [5] and surgical reconstruction of the orbit may become

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necessary in order to protect the intracranial contents and re-establish an aesthetic craniofacial silhouette [6–8]. Different surgical and reconstructive strategies have been advocated for patients with spheno-orbital meningioma [9, 10] however there is a paucity of high-quality studies to guide decision-making in patients undergoing repeat surgery. Previous studies have often excluded recurrent tumours making it difficult to determine best practice in this difficult subgroup of patients, and this study aims to address this knowledge gap.

During the study's period, the surgical management of patients with spheno-orbital meningioma at our institution evolved in line with surgical trends. In this study, we assessed the surgical, visual and cosmetic outcomes of patients treated at a single tertiary neurosurgical centre over an 11-year period in order to determine the main factor whether smaller surgical approaches using newer reconstructive methods impacted the surgical and clinical outcomes of patients undergoing repeat surgery.

Methods

We retrospectively analysed the medical records of consecutive patients who underwent surgery for a spheno-orbital meningioma at King's College Hospital, London, between January 2005 and August 2016. All patients with a diagnosis of a medial sphenoid wing meningioma or spheno-orbital meningioma were identified from the hospital's operative database and cross-referenced with data from the hospital's clinical coding department and pathology database. Patients with a purely lateral sphenoid wing meningioma, not involving the orbital structures, were excluded from the study.

The following data were collected for each patient: demographic features, presenting symptoms, previous surgical and oncological treatments, preoperative radiological characteristics of the tumour (incorporation of major vessels and cavernous sinus involvement), WHO tumour grade, procedural details (including involvement of maxillofacial surgeons, incision type, craniotomy type, need for clinoidectomy, orbital reconstruction and/or eye exenteration, Simpson grade and type of cranioplasty [if applicable]), complications, subsequent oncological treatments, visual and cosmetic outcomes. Proptosis, visual acuity and diplopia were stratified as improved, unchanged or reduced. Cosmetic outcome was assessed by evaluating the patient's postoperative imaging and by collecting patient-reported outcome measures (PROM) via telephone follow up using a five-point visual analogue scale to assess their satisfaction with their postoperative appearance (1 = very poor, 2 = poor, 3 = neutral, 4 = good, 5 = excellent). Appropriate non-parametric statistical analyses (Fisher's exact test and Mann-Whitney *U* test) were performed using the GraphPad Prism software.

Results

Thirty-four procedures were performed in 31 patients during the study period (M:F 12:22, median age 49 years [interquartile range (IQR) 44–58 years]) with surgery having previously been undertaken in 15 cases (Table 1). Twenty-two patients (71.0%) presented with visual symptoms, 13 of whom had no other symptoms. Typical visual symptoms included loss of visual acuity, proptosis and diplopia. Other associated symptoms included seizures, headaches, trigeminal pain, confusion and incidental radiological growth. Radiological investigations demonstrated major arterial vessels either closely adhered to, or incorporated within, 13 tumours, and 9 tumours were associated with cavernous sinus involvement.

Twenty-four cases (70.6%) were performed jointly with the unit's oral maxillofacial surgeons (OMFS), including 11 primary cases (57.9%) and 13 recurrent procedures (86.7%). A pterional craniotomy was performed in 7 operations, a standard orbitozygomatic craniotomy (S-OZ) was performed in 19 cases and 8 patients underwent a modified mini-orbitozygomatic craniotomy (MM-OZ) (Table 2, Fig. 1). With the exception of one patient, all pterional craniotomies were performed using a standard unilateral curvilinear skin incision whereas 78.9% of patients who underwent a S-OZ craniotomy had a bicoronal skin incision, compared with 37.5% of patients undergoing a MM-OZ craniotomy. A traditional one-piece craniotomy was performed in all pterional cases, in 53% of S-OZ and 62.5% of MM-OZ cases. A clinoidectomy, orbital reconstruction and/or eye exenteration was only performed when using either the S-OZ or MM-OZ approach (Table 2). The following Simpson resection grades were achieved in patients undergoing primary surgery: grade I, 4 patients (21.1%); grade II, 4 patients (21.1%); grade III, 7 patients (36.8%); grade IV, 3 patients (15.8%); unknown, 1 patient (5.3%), whereas in patients having repeat surgery (n = 15), 14 patients (93.3%) had a Simpson grade III resection and 1 patient (6.7%) had a grade IV resection (Table 2). Total tumour resection (Simpson I–II) was significantly higher in patients undergoing primary surgery ($p = 0.0036$) but there was no statistical difference in the degree of achieved tumour resection in relation to the type of surgical approach (Table 3). Final histological analysis confirmed WHO I tumours in 23 cases with WHO II atypical meningiomas confirmed in the remaining 11 cases (Table 2).

No calvarial reconstruction was required following any pterional craniotomy. In S-OZ cases, a single split calvarial bone graft was used in one case (5.3%), titanium mesh was used for calvarial reconstruction in 10 cases (52.6%), and a customised PEEK cranioplasty implant used in 3 patients (15.8%). No cranioplasty was required in 5 patients (26.3%) who had a S-OZ craniotomy. In cases where a MM-OZ approach was used, 3 cases (37.5%) did not require cranioplasty, 2 patients (25%) had a titanium mesh cranioplasty, and 3

Table 1 Patient demographics, presenting symptoms and tumour features

Patient demographics	*n* (%)
Patients	31
Procedures	34
Previous surgery	15
Sex	M:F 12:22
Median age	49 years (IQR 44–58 years)
Symptoms	
Visual symptoms	22 (71.0)
Exclusively visual symptoms	13 (41.9)
Visual loss	13
Proptosis	13
Diplopia	6
Seizure	7 (34.0)
Headache	6 (19.4)
Trigeminal pain	3 (9.7)
Confusion/somnolence	3 (9.7)
Radiological growth (otherwise asymptomatic)	5 (16.1)
Radiological appearance	
Major arterial vessel adhered to, or incorporated within, the tumour	13 (41.9)
Cavernous sinus involvement	9 (29.0)

patients (37.5%) had a PEEK customised implant (Table 3). The first PEEK implant was used in 2014, following which it became the reconstructive method of choice constituting 86% of all implants used in the series in subsequent years (Fig. 2). The choice of calvarial reconstruction was not influenced by whether or not the patient had undergone previous surgery.

Surgical timings were available for 31 patients and were measured from the start of anaesthetic induction. The median length of surgery (including anaesthetic time) was 6 h, 45 min (IQR 5 h, 57 min; 7 h 40 min) and was significantly shorter in primary cases. The median duration of primary surgery was 6 h, 23 min (IQR 5 h, 38 min; 7 h, 7 min) compared with 7 h, 33 min (IQR 6 h, 29 min; 8 h, 4 min) when operating on recurrent tumours ($p = 0.0375$). There was also a trend towards shorter operations if no cranioplasty was required (median length of surgery, 6 h, 17 min [IQR 4 h, 56 min; 6 h, 35 min]) without the need for a cranioplasty compared with 6 h, 54 min (IQR 6 h, 18 min; 7 h, 46 min) with a cranioplasty

Table 2 Surgical and pathological details

	Primary surgery *n* = 19 (%)	Repeat surgery *n* = 15 (%)	Total *n* = 34 (%)
Surgical approach			
Pterional craniotomy	6 (31.6)	1 (6.7)	7 (20.6)
Standard orbitozygomatic craniotomy	8 (42.1)	11 (73.3)	19 (55.9)
Modified mini-orbitozygomatic craniotomy	5 (26.3)	3 (20.0)	8 (23.5)
Simpson resection grade			
I	4 (21.1)*	0*	4 (11.8)
II	4 (21.1)*	0*	4 (11.8)
III	7 (36.8)	14 (93.3)	21(61.8)
IV	3 (15.8)	1 (6.7)	4 (11.8)
Unknown	1 (5.3)	0	1 (2.9)
Histology			
WHO grade I	14 (73.7)	9 (60.0)	23 (67.6)
WHO grade II	5 (26.3)	6 (40.0)	11 (32.4)
WHO grade III	0	0	

*Significant difference in gross total resection (Simpson I–II) between primary and repeat surgery cases ($p = 0.0036$)

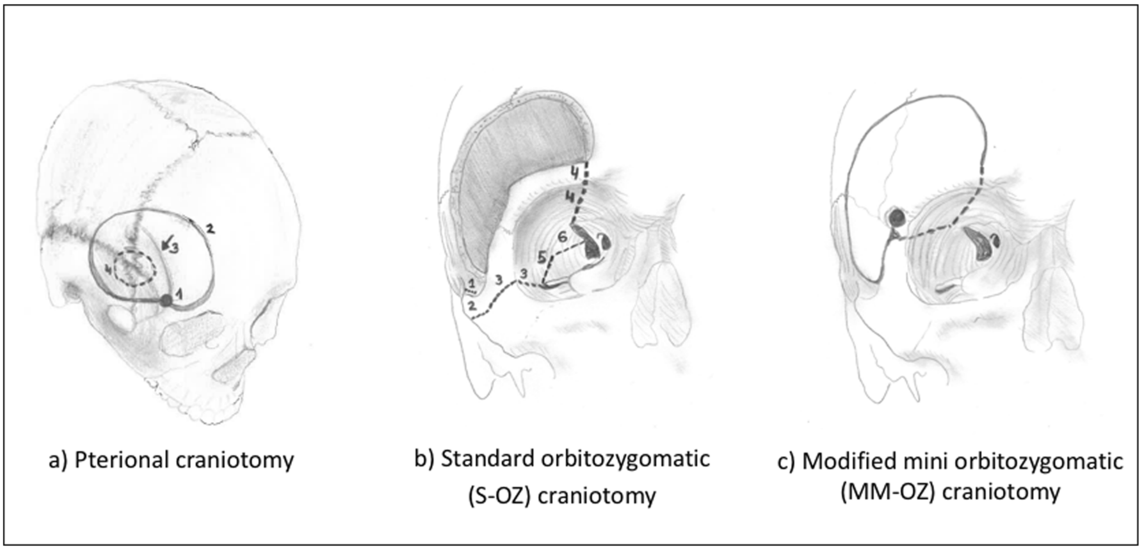

Fig. 1 Line drawings illustrating the three approaches used in this series. **a** Pterional craniotomy. Principal burr hole is placed at the anatomical keyhole (1), a depression at the junction of the superior orbital ridge, zygomatic bone and superior temporal line; (2) standard pterional craniotomy; (3) superior temporal line; (4, dashed line) the anatomical pterion defined as the junction of the frontal, parietal, temporal and sphenoid bones. **b** Standard orbitozygomatic (S-OZ) craniotomy. First, a standard pterional craniotomy (a) is performed. Following this, an orbitozygomatic osteotomy is performed sequentially as numbered: (i) base of the zygomatic arch (1) extending to the lateral (2) and medial (3) zygoma; (ii) from the orbital roof (4), lateral to supraorbital notch extending inferoposteriorly to the superior orbital fissure; (iii) a final osteotomy connecting the inferior and superior orbital fissures (5 and 6). **c** Modified mini-orbitozygomatic (MM-OZ) craniotomy. A burr hole is placed near the anatomical keyhole and a craniotomy is fashioned as illustrated, incorporating an orbital cut through the superolateral part of the orbit. As described by Lemole et al., this technique may be further modified to a supraorbital or subtemporal approach depending on the location of the meningioma

($p = 0.13$). The type of cranioplasty used did not significantly alter the length of surgery.

Overall, surgical complications occurred in 14 cases (41.2%) including one perioperative death (mortality rate of 3%) (Table 4). The single mortality occurred in a 61-year-old gentleman who underwent primary surgery. A Simpson III resection was achieved and his initial postoperative recovery was uncomplicated. He remained mildly confused postoperatively so was transferred back to his local hospital to continue his rehabilitation but suffered a fatal cardiac arrest 10 days after surgery. There was no significant difference in the complication rates between patients undergoing primary surgery and repeat surgery (47.4% and 33.3%, respectively; $p = 0.4953$) or between the different surgical approaches employed. In total, five patients (14.7%) suffered complications necessitating surgical intervention. Following cranioplasty, there were no documented cases of pulsatile enophthalmos but two patients developed visual deterioration and a new cranial nerve palsy (6%). Three patients developed a postoperative haematoma, including two cranioplasty cases, with one cranioplasty and one non-cranioplasty patient requiring the surgical evacuation of the haematoma.

Follow up data was available for 30 patients with a median length of follow up 52 months (range 1 to 120 months) (Table 5). Four patients (11.8%) underwent radiotherapy following their surgery and four patients (11.8%) required further surgical treatment. Postoperative visual outcomes were available in 28 patients (Table 5). Visual acuity improved in seven patients (54%) who presented with visual loss and remained unchanged in the other six patients. For those patients with postoperative follow up data, vision improved or remained unchanged in 92.9% and there was no significant difference in visual outcome between patients having primary or repeat surgery (Table 5). Three patients presenting with diplopia experienced an improvement in their symptoms (50%), and of the 13 patients with proptosis, seven (53.5%) had complete resolution of their symptoms and further 5 patients (38.5%) demonstrated an improvement in the degree of proptosis (outcome for one patient unknown). Two patients with normal visual acuity preoperatively deteriorated following the surgery and two other patients experienced new diplopia, although one patient had continued signs of improvement at the time of their last follow up. Patient-reported cosmetic outcomes were obtained in 18 patients. Good cosmetic results (score 3 to 5) were achieved in all cases with 66.7% of patients rating their postoperative cosmetic appearance as good (27.8%) or excellent (38.9%) (Table 5). Patient-reported cosmetic outcome scores were not higher in patients undergoing repeat surgery, and the type of cranioplasty used did not affect the outcome.

Table 3 Surgical details and clinical outcomes according to the surgical approach

	Pterional craniotomy $n = 7$			Standard orbitozygomatic craniotomy (S-OZ) $n = 19$			Modified mini-orbitozygomatic craniotomy (MM-OZ) $n = 8$		
	Primary surgery $n = 6$ (%)	Repeat surgery $n = 1$ (%)	Total $n = 7$ (%)	Primary surgery $n = 8$ (%)	Repeat surgery $n = 11$ (%)	Total $n = 19$ (%)	Primary surgery $n = 5$ (%)	Repeat surgery $n = 3$ (%)	Total $n = 8$ (%)
Surgical details									
Bicoronal incision	1 (16.7)	1 (100)	1 (14.3)	7 (87.5)	8 (72.7)	15 (78.9)	1 (20.0)	2 (66.7)	3 (37.5)
Craniotomy									
One-piece	6 (100)	1 (100)	7 (100)	5 (62.5)	5 (45.5)	10 (52.6)	4 (80.0)	1 (33,3)	5 (62.5)
Two-piece				3 (37.5)	6 (54.5)	9 (47.4)	1 (20.0)	2 (66.7)	3 (37.5)
Clinoidectomy				2 (25.0)	1 (9.1)	3 (15.8)			1 (12.5)
Orbital reconstruction				6 (75.0)	6 (54.5)	12 (63.2)	1 (20.0)	3 (100)	4 (50.0)
Eye exenteration					3 (27.3)	3 (15.8)			
Calvarial reconstruction									
None	6 (100)	1 (100)	7 (100)	1 (12.5)	3 (27.3)	5 (26.3)	3 (60.0)		3 (37.5)
Split calvarial					1 (9.1)	1 (5.3)			
Titanium mesh				5 (62.5)	5 (45.5)	10 (52.6)	1 (20.0)	1 (33.3)	2 (25.0)
PEEK				2 (25.0)	1 (9.1)	3 (15.8)	1 (20.0)	2 (66.7)	3 (37.5)
Simpson tumour resection grade									
I				1 (12.5)		1 (5.3)	3 (60.0)		3 (37.5)
II	1 (16.7)		1 (14.3)	2 (25.0)		2 (10.5)	1 (20.0)		1 (12.5)
III	2 (33.3)	1 (100)	3 (42.9)	4 (50.0)	10 (90.9)	14 (73.7)	1 (20.0)	3 (100)	4 (50.0)
IV	3 (50.0)		3 (42.9)		1 (9.1)	1 (5.3)			
Unknown				1 (12.5)		1 (5.3)			
Visual outcome (visual acuity)									
Improved				2 (25.0)	3 (27.3)	5 (26.3)	1 (20.0)	1 (33.3)	2 (25.0)
Unchanged	3 (50.0)		3 (42.9)	6 (75.0)	6 (54.5)	12 (63.2)	3 (60.0)	1 (33.3)	4 (50.0)
Reduced	1 (16.7)	1 (100)	2 (28.6)						
Unknown	2 (33.3)		2 (28.6)		2 (18.2)	2 (10.5)	1 (20.0)	1 (33.3)	2 (25.0)
Cosmetic outcome									
Very poor									
Poor									
Neutral	1 (16.7)		1 (14.3)	2 (25.0)	1 (9.1)	3 (15.8)		2 (66.7)	2 (25.0)
Good				2 (25.0)	1 (9.1)	3 (15.8)	1 (20.0)	1 (33.3)	2 (25.0)
Excellent	1 (16.7)		1 (14.3)	1 (12.5)	3 (27.3)	4 (21.1)	2 (40.0)		2 (25.0)
No outcome data	4 (66.7)	1 (100)	5 (71.4)	3 (37.5)	6 (54.5)	9 (47.4)	2 (40.0)		2 (25.0)

Discussion

Surgical approach and calvarial reconstruction

Spheno-orbital meningiomas are complex and challenging tumours that require careful preoperative planning and benefit from a multidisciplinary approach involving neurosurgeons, ophthalmologists, neuro-oncologists and oral and maxillofacial surgeons. The orbitozygomatic (OZ) craniotomy remains one of the most widely used and versatile approaches to the skull base [11], and is typically the chosen approach for spheno-orbital meningiomas. Compared with a pterional craniotomy, a standard orbitozygomatic craniotomy (S-OZ) increases exposure through the additional removal of the zygomatic arch and orbital rim [12, 13], and may be performed as a one-piece [14, 15] or two-piece craniotomy (Fig. 1) [16]. The perceived advantage of the two-piece technique is that it produces a better view of the frontal lobe's basal portions and it may reduce the risk of enophthalmos and cosmetic defects [17]. However, if complete resection of the zygoma is unlikely to significantly improve the exposure of the target tumour, a one-piece S-OZ may be successfully used to approach a spheno-orbital meningioma. During the course of this study, our approach to these tumours evolved and we now routinely

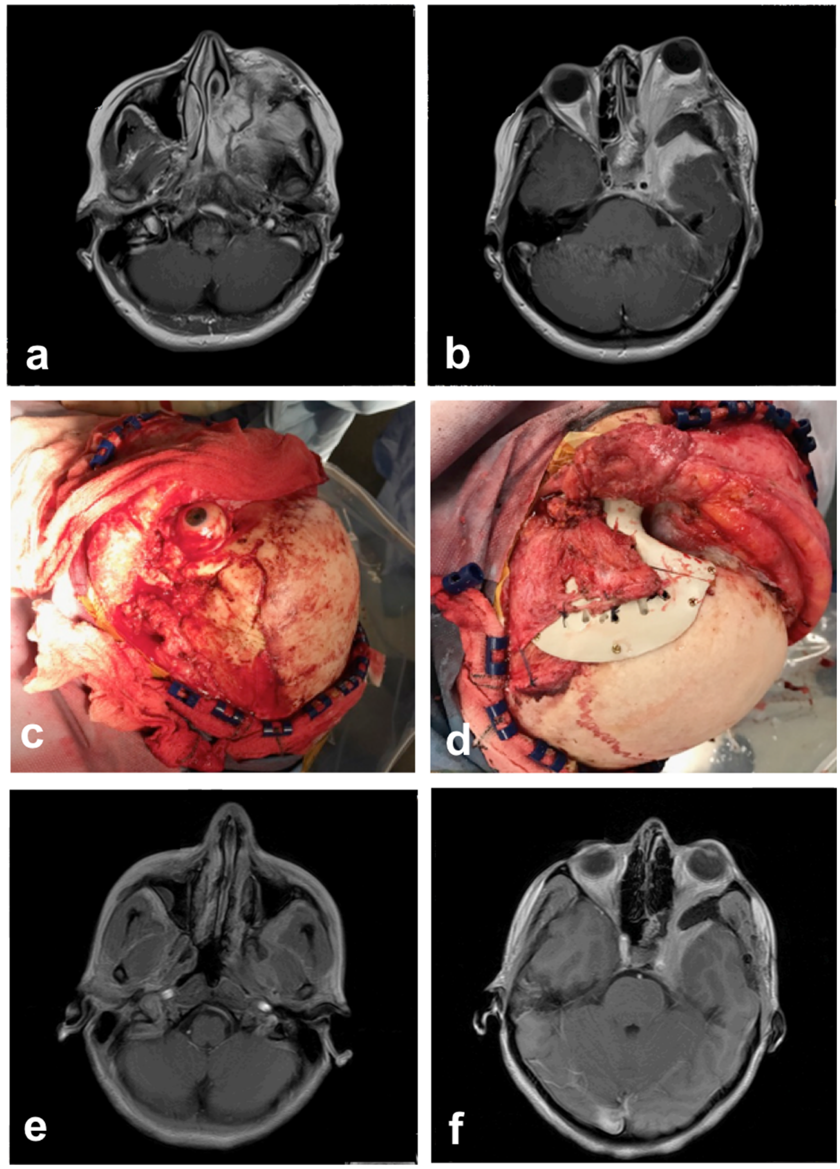

Fig. 2 Left spheno-orbital meningioma. **a**–**b** Preoperative contrast-enhanced T1-weighted MRI. Note the extensive tumour present in the infratemporal fossa (**a**) and the significant proptosis (**b**); **c**–**d** Intraoperative pictures. Standard OZ performed through a bicoronal incision; **c** exposure prior to craniotomy; **d** custom-made PEEK cranioplasty secured in place with temporalis sutured to flap; **e**–**f** Postoperative contrast-enhanced T1-weighted MRI. Small residual en plaque tumour seen in the middle fossa dura but significant improvement in proptosis achieved with a good cosmetic result

Table 4 Perioperative complications and morbidity

	Primary surgery $n = 19$ (%)	Repeat surgery $n = 15$ (%)	Total $n = 34$ (%)
Any complication	9 (47.4)	5 (33.3)	14 (41.2)
Complication type			
Seizure	2 (10.5)	2 (13.3)	4 (11.8)
Haematoma	2 (10.5)	1 (6.7)	3 (8.8)
Requiring surgical evacuation	2 (10.5)	0	2 (5.9)
Oedema and raised ICP	2 (10.5)	0	2 (5.9)
Requiring surgical intervention	2 (10.5)	0	2 (5.9)
Infarct	2 (10.5)	1 (6.7)	3 (8.8)
CSF leak	2 (10.5)	0	2 (5.9)
Meningitis	1 (5.3)	2 (13.3)	3 (8.8)
New cranial nerve palsy	1 (5.3)	1 (6.7)	2 (5.9)
Death	1 (5.3)	0	1 (2.9)

Table 5 Clinical outcomes in patients undergoing primary and repeat surgery

	Primary surgery $n = 19$ (%)	Repeat surgery $n = 15$ (%)	Total $n = 34$ (%)
Median length of follow up	40.5 months (range 3–120 months)	66.5 months (range 1–113 months)	52 months (range 1–120 months)
Tumour outcomes			
Postoperative radiotherapy	1 (5.3)	3 (20.0)	4 (11.8)
Tumour recurrence requiring further surgery	2 (10.5)	2 (13.3)	4 (11.8)
Visual outcomes			
Visual acuity (for all patients with available follow up data)	$n = 16$ (%)	$n = 12$ (%)	$n = 28$ (%)
Improved	3 (18.8)	4 (33.3)	7 (25.0)
Unchanged	12 (75.0)	7 (58.3)	19(67.9)
Reduced	1 (6.3)	1 (8.3)	2 (7.1)
Resolution of diplopia	$n = 4$ (%)	$n = 2$ (%)	$n = 6$ (%)
Improved	2 (50.0)	1 (50.0)	3 (50.0)
Unchanged	1 (25.0)	0	1 (16.7)
Unknown	1 (25.0)	1 (50.0)	2 (33.3)
Resolution of proptosis	$n = 8$ (%)	$n = 5$ (%)	$n = 13$ (%)
Complete resolution	3 (37.5)	4 (80.0)	7 (53.8)
Improved	4 (50.0)	1 (20.0)	5 (38.5)
Unchanged	0	0	0
Unknown	1 (12.5)	0	1 (7.7)
Cosmetic outcome	$n = 10$ (%)	$n = 8$ (%)	$n = 18$ (%)
Very poor	0	0	0
Poor	0	0	0
Neutral	3 (30.0)	3 (37.5)	6 (33.3)
Good	3 (30.0)	2 (25.0)	5 (27.8)
Excellent	4 (40.0)	3 (37.5)	7 (38.9)

perform a one-piece modified mini-orbitozygomatic craniotomy (MM-OZ) as described by Lemole et al. through a unilateral fronto-temporal skin incision [18]. By utilising a cutting guide, an osteotomy can be taken through the body of the zygoma and avoid the need for a zygomatic osteotomy. The access is as good as the standard OZ approach and reduces the operative time and a larger dissection.

There has been a considerable advancement in modern cranioplasty techniques but calvarial reconstruction following an orbitozygomatic craniotomy remains technically challenging. Successful cranioplasty aims to reconstruct the anatomy of the skull and restore initial facial contours in order to achieve a good cosmetic result. Various materials and methods of cranioplasty have been described (Table 6) [19, 20], and our cranioplasty technique has also changed with experience. In our series, all but one of the cases requiring primary cranioplasty were performed using either a customised titanium mesh or polyetheretherketone (PEEK) implant.

Careful preoperative planning would identify the abnormal bone using a CT scan obtained with a 0.625-mm slice thickness. This enabled excellent visualisation, permitting us to accurately estimate bone involvement—typically including the calvarial and orbital roof regions. A 1-cm margin was then used to design the implant which provides excellent access to resect the affected dura. In cases where bony involvement was more extensive than expected, further drilling was performed but no additional cranioplasty was needed in any of the cases as the infiltrated bone was usually at the sphenoid wing. If the periorbital membrane was infiltrated with tumour then it was resected and any frank infiltration tumour was removed. Often, pedicled pericranial flaps were used over the deficient dura, but we avoided the use of synthetic dural substitutes and always reconstructed the orbital roof using a rigid material to restore orbital volume and also to avoid hypoglobus.

Titanium lends itself to being an excellent graft material due to its biocompatibility and its resistance to corrosion and mechanical forces [21]. We manufactured a customised graft before surgery using a preoperative CT scan, but titanium mesh may alternatively be moulded in theatre during surgery. Newer synthetic cranioplasty materials include hydroxyapatite, acrylic, polymethylmethacrylate (PMMA) and polyetheretherketone (PEEK) [19, 20]. The main advantage of these synthetic materials is their radiolucency, partial elasticity and lack of heat conductance, and the fact that they may be customised for each individual patient using modern three-dimensional (3D) printing technologies [19]. During the study period, our practice

Table 6 Management of spheno-orbital meningiomas—a summary of the literature. NA, not available; SCB, split calvarial bone; (P)MMA, (Poly)methyl methacrylate

	Cases	Simpson resection I–II	Improved vision	Improved proptosis	CN palsy	Morbidity (mortality)	Cosmesis (good)	Cranioplasty	Material	Adjuvant therapy	Re-growth	Follow up
De Jesús and Toledo, 2001	6	83.3	50.0	100.0	NA	NA	NA	NA	NA	16.7	33.3	NA
Honeybul et al., 2001	15	40.0	NA	84.6	13.3	NA	Mostly	100.0	NA	NA	NA	NA
Sandalcioglu et al., 2005	16	69.0	NA	NA	12.5	25.0	NA	100.0	SCB	56.3	56.2	68.0
Bikmaz et al., 2007	17	82.3	70.0	100.0	5.9	29.0	NA	100.0	NA	NA	7.1	36.0
Ringel et al., 2007	63	23.0	64.0	77.0	30.1	32.0 (3.2)	NA	NA	PMMA	NA	39.0	54.0
Mariniello et al., 2008	60	66.7	50.0	NA	NA	NA (3.3)	NA	NA	NA	0.0	42.3	138.0
Cannon et al., 2009	12	66.7	16.6	50.0	16.7	16.6	NA	0.0	–	8.3	33.3	31.0
Franquet et al., 2009	23	69.6	NA	61.1	0.0	NA	NA	NA	NA	13.0	NA	NA
Shrivastava et al., 2005	25	70.0	87.0	96.0	8.0	16.0	NA	100.0	NA	NA	8.0	5.0
Heufelder et al., 2009	21	33.3	76.0	94.4	23.8	4.7	85.0	100.0	SCB	9.5	39.0	65.6
Li et al., 2009	37	24.3	69.0	100.0	21.6	2.7	NA	16.2	NA	NA	18.9	NA
Mirone et al., 2009	71	83.0	NA	87.0	4.2	NA	NA	83.7	NA	NA	5.0	76.8
Scarone et al., 2009	30	90.0	85.0	86.0	13.0	3.3	NA	0.0	–	NA	10.0	61.0
Civit et al., 2010	41	20.0	NA	87.0	9.0	10.4	NA	100.0	MMA	NA	NA	NA
Honig et al., 2010	30	33.0	65.0	NA	0.0	63.1	NA	36.0	SCB	27.0	27.0	33.7
Oya et al., 2010	39	38.5	66.7	73.5	7.8	28.2	NA	0.0	–	NA	17.9	40.7
Schick 2010	77	54.5	30.8	78.8	3.0	26.0	Satisfied	5.2	SCB	11.7	12.9	57.9
Saeed et al., 2011	66	9.1	30.0	30.0	NA	16.6	NA	NA	SCB	22.7	17.0	102.0
Boari et al., 2013	40	56.0	66.7	92.5	5.0	17.5	NA	100.0	Titanium	45.0	10.0	72.6
Marcus et al., 2013	19	57.8	52.6	100.0	31.5	42.3 (5.3)	NA	100.0	Titanium	10.5	10.5	60.0
Forster et al., 2014	18	72.2	NA	100.0	0.0	27.9	NA	72.2	Titanium	NA	11.1	43.9
Talacchi et al., 2014	47	51.0	66.6	100.0	4.3	10.6	NA	NA	PMMA	10.6	29.7	52.0
Leroy et al., 2016	70	31.0	14.0	86.0	22.9	42.8	NA	100.0	Autograft	12.9	28.6	60.0
Terrier et al., 2016	130	40.0	44.5	32.5	16.1	17.6	49.6	62.0	Titanium	7.7	29.0	76.4
Freeman et al., 2017	25	68.0	16.0	86.4	8.0	24.0	NA	100.0	Titanium	32.0	48.0	44.8
Present study	*34*	*24.0*	*54.0*	*85.0*	*6.5*	*41.2 (2.9)*	*66.7*	*55.9*	*SCB, Titanium, PEEK*	*6.5*	*12.9*	*52.0*

evolved and it is now our preference to use custom-made PEEK implants in patients undergoing surgery for spheno-orbital meningioma because we believe this method provides better results including improved cosmetic outcome (Fig. 2).

All reconstructive methods and materials have their advantages and disadvantages. The ability to restore with PEEK allows for resection of the supraorbital bar and a more accurate reconstruction. This affords excellent access from an anterior approach to tumours affecting the superior orbital fissure and optic foramen rather than from a more traditional lateral approach. The ability to reconstruct complex three-dimensional defects with PEEK also gives reassurance that any size and shape of the defect can be accurately restored. PEEK implants are slightly more expensive than other materials but, in our experience, PEEK cranioplasties handled better than titanium mesh and could easily be drilled to provide additional fixation points if required.

Tumour resection and recurrence

The surgical management of spheno-orbital meningiomas is challenging because it is often very difficult to achieve a radical Simpson I resection due to the invasion of local structures such as the cavernous sinus and surrounding dura. Consequently, there is significant variation in the reported Simpson resection grades achieved in spheno-orbital meningioma surgery (Table 6) [1–4, 22–42]. Overall, in our series, 23.6% of patients had a Simpson grade I or II resection with a Simpson grade III resection reported in the majority of patients (61.8%); however, total tumour resection (Simpson I–II) was significantly higher in patients undergoing primary surgery ($p = 0.0036$). The choice of surgical approach did not affect the degree of achieved surgical resection (Table 3).

The Simpson resection grade is based upon the surgeon's impression during surgery which is prone to inter-observer variability and bias and may explain the comparatively higher tumour recurrence rates in other series reporting a more radical resection grade (Table 6) [30, 34, 38, 42]. Nevertheless, it is interesting to note that despite the lower resection grades achieved in repeat surgeries, the rate of tumour recurrence requiring further surgery in our study was comparatively low (13.3%) and was not significantly different to that observed following the primary surgery (10.5%). Furthermore, in complex spheno-orbital meningiomas with cavernous sinus or orbital canal involvement, it is not always appropriate to aim for an aggressive resection given the slow-growing nature of these tumours and the potential morbidity attempting radical resection could cause.

Complications

Like many other series, our results confirm that spheno-orbital meningioma surgery is a high-risk procedure (Table 6). Patients should therefore be counselled appropriately and time should be taken to consider the aims of surgery with respect to the patient's age, symptoms and co-morbidities. We observed an overall complication rate of 41% which, although high, is similar to other published studies (Table 6) [29, 31, 33, 37]. In particular, several studies have highlighted the high risk of developing a new cranial nerve palsy following surgery with a reported complication rate of 3–31.5% [4, 33, 39, 40]. In our cohort, only two patients (5.9%) developed a new cranial nerve palsy but other complications were more common (Table 4). The choice of surgical approach and the presence or absence of cranioplasty did not affect the complication rate, and the complication rate was actually lower in patients undergoing repeat surgery (not statistically significant).

Visual outcomes

Proptosis and visual loss are the most common clinical manifestations of spheno-orbital meningiomas, but the degree of visual improvement observed following surgery varies greatly in the reported literature (Table 6) [1, 2, 4, 23, 24, 33, 36, 42]. A wide variation in visual improvement has been recorded in other studies (16.6–85%) [2, 24, 36, 39], and it is likely that the degree of the preoperative visual deficit has a significant effect on postoperative recovery [36]. In our series, the degree of proptosis improved in all patients and resolved completely in a third of patients, diplopia improved in two-thirds of patients, and visual acuity improved (25.0%) or remained stable (67.9%) in nearly all patients (Table 5). Most importantly, this study demonstrated that recurrent tumour surgery was not associated with worse clinical outcomes (Table 5) and that in selected patients, surgery via a minimal MM-OZ approach can achieve comparable visual results (Table 3).

Choice of cranioplasty material and cosmetic outcomes

Various materials may be used for cranial reconstruction (Table 6), but there is no clear consensus if the choice of material affects the patient's final cosmetic result and evidence relating to cosmetic outcome following repeat surgery is particularly scarce. In recent years, surgeons have preferred using alloplastic materials for calvarial reconstruction. Earlier in our series, we used mostly titanium mesh, either pre-fabricated using the patient's preoperative CT scan or moulded in theatre, but over the last 5 years, we have favoured a customised PEEK implant because we believed that this method provided better cosmetic results (Fig. 2).

However, our results suggest that cosmetic outcomes are not influenced by the choice of surgical approach or calvarial reconstructive material (Table 3). Neither did repeat surgery adversely affect the cosmetic outcome (Table 5). Two previous studies have attempted to assess cosmetic outcome in patients undergoing spheno-orbital meningioma surgery [4, 28], but no previous study has evaluated the cosmetic results of PEEK cranioplasties in this patient population. Terrier et al. and Heufelder et al. used general quality of life scores (Glasgow Outcome Scale or SF36 questionnaire) to assess reconstructive outcomes following surgery for spheno-orbital meningiomas using the split calvarial bone graft and titanium cranioplasties, respectively [4, 28]. Our study is limited by small numbers but in 6 patients who received a PEEK cranioplasty, 3 patients rated their cosmetic outcome as "good", 1 patients rated it "excellent", and 2 patients were neutral.

Limitations

This study is limited by the small number of patients however spheno-orbital meningiomas are rare tumours, and this study offers a practical illustration of neurosurgical practice at a tertiary skull base centre. Despite its size, this study did confirm that repeat surgery is not associated with worse surgical, visual or cosmetic outcomes. Analysis of cosmetic outcome was also limited by the fact that several patients had moved away from the area and, in the absence of up-to-date records, it was not possible to trace these patients to conduct telephone follow up. Nevertheless, our results suggest that, in selected patients, surgery performed via a minimal MM-OZ approach may offer comparable clinical outcomes but further work is required to confirm which type of cranioplasty material offers the best postoperative cosmetic outcome.

Conclusions

Spheno-orbital meningiomas are a highly complex and challenging entity that requires careful preoperative patient counselling, multidisciplinary planning and long-term follow up. Surgery is a high-risk procedure and thoughtful consideration should be given to the aims of surgery in order to minimise morbidity. In our study, the predominant factor affecting surgical and clinical outcomes was whether the patient was undergoing primary or repeat surgery. The choice of surgical approach and method of calvarial reconstruction did not affect surgical or clinical outcomes. Surgical approaches to a spheno-orbital meningioma should be tailored to the patient, but we have demonstrated that good visual outcomes and excellent cosmetic results may be achieved with a smaller craniotomy and custom-made implants, irrespective of whether the operation is the patient's first procedure.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Statement of informed consent This study was approved by the institution's research committee without the need for informed consent.

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