Microsurgical management of tuberculum sellae meningiomas by the frontolateral approach: Surgical technique and visual outcome

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ABSTRACT

Objectives: The aim of this study was to evaluate visual outcome in patients with tuberculum sellae meningioma (TSM) treated microsurgically using the frontolateral or fronto-orbital approach and optic canal unroofing to resect tumor involvement of the optic canal.

Methods: Data from 67 patients with TSMs who underwent microsurgical treatment by a frontolateral approach (n = 44) or fronto-orbital approach (n = 23) between January 2002 and December 2008 were retrospectively collected and analyzed. Change in visual function was evaluated as the main outcome.

Results: Total tumor resection was achieved in 62 of 67 cases (92.4%). Postoperative, visual acuity was improved in 87 eyes (64.9%) and unchanged in 39 eyes (29.1%), and the optic nerve was therefore preserved in 126 of 134 eyes (94.0%). Visual field deficits were improved or stable in 65 eyes, no patient experienced worsening of vision in both eyes. There was no mortality in our series.

Conclusions: The frontolateral approach with microsurgical dissection of the Sylvian fissure provides quick access to TSMs, which can be resected safely and totally. Visual function is improved and neurological and ophthalmological morbidity is minimal. Optic nerve decompression by intradural clinoidectomy and optic canal unroofing is likely to increase the rate of reducing or eliminating preoperative visual symptoms.

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1. Introduction

Tuberculum sellae meningiomas (TSMs) originate from the tuberculum sellae, and chiasmatic sulcus [1], and grow in a subchiasmal location [2]. These tumors tend to displace the optic chiasm backwards and the optic nerves laterally and superiorly, and commonly extend into both optic canals. The primary goal of surgery is to improve or at least maintain visual function, but this objective poses a formidable surgical challenge [3], because of, the risk of postoperative visual impairment. Recent articles report that 10–20% of patients experience worsening of preoperative visual function [4]. Several authors have reported that unroofing of the optic canal and anterior clinoidectomy can improve visual outcome [5,6]. The aim of the present study was to evaluate visual outcome in TSM patients treated microsurgically using the frontolateral or fronto-orbital approach involving unroofing of the optic canal.

2. Clinical materials and methods

2.1. Clinical materials

Pre- and postoperative data were collected from clinical and operative records, date included duration of visual symptoms, visual acuity, maximum tumor size, tumor consistency, tumor extension into the optic canal, adhesion to the optic nerve, extent of optic canal unroofing, and tumor resection. Preoperative magnetic resonance imaging (MRI) and intraoperative inspection were used to assess tumor extension into the optic canal. Tumor consistency was defined as ‘soft’ when most of the tumor could be aspirated with a suction tube or low-power Cavitron ultrasonic surgical aspirator (CUSA; Valleylab, Boulder, CO, USA), ‘intermediate’ when half of the tumor could be aspirated, and ‘hard’ when most of the tumor could not be aspirated even with a CUSA. The degree of adhesion to the optic nerve was defined as severe when the tumor and optic nerve could not be divided with microscissors.

2.2. Patient characteristics

During the period from January 2002 to December 2008, we treated microsurgically 67 patients (39 female and 28 male; mean age, 48.7 years; range, 28–76) who presented with visual
disturbances of varying degrees in one or both eyes, and who received a diagnosis of TSM at the Xuanwu Hospital. Information about clinical history, signs, surgical approach, and outcome was obtained retrospectively.

2.3. Signs and symptoms

The most common symptoms and signs on admission were visual disturbances that started in one eye, worsened, and then spread to the other eye. Visual disturbances include visual acuity and visual field. Visual symptoms occurred early and usually progressed slowly. Severe visual deficit would be produced if the scale of visual acuity measurement sufficient to impair finger counting at a distance of 1 m. All patients presented with symptoms and signs of visual dysfunction and various types of visual field defects (usually asymmetrical). The mean duration of visual symptoms was 21.0 months (range, 3–71 months). Other symptoms included headache (n = 32), altered behavior (n = 15), endocrine disturbance (n = 3) and seizures (n = 1). The examinations for visual field defects included pre- and postoperative visual acuity, fundoscopy, and perimetry.

2.4. Radiological imaging

To plan surgical strategy, preoperative computed tomographic (CT) and MRI scans were performed in all patients, to obtain the following information: the primary location of the tumor; relationship between the tumor, the optic nerve, and the internal carotid artery (ICA); involvement of the optic canal and orbit; and presence of hyperostosis, unilateral or bilateral involvement of the optic nerve. CT scans with thin cuts through the cranial base provide better delineation of osseous anatomy and can be helpful in identifying areas of bony hypertrophy (Fig. 1A). Intratumoral calcification, enostosis and hyperostosis were encountered in firm (‘intermediate’ and ‘hard’) varieties of meningiomas.

T1- and T2-weighted MRI in all three planes was conducted to determine the relationship of tumors to neighboring structures, the superior and lateral extent of the tumor, and compression of the optic apparatus. Enhanced-MRI was used to reveal homogeneous hypertensive lesions (Fig. 1B and C). Thirty-six tumors extended posteriorly into the sellar diaphragm, 19 to the anterior clinoid process, and 27 to the optic canal (Fig. 1C and D). Median tumor diameter was 3.2 cm (range, 2.3–6.3 cm). Digital subtraction cerebral angiography (DSA) was performed in 43 patients, to locate the feeding vessels and assess the extent of tumor vascularization, the position of the carotid arteries, their branches, and their relationship to the tumor (Fig. 1E). In another 12 patients CT angiography (CTA) was performed to visualize encasement of the internal cerebral artery (ICA) and the anterior cerebral artery (ACA).

2.5. Surgical techniques

2.5.1. Surgical principles

First, no active coagulation was used and no aspiration was carried out in the arachnoid plane of the tumor. Next, the contralateral optic nerve was identified and the tumor under this optic nerve on the medial side of the contralateral ICA was removed by dissecting and debulking from the skull base, proceeding along the interoptic fold to the arachnoid structures, ipsilateral optic nerve, A1 segment, and optic chiasm. Tumor tissue was removed from underneath the optic chiasm in a contralateral to ipsilateral direction, and finally from the pituitary stalk and interpeduncular cistern. The most important steps were the interruption of the basal blood supply and dissection from crucial arachnoid structures. No attempt was made to remove tumor from underneath this nerve, which was under high tension.

2.5.2. Method of craniotomy

All operations were carried out through a frontolateral or fronto-orbital approach, on the side of visual deterioration. The patient’s head was rotated to the contralateral side at an angle of 10° to 15°, and the trunk was elevated 30° above heart level to facilitate venous drainage and reduce brain swelling. A slight head reposition was performed to allow the frontal lobe to fall away from the anterior cranial fossa, and this minimized frontal lobe retraction with maximal exposure. A single burr hole was introduced just posterior to the anterior temporal line using a high-speed drill. The direction of drilling was adjusted such that opening of the periorbita was prevented. A free bone flap (usually 3.5–4 cm × 4–5 cm) was raised (Fig. 2A). A perforation was drilled into the inner edge of the supraorbital bone in order to optimize the angle of approach to the frontobasal area. Whenever the frontal and/or sphenoid sinuses were opened, an autologous pericranial membrane flap, or temporal fascia with fibrin glue was used for reconstruction of the basal dural defect and to prevent rhinoliquorrhea.

The dura was opened in a curved fashion toward the supraorbital rim, and cerebrospinal fluid (CSF) was drained by opening the Sylvian fissure. The Sylvian fissure should be opened widely, starting distally and extending proximally, keeping the arachnoid of the fissure under some tension with self-retaining retractors to facilitate the opening of the Sylvian arachnoid. This procedure leads to spontaneous sinking of the frontal lobe, making significant retraction of the frontal lobe unnecessary. To protect the cerebral cortex and to minimize pial injury from cottonoid adherence, a single-layer piece of gelatin sponge was placed directly on the brain under each retractor, and then covered with a cottonoid. Although the retractors were fixed with mild pressure on the frontal lobe, their main function was to cover and protect the cortex from inadvertent intraoperative damage.

2.5.3. Exposure of the tumor

Frontolateral retraction and arachnoid dissection along the proximal olfactory tracts extended the operative field to the anterior cerebral artery (ACA). The deepest area of the olfactory tract always crossed over the optic nerve and obstructed the roof of the optic canal. Therefore, it was necessary to dissect the olfactory tract as deeply as possible and mobilize it to avoid injury during drilling of the optic canal. The ICA was identified and this led to the ipsilateral optic nerve which in some cases was obscured by tumor tissue. Next, we opened the arachnoid across the superior surface of the optic nerve. When the optic nerve was significantly displaced and flattened out, it was deemed prudent to open the arachnoid along its lateral margin, then along its medial margin, proceeding further medially along the anterosuperior side of the tumor. The relationship of the optic nerves and chiasm to the tumor varied greatly. In some the ipsilateral optic nerve was elevated by the tumor; in others the chiasm was tilted obliquely and/or the opposite optic nerve was situated below the tumor. For tumors larger than 3 cm, the ipsilateral optic nerve was invariably covered by an extension of tumor which could be easily displaced form the superior surface of the ipsilateral optic nerve using a cottonoid. As soon as the ipsilateral optic nerve was uncovered, attention was directed to exposing the olfactory nerve for its preservation.

2.5.4. Microsurgical tumor resection

The tumor capsule was microsurgically dissected from the arachnoid layer, opened medially to the ipsilateral optic nerve, and debulked to decompress the optic nerve. The anterior tumor capsule was opened after the feeding arteries were coagulated to interrupt basal blood supply, and the ipsilateral optic nerve was
Fig. 1. Preoperative CT, MRI scans and DSA, showing the tumor located at tuberculum sella, predominantly medial to optic nerve. (B–D) A 57-year-old woman with a 35 mm meningioma and right supraclinoid carotid encased. (A) CT showed the largely calcified meningioma tumor, engulfing intracranial vessels (arrows). (B) Coronal view of T1-weighted contrast-enhanced MRI scan, clearly showing the tumor originated from the tuberculum sella and extending into right suprasellar region and encasing the ICA. (C) Sagittal view, showing the suprasellar extension of the tumor, extending into the sella. (D) Axial view, the tumor compressed the optic apparatus with the single arrow indicating tumor in the optic canal. (E) DSA showed ACA displacement supralaterally.

Exposed. Before the tumor was debulked internally, the basal aspect of the tumor was devascularized with a bipolar coagulator. This procedure allowed early interception of tumor feeder vessels, and caused the tumor to become soft and anemic, and thus could easily be detached from the arachnoidea of the gyrus rectus, and A1 segment. Tumor resection was continued in a piecemeal fashion until the optic chiasm and the contralateral optic nerve were visible, often using a gentle push–pull technique whereby tumor tissue was detached from the arachnoid trabeculae through the optic-carotid space and then removed with angled bipolar forceps between the...
optic nerves. During the initial decompression, a 2–3-mm layer of tumor was cauterized and left at the dural attachment, to prevent bleeding when the dura was stripped from the bone. The tumor was further debulked to reduce its volume until the contralateral optic nerve became visible.

The corridor used to resect the residual tumor with angled bipolar forceps extended either medially between the optic nerves or laterally between the ipsilateral optic nerve and ICA. After achieving some tumor capsule relaxation, the ipsilateral optic nerve and chiasm could be freed via sharp dissection along the tumor capsule–arachnoid interface. Once the ipsilateral optic nerve and chiasm had been decompressed, the tumor capsule was separated from its dural attachments along the cranial base. After additional internal tumor decompression posteriorly and superiorly, the volume of the superior pole tumor on the ipsilateral side was reduced, leading to retraction from the underlying arachnoid covering the right ACA. This separation starts distally and proceeds proximally along the vessel until the tumor capsule collapses anteromedially toward the cavitated tumor bed. The tumor was then removed from the A1 segment and the chiasm. The redundant tumor capsule on the ipsilateral side was then excised through the intact arachnoid. Removal of the ipsilateral and middle portions of the tumor creates considerable working space, permitting removal of the contralateral optic nerve. Finally, the tumor matrix was coagulated, preferably with a CUSA, and disconnected from its attachment to the planum and tuberculum sellae at the midline using bipolar coagulation and microscissors. Meticulous dissection and removal of tumor tissue from the hypothalamus and pituitary stalk were mandatory. For larger meningiomas, resection between the ICA and the oculomotor nerve, as well as around the posterior communicating artery (PcomA) might also be needed. Finally, the posteriorly displaced infundibulum was identified and preserved (Fig. 2B). Any hyperostotic bone was removed with an appropriately sized cutting burr. A margin of dura surrounding the tumor attachment, along with any residual tumor tissue, must be resected and/or thoroughly coagulated to minimize subsequent tumor recurrence. Osseous bleeding was controlled using small pieces of bone wax or bipolar cautery.

2.5.5. Tumor resection from the optic canal

The basal portion of the tumor and its dural attachment sometimes extend into the optic canal. When this occurs, the optic canal should be unroofed. The optic canal was drilled away to remove the tumor and its dural attachment in 27 cases. The dura over the planum sphenoidal and the lesser sphenoid wing was coagulated, incised, and peeled back, to reveal the base of the anterior clinoid process, the roof, and the lateral wall of the optic canal (Fig. 2C). The bone over the optic canal was drilled away, and intradural optic canal unroofing was performed with a high-speed drills (a hand-controlled variable-speed pneumatic drill equipped first with a 2- or 3-mm cutting carbide burr, and then with a 2-mm carbide drill), and the bone was shaved away from the
dura overlying the optic canal. The opening of the bony canal and the dural sheath allowed easier manipulation for tumor removal and, with less potential damage to the nerve. The dural sheath of the optic nerve was opened longitudinally up to the annulus of Zinn. With deroofing of the canal, the optic nerve could be mobilized and the tumor below the nerve could then be aspirated. Residual tumor around the optic nerve was carefully removed and the basal portion of the tumor was resected without difficulty with blunt microinstruments (Fig. 2D). After release of the optic nerve, a discolored band representing the area of maximal pressure by the falciiform ligament on the optic nerve was often observed. If a small nodule of residual tumor was found, it could be removed with minimal manipulation of the optic nerve using small, cupped microdissectors. In addition in 6 cases, the chiasmatic sulcus and tuberculum sellae were opened to remove tumor penetrating the anterior wall of sphenoid sella and sphenoid sinus.

2.5.6. Preservation of optic nerves and vasculature

Although the adjacent arachnoid cisterns collapsed as a result of progressive tumor compression, the arachnoid layers remained intact, and CSF pulsations continued to occur in the collapsed arachnoid space. To preserve remaining vision, dissection of the optic nerve and chiasma should be meticulous. The arachnoid layers of the chiasmatic and lamina terminalis cisterns were dissected. As tumor resection proceeded in the depth between the optic nerves inferior to the chiasm, the pituitary stalk could eventually be discerned at the posterior limit of the tumor. This latter structure was usually displaced posteriorly and, in larger tumors, was sometimes also enveloped. The posterior margin of the tumor was removed from the hypophyseal arteries, the posterior arachnoid layers of the chiasmatic cistern, and Liliequist’s membrane. In addition to minimizing manipulation of the optic nerves and major intracranial vessels, meticulous preservation of vascular structures during tumor resection was paramount for optimal visual, hormonal, and neurological outcomes.

Protection of the optic nerves and chiasmal blood supply was also extremely important to preserve vision. Damage to superior hypophyseal branches and perforators from the PcomA must be avoided. The ACA-complex was commonly enveloped by a large tumor located dorsal to the chiasm. It was helpful to preserve the small arteries located around the tumor within the arachnoid layers so as to maintain the integrity of the PcomA, anterior choroidal artery, and their perforating arteries.

2.5.7. Postoperative management

High-dose intravenous corticosteroids were given immediately for 5 days postoperatively, and then tapered slowly, to minimize optic nerve and brain edema that might occur from manipulation and retraction during surgery. For patients with large tumors who underwent long operations, endotracheal tubes were placed until they were fully awake and following commands, protecting the patients from possible aspiration or respiratory compromise. Fluid balance and electrolytes were monitored closely for at least 48h after surgery. Neuro-ophthalmology and endocrine monitoring was routinely performed before and after surgery.

2.6. Follow-up

All 67 patients were followed-up regularly by the Neurosurgery and Ophthalmology services at 6-month intervals for the first year, and annually thereafter. Radiology or clinical status data were obtained from the most recent follow-up records and serial yearly imaging studies. The follow-up period varied from 6 to 48.5 months.

<table>
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<tr>
<th>Table 1</th>
<th>Results of visual function in relationship to tumor size.</th>
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<tr>
<td>Size of tumor a (cases)</td>
<td>Postoperative visual function (eyes)</td>
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<tr>
<td></td>
<td>Improved</td>
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<tr>
<td>Less than 3 cm (29)</td>
<td>49/58</td>
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<tr>
<td>Larger than 3 cm (38)</td>
<td>38/76</td>
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<td>Total (67)</td>
<td>87/134 (64.9%)</td>
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a Maximum tumor diameter.

(mean, 29.3 months). Five patients with residual tumor received gamma knife radiotherapy. Visual acuity and field assessment were performed pre- and postoperatively in all patients. At follow-up, tumor growth was found in two cases, and absolute visual acuity was improved further in four patients. Visual acuity did not deteriorate with longer follow-up.

3. Results

3.1. Tumor removal

All tumors originated from the tuberculum sellae dura. The pituitary stalk was preserved in all but two cases. The optic canal was unroofed unilaterally in 23 cases and bilaterally in 4 cases with binocular visual disturbances. In 6 patients, the tumor had extended into the pituitary fossa underneath the diaphragm, requiring opening of the sphenoid sinus through the tuberculum sellae and, tumor resection using a transsphenoidal approach. The extent of tumor removal was evaluated using an T1-weighted MRI postoperatively. Total resection was achieved in 62 patients (Fig. 3), and subtotal resection, owing to small tumor residua around the vessels or adherence of tumor to the optic nerve and/or chiasm, was achieved in 5 patients.

3.2. Visual outcome

Visual outcome analysis was performed in the immediate postoperative period, and preferably on discharge. Examinations of visual outcome (both visual acuity and fields) were conducted for 134 eyes in 67 patients. On discharge, absolute visual acuity was improved in 87 eyes (64.9%), and remained the same in 39 eyes (29.1%). Therefore, the optic nerve was preserved in 126 of 134 eyes (94.0%). We observed postoperative deterioration of visual acuity in 8 of 134 eyes (6%), increased visual loss (<0.1) in 1 eye, and total blindness in 1 eye. In cases of improved vision, the improvement occurred in both eyes in 23 patients (34.3%, 23/67), and in one eye in 41 patients (60.7%, 41/67). No patient experienced worsening of vision in both eyes. In patients who benefited from treatment, visual acuity continued to improve or persisted throughout the follow-up period. Visual field deficits were also improved or stable in 65 eyes after surgery, including the eyes of 8 patients whose deficits resolved completely. Visual acuity was preserved in 69 eyes (preoperative visual acuity, 0.5–1.0), and deteriorated or was lost in 5 eyes (visual acuity, 0.1 or less).

3.3. Tumor size and visual outcome

In 29 patients with tumors of maximum diameter <3 cm, visual acuity improved postoperatively in 49 eyes (84.5%). In 38 patients with tumors of maximum diameter of ≥3 cm, visual acuity improved postoperatively in 38 eyes (50%) (Table 1).

3.4. Complications

We observed postoperative paresis of the frontalis branch of the facial nerve (n = 2). CSF rhinorrhea from the frontal sinus, which
Fig. 3. The postoperative images were from the same patients as those in Fig. 1. The axial (A), coronal (B), and sagittal (C) T1-weighted contrast-enhanced MRI scans after TSM resection through a right frontolateral approach obtained 1 month later, confirmed total tumor removal.

was adequately treated by lumbar drainage \( (n=1) \), infarction of the caudate nucleus \( (n=1) \), infarction of the temporal lobe \( (n=1) \), epileptic seizure \( (n=1) \), permanent hyposmia or anosmia \( (n=9) \), and transient diabetes insipidus \( (n=4) \). None of the patients developed meningitis.

4. Discussion

4.1. Preoperative evaluation

Oculomotor, neurological, and endocrinological function tests were carried out preoperatively. Multiplanar, contrast-enhanced MRI is the imaging modality of choice for accurate diagnosis. Primary goals of preoperative evaluation were to determine tumor size, the tumor’s anatomic relationship to neighboring neurovascular structures, and the location of the ICA and the ACA-complex in relationship to the meningioma. Imaging features of tumors that permitted differentiation from pituitary macroadenomas included dural attachment, the presence of a dural-based tail, and lack of expansion into the sella turcica. Peritumoral edema and tumor calcification are uncommon in TSM, but when this occurs is likely to be indicative of the firm nature of the tumor. Peritumoral edema can also be related to the ability of meningiomas to invade, and can influence the risk of recurrence \[7\]. Determining the relationship of the tumor to the ICA, the ACA-complex, and their perforating branches is crucial. Usually, the ICA is displaced posterolaterally, whereas the ACA is displaced posterosuperiorly. Despite MRI evidence of ICA encasement, tumor lobulations tend to engulf the ICA, and microsurgical dissection from the vessel wall is relatively straightforward.

Preoperative sagittal sections on MRI parallel to the course of the optic nerves often indicate tumor extension into the optic canal. T2-weighted MRI can be used to estimate tumor hardness, an important prognostic factor for visual impairments \[8\]. Tumor tended to be firmer when the adjoining vessels were displaced rather than encased. The more extensive the tumor involvement of the optic nerve, as indicated by the extent of visual deficit, the more intense was the signal of the optic nerve and of the ICA and its branches to the tumor. The position of the tumor posterolateral to the ICA and posterosuperior to the ACA-complex is usually an indicator of relatively easy, safe, and complete surgical removal. Although the anatomic boundaries between the tumor capsule, arachnoid, and surrounding neurovascular structures are well defined, they are not defined between the tumor and dura mater. Meningiomas usually penetrate the dura with impunity, and encase the arteries and the cranial nerves. However, detection of the presence and degree of tumor involvement within the optic canal is sometimes difficult even with thin MRI sections. Digital subtraction angiography (DSA) can show encasement, displacement, and thinning of the surrounding tumor vasculature. Preoperative embolization is not indicated, because TSMs derive their blood supply from the posterior ethmoidal branches, meningohypophyseal trunk, A1 branches, and Heubner’s artery. Moreover, the tumor’s main vascular supply can be interrupted easily at surgery.
4.2. Microsurgical anatomy of TSMs

TSMs usually tend grow in a superior and anterolateral direction, compressing one or both optic nerves and the optic chiasm, and thereby leading to asymmetrical visual dysfunction. They are distinguished from anterior cranial fossa tumors by elevating rather than depressing the optic nerves and chiasm with continued growth. TSMs also tend to displace the arachnoid membrane ahead of them, and to push up and stretch the arachnoid of the floor of the chiasmatic cistern over the tumor, thereby separating the tumor from the optic apparatus and vascular structures. The tumor quite often has multiple lobules, and these can wrap around these structures without actually encasing them. With continued growth, the tumor encroaches upon the adjacent structures (ICA, lamina terminalis). TSMs constitute an anatomically well-defined subpopulation of meningiomas, with a distinctive growth pattern.

Subchiasmal growth and posterolateral displacement of the optic chiasm is universal. Small tumors are commonly located off the midline, causing monocular symptoms and signs, whereas larger tumors are extended through the midline, often causing binocular deficits. Anatomically, growth is restricted laterally by the ICA, PcomA, and the arachnoid of the carotid cistern; posteriorly by the infundibulum and Liliequist’s membrane; and superiorly by the optic chiasm, the lamina terminalis, and the ACA-complex. Further enlargement can lead to encasement of the ACA-complex and the ICA or even the PcomA laterally, through the optic–carotid triangle. Because the optic nerves are fixed at the optic foramen, with continued tumor growth, they can be angulated and asymmetrically enveloped. The ICAs are displaced laterally and still covered by a displaced arachnoid layer. The ACAs, which are dorsal to the optic chiasm, are usually stretched and can become embedded by tumors larger than 3.5 cm in size. Posteriorly, the tumor can extend into the interpeduncular cistern, displacing the pituitary stalk.

4.3. Techniques for total tumor resection

The extent of tumor resection determines tumor recurrence and regrowth. Surgical resection should be as complete as possible to avoid the risk of future recurrence. Nevertheless complete tumor resection should not be achieved at the cost of increased morbidity. If performed properly and in a timely fashion, surgical treatment of TSM can achieve highly satisfactory results with excellent long-term outcome. In recent microsurgical series, including the present series, high rates of complete tumor resection could be achieved without increasing morbidity [9–12]. Some surgeons prefer a pterional approach, or bifrontal approach, but without extensive decompression by drilling of the bony optic canal, that would result in incomplete tumor resection. Residual tumors in the optic canal can also be a source of tumor recurrence, and it has been recommended that the optic canal should be opened in order to remove small pieces of residual tumor [4,5]. In our series, extension into the optic canal was relatively common (~28 of 67 patients by preoperative radiological examination and/or intraoperative inspection). Optic canal unroofing was performed in 27 of these patients, but was not performed in one patient where subtotal tumor excision was achieved without unroofing. Fahrbusch and Schott [12] reported that only 2.1% of patients with complete tumor removal had recurrence. In our experience, successful complete resection depended on tumor size, tumor location, and whether the ICA and ACA-complex were completely encased. In most cases, the residual tumor tissue remained in the cavernous sinus, in the orbital apex, or adherent to the ICA and its perforators. Complete removal of the tumor from the optic nerve and unroofing of the bony optic canal were crucial. First, in large tumors, bony optic canal unroofing facilitates locating the optic nerve in a normal area and following it into the tumor. Second, this space is helpful for optic nerve displacement, so that tumor recurrence or regrowth will not compromise vision, for a longer time period. Third, in cases requiring postoperative radiotherapy, an optic nerve free of disease is spared the deleterious effects of radiotherapy, and safer radiation doses can be used for tumor control.

4.4. Preservation of visual acuity

In recent microsurgical series, the rate of visual improvement after surgical resection was 25–80% in suprasellar meningiomas [3,12,13]. Surgical approach and technique has a clear influence postoperative visual outcome [10,14]. In our experience, the size of the tumor and, the duration and degree of visual deterioration can also influence postoperative visual outcome. Rosenstein and Symon [14] reported better visual outcome in patients with tumors smaller than 3 cm than in those with tumors larger than 3 cm. We found an improvement of visual acuity in 84.5% patients with small tumors (maximum diameter, <3 cm) and in 40.8% of 67 patients with larger tumors (>3 cm). Tumor extension into the optic canal was reported to occur in up to 20% of patients with TSM [3]. Ari et al. [1] emphasized that the presence of preoperative visual disturbance implied the need for optic canal deroofing, although in the study of Park et al. [15] the canal was not opened. Residual tumor in the canal is likely to be the origin of recurrence and/or explain a lack of visual improvement [16]. However, the decompression of the optic pathway is a major goal of surgery, and optic canal unroofing and anterior clinoidectomy to decompress the optic nerve have been reported to improve visual results and allow more radical surgery [17,18]. A retrospective study of 32 TSM patients by Otani et al. [5] recommended selective extradural anterior clinoidectomy for complete removal with preservation of visual function. Landeiro et al. reviewed 23 patients TSMs using unilateral subfrontal supraorbital osteotomy and performed intradural/extradural optic canal unroofing [19], the optic canal and clinoid were drilled extradurally in eight patients and intradurally in nine patients. We preferred to drill optic canal unroofing intradurally after dissection and removal of overlying tumors to expose the optic canal, it is shown that either the intradural or extradural approach to drill an anterior clinoidectomy is equally used in anterior clinoidectomy.

The key to preserving visual function is to minimize direct manipulation or trauma to the optic nerves and avoid injury to the blood supply of the optic apparatus [11]. To preserve normal vascular supply, especially for the small arteries supplying the optic nerve and chiasm, the arachnoid plane should remain intact, and sufficient tumor debulking should be carried out before tumor capsule removal. Visual acuity was improved in 50–66% and, unchanged in 17–28% of the cases reported here. Visual deterioration was previously reported in 10–40% of patients surgically treated for TSMs [10,12,13,20]. Fahrbusch and Schott [12] reported an 8% risk of visual deterioration from preoperative levels compared with 19% in patients with poor preoperative vision. In a retrospective study of 27 patients by Kim et al. [8], visual dysfunction was improved in 44.4%, unchanged in 33.3% and worsened in 22.2%. In our series, visual acuity improved or remained unchanged in 94.1% of 67 patients after surgery, and the risk of visual deterioration was 5.9%. Thus, the combination of decompression, optic canal unroofing, and total tumor resection is likely to increase the rate of improved postoperative optic nerve function.

4.5. Surgical approach and visual outcome

The subfrontal approach provides a better medial view of the suprasellar region, but the prominent orbital roof often obstructs this view. Consequently excessive frontal lobe retraction might become necessary. The bilateral subfrontal approach is appropriate for larger tumors and bilateral ICA encasement. However, opening
of the frontal sinus carries a high risk of CSF leakage and meningioma, olfactory nerve damage, and possible bifrontal lobe injury from retraction. The pterional approach provides a frontolateral view between the optic nerves, as well as a lateral view through the carotid cistern and is associated with less risk of olfactory nerve damage and requires less brain retraction. All structures can be reached easily, compared with the subfrontal approach, CSF can be drained early from the basal cisterns, and the ICA and optic nerve can be identified early. The main disadvantage is that it can be difficult to remove tumor located underneath the ipsilateral optic nerve without considerable manipulation. Recent reports have indicated that an extended transsphenoidal approach could be safe and effective for the removal of relatively small (<3 cm) TSMs that exhibit a vertical and symmetrical path of growth [10,21]. However, this approach is restricted to small midline TSMs and without encasement of the ICA or ACA, and there is a high rate of postoperative CSF leakage [22].

In our series of cases, the frontolateral approach allowed early CSF release and identification of the relevant anatomy, provided a short route to the lesion, minimized injury to the olfactory nerves, and also minimized the risk of CSF leakage or infection of the frontal sinus. Even large tumors, can be completely resected with low recurrence rates using this simple and minimally invasive frontolateral approach. For intradural resection, the authors emphasize splitting the Sylvian fissure to gain better access to the tumor, with less retraction. To obtain additional room for manipulation of the instruments, and to reduce the amount of brain retraction, osteotomies are drilled as required. In our opinion, the orbitofrontal approach should be used if most of the tumor is lateral to the optic nerve and the ICA. The supraorbital rim is removed to augment the subfrontal exposure. Nakamura et al. [6] reported three different approaches to microsurgically remove TSMs from 1978 through 2002. Of these approaches, the frontolateral approach was considered to be the least invasive and led to the best visual outcome [6].

4.6. Surgical technique
4.6.1. Technique of dissection and tumor removal
The key to safe and effective TSM removal is more in understanding the relationship of the tumor’s interface with the arachnoid than in the details of the specific approach. Identification of the normal anatomic relationships of the basal cisterns can provide a natural pathway to follow towards the tumor, and preservation of the arachnoid layer separating the tumor from surrounding structures can greatly protect the optic apparatus, ICA and perforating branches. To avoid postoperative visual deterioration and neurovascular injuries, the integrity of the arachnoid plane should be preserved at the interface between the tumor and the optic apparatus on the one hand and the pituitary stalk on the other, along with its feeding vessels. Sharp arachnoid dissection of the Sylvian, carotid, and lamina terminalis cisterns allows for CSF drainage and brain relaxation. Surgical dissection should be performed between the arachnoid and the tumor capsule, thus leaving a layer of arachnoid covering the ACA-complex and the perforators. The ipsilateral optic nerve should be the first landmark to be identified, followed by the ipsilateral ICA.

Tumor debulking is then performed progressively with a combination of sharp dissection, suction, and use of the USA until the chiasm and the contralateral optic nerve become visible. The tumor is then partially excised close to the base of attachment, and some of the feeder vessels traversing this portion of the tumor can be cauterized with bipolar coagulation, minimizing blood loss. Coagulation should be limited to the midportion of the tumor to avoid injury to the optic nerves. The inferior surface of the optic nerves and the chiasm receive their blood supply from the superior hypophyseal arteries, arising from the supraclinoid ICA, and surgical dissection of tumor from the under-surface of the optic nerve can be a formidable task. It is best to proceed with tumor dissection from the inferior surface of the contralateral optic nerve, and this is easier to identify at the beginning, and then proceed toward the ipsilateral optic nerve so as to minimize manipulation of the already affected structure. When the tumor is densely adherent to the optic apparatus, the better choice is to leave tumor fragments on the nerves rather than to strip the nerves clean, because nerves that are stretched and distorted by the tumor mass are fragile and poorly with stand manipulation. The dissection of small tumors can be relatively straight forward, but that of large tumors can reveal either no arachnoid membrane at all or only one intact layer.

4.6.2. Preservation of momentous structure
The goal of surgery is to improve or stabilize visual function. When resecting meningioma, small vessels in the stretched arachnoid layer and the tumor-encased contralateral and ipsilateral arteries of the ACA-complex should be preserved completely and not coagulated in error. Despite encasement of the ICA and ACA-complex as seen on MRI, dissection of the tumor from these arteries is relatively simple. Early identification of the ACA-complex during surgery is necessary. Sometimes, small branches of the ACA contribute to the tumor vascular supply [23]. The optic nerves are fixed within the optic canal, and the falciform ligament is the most common site of compressive injury to the nerve. The optic nerve is elevated by the tumor and is susceptible to mechanical trauma via, compression between the tumor and the sharp edge of the faliform ligament. Before optic nerve manipulation, it is advisable to release the faliform ligament to minimize the chance of optic nerve injury. Notably, in our cases, there were few tumor adhesions within the optic canal and there, the tumor could be removed easily. Careful exploration of the area of the optic canal is crucial to ensure adequate optic nerve decompression and complete tumor removal. The optic nerve can be completely mobilized and decompressed by unroofing of the optic canal and opening of the optic sheath. Tumor invasion and firm adherence to the optic nerve and the ACA-complex can preclude complete tumor resection.

5. Conclusion
The primary goals of TSM surgery are to tumor removal, and improved visual function with minimal morbidity. Opening the optic canal and/or the sphenoid sinus were found to be mandatory for removal of the basal portion of the tumor and are thus essential for radical tumor removal. We consider the frontolateral approach to be of great clinical value. This minimally invasive approach allows rapid access to the tumor and high rates of total tumor removal. Optic canal unroofing and gentle tumor removal are required when tumors extend into the optic canal.

References


