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CLINICAL ARTICLE - BRAIN TUMORS

Impact of anterior clinoidectomy on visual function after resection of meningiomas in and around the optic canal

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Abstract
Background Meningiomas of the anterior and middle skull base frequently involve the optic nerve and cause progressive visual impairment. Surgical decompression of the optic nerve is the only option to preserve visual function. Depending on the invaded structures, optic nerve decompression can be part of a complete tumor removal or the main surgical intention in terms of local debulking. However, bony decompression of the optic canal including anterior clinoidectomy for optic nerve decompression is still a surgical maneuver under discussion.
Methods From 2006 to 2011, 46 consecutive patients with skull base meningiomas in and around the optic canal were operated. The pterional approach was tailored for each patient. Resection included bony decompression of the optic canal with or without anterior clinoidectomy. Visual acuity and fields were evaluated pre- and postoperatively.
Results Fifty-three percent of patients underwent anterior clinoidectomy, 23 % optic canal unroofing, and 24 % any bony decompression. In 21 patients (46 %), gross total resection (GTR, Simpson grade I or II) was achieved, while 25 patients (54 %) received subtotal resection (STR, Simpson grade III or IV). Sixty-three percent of patients presented with preoperative visual impairment. Postoperative visual changes were significantly related to preoperative visual function. While all patients with normal preoperative vision remained unchanged, in patients with impaired vision, surgery caused improvement in 70 % and deterioration in 10 % of patients ($p<0.0001$). In patients with anterior clinoidectomy, vision improved more frequently than without anterior clinoidectomy ($p<0.05$).
Conclusions Anterior clinoidectomy is safe and may improve visual outcome in meningiomas in and around the optic canal.

Keywords Anterior clinoid process · Optic nerve · Visual function · Skull base · Meningioma

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Introduction

Meningiomas originating from the cavernous sinus, anterior clinoid process, sphenoid wing, and tuberculum sellae are frequently diagnosed by visual impairment due to optic nerve compression. Quite regularly, these tumors extend into the optic canal. Surgical decompression of the optic nerve is the only option to preserve visual function and has been described in various single- or double-center series [4, 13, 14]. Depending on the invaded structures, optic nerve decompression can be achieved after complete tumor removal, but may also be the main surgical intention in terms of local debulking [1]. Despite the variety of reports on this topic, the recommendation of the extent of bony decompression in such tumors is highly controversial. Some authors favor optic canal unroofing or even a more extended optic canal drilling including anterior clinoidectomy, although the risk of optic nerve injury either by direct injury of the drill itself or the resulting heat and the risk of a laceration of the carotid artery cannot be denied [2]. Other authors advocate purely soft tissue decompression including the use of angled endoscopes to control hidden corners [1, 5, 8, 12, 14].

The aim of this report therefore is to show the differences in patients harboring meningiomas around the optic canal, who underwent extended optic canal decompression including anterior clinoidectomy to those patients who received decompression of the optic nerve without anterior clinoidectomy. Visual outcome, further cranial nerve deficits, and complications were evaluated.

Materials and methods

Patients

From 2006 to 2011, we operated on 46 consecutive patients harboring meningiomas of the cavernous sinus, anterior clinoid process, sphenoid wing, and tuberculum sellae. Forty-four patients suffered from meningioma WHO grade I and two from meningioma WHO grade II. Mean age was 61±13 years (median, 50 years; range, 35–86 years); 34 patients (74 %) were female and 12 (26 %) were male. Mean follow-up was 25 months (median, 24 months, range, 1–67 months).

Neurological assessment

Every enrolled patient was thoroughly examined for cranial nerve deficits and further neurological impairment preoperatively, at the first postoperative day, the day of discharge, and on postoperative follow-up.

Ophthalmologic assessment

Visual status was evaluated by an ophthalmologist preoperatively, 4–7 days after surgery and on long-term follow-up. Postoperative visual outcome was defined by comparing the preoperative visual status to the status 3 months after surgery. We differentiated between improved, unchanged, and worse visual status and evaluated vision acuity and visual field separately.

Required imaging studies

Pre- and postoperative magnetic resonance imaging (MRI) scans were performed in all patients. Association between the tumor and the ICA was assessed preoperatively by carotid artery sensitive MRI series or by computed tomography angiography (CTA) if required by the surgeon. MRI included T1 without and with contrast, T2, and T2 FLAIR sequences. In some cases, computed tomography (CT) with or without CTA with slices of 1-mm thickness was used for anatomical coregistration of the neuronavigation system.

Three and 12 months after surgery, each patient underwent an MRI scan for evaluation of the extent of resection according to the protocol mentioned above. On long-term follow-up, MRI was performed annually.

Surgical technique

All patients underwent a tailored pterional craniotomy on the side of major visual impairment. Over the years, with increasing experience, the technique of optic canal drilling progressed. In the beginning, a predominant intradural preparation was performed. The dura above the optic canal and the anterior clinoid process including the falciforme ligament was excised; bone of the roof of the optic canal and/or the anterior clinoid process was drilled as needed. Thereafter, a combined intra- and extra-dural drilling was performed; again the extent of drilling was tailored to the need of tumor resection. Due to the excellent experience with extended bony resection, we currently prefer a pure extradural drilling [2]. The dura is peeled off the orbital roof and the lateral orbital wall. The sphenoid wing is drilled from lateral to medial, and bony protuberances of the orbital roof are flattened. Approximately 1 cm ventral to the superior orbital fissure, the orbital wall is reduced to a thin lamella. The dural reflexion periorbita/temporal dura is exposed, thereby the superior orbital fissure is opened [2, 3]. Subsequently, the orbital roof just medial to the meningoorbital band is drilled. Further drilling dorsally unroofs the optic canal. After partial transection of the meningoorbital band, the anterior clinoid process is hollowed, and after several microfractures, completely removed. Drilling medial to the optic canal is stopped when the sphenoid sinus is opened. Only thereafter the frontotemporal dura is opened in a flapwise fashion pedicled to the sphenoid wing. The falciforme ligament and the dura of the optic canal are divided towards the annulus tendinosus. After this wide exposure of the optic nerve, the tumor is reduced (Figs. 1, 2).

Ethical standard

The study is well in accordance with ethical standards of the local ethics committee (registration number: 5551/12) and the Declaration of Helsinki.

Statistical analysis

Chi-square or Fisher's exact test were used. Differences between groups were tested by the Kruskal–Wallis test for non-parametric one-way analysis of variance (ANOVA), followed by Dunn's test or the Student–Newman–Keuls test as post hoc tests. Differences between the two groups were tested with the Mann–Whitney–Wilcoxon test for multiple comparisons of

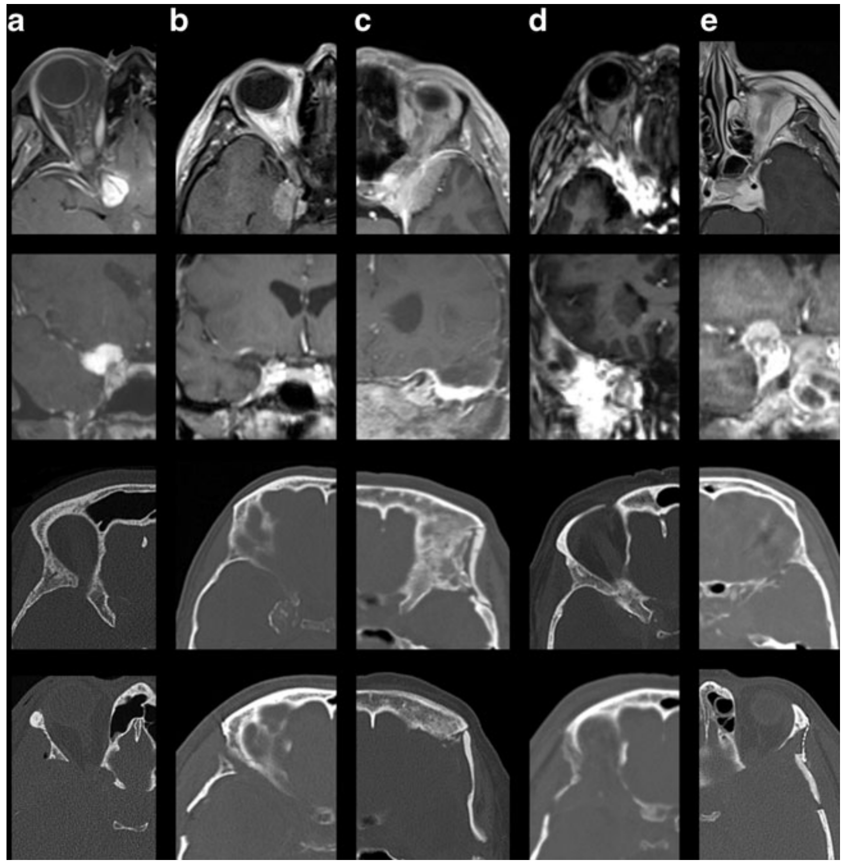

Fig. 1 Illustrative MRI (*upper row*) and CT images (*middle row*) of cases with meningiomas involving the optic canal who underwent anterior clinoidectomy as shown on postoperative CT images (*lower row*). The columns represent different tumor locations: anterior clinoid process (**a**), tuberculum sellae (**b**), sphenoid wing (**c**), sphenoorbital (**d**), and cavernous sinus (**d**) meningioma

ranks among independent samples. $p<0.05$ was considered significant. All results are presented as mean ± standard deviation (SD) (GraphPad Prism 5.0, La Jolla, CA, USA).

Fig. 2 3D reconstruction of a patient who underwent resection of the right anterior clinoid process

Results

From 2006 to 2011, three experienced surgeons operated on 46 consecutive patients with meningiomas affecting the optic nerve. Forty-six percent of tumors were on the right and 54 % were on the left side. There were 18 patients (39 %) who suffered from tumors of the anterior clinoid process, eight (17 %) of the sphenoid wing, six (13 %) sphenoorbital, four (9 %) of the cavernous sinus, four (9 %) of the sphenoid plane, four (9 %) of the tuberculum sellae, and two (4 %) patients with petroclival meningiomas. Only two patients had WHO grade II tumor (4 %), while 44 patients suffered from WHO grade I meningioma. The patients with grade II tumor as well as two further patients underwent preoperative radiotherapy and two other patients underwent surgery prior to presentation to our department.

Resection and bony decompression

In 21 patients (46 %) we were able to achieve gross total resection (GTR, Simpson grade I or II), while 25 patients (54 %) received subtotal resection (STR, Simpson grade III or IV); 24/46 (52 %) of patients underwent near 270° optic canal bony decompression including anterior clinoidectomy; 10/46

(22 %) patients received an unroofing of the optic canal. In 12/46 (26 %) patients, tumor resection was performed without bony decompression of the optic canal.

Vision impairment

Preoperative vision impairment had a mean preoperative duration of 31 months (median, 13 months, range, 1 day–113 months).

Prior to surgery, 57 % had a deficit in visual acuity, which improved significantly in 79 % of patients, remained unchanged in 17 %, and deteriorated in 4 % (one patient) of these patients. All patients without preoperative visual deficit remained unchanged ($p<0.0001$; Fig. 3a). Without regard to preoperative vision, 44 % of all patients improved, 54 % remained unchanged and 4 % even deteriorated. With regard to the visual field, 67 % of all 46 patients showed impairment. Of these 31 patients, 54 % improved, 25 % remained unchanged, and 21 % deteriorated significantly with regard to visual field deficits. In contrast, all patients without preoperative visual field impairment remained unchanged ($p<0.001$; Fig. 3b). Without regard to preoperative visual field, 36 % of all patients improved, 50 % remained unchanged and 14 % even deteriorated. However, vision improvement was independent of the preoperative duration of impaired vision.

Anterior clinoidectomy

The distribution of patients who underwent AC as a sign of maximum bony decompression was statistically independent of the operating surgeon and any preoperative visual impairment. However, 53 % of patients underwent anterior clinoidectomy. With regard to vision acuity, 61 % of these cases improved and 39 % remained unchanged. Without anterior clinoidectomy, only 25 % of patients improved, while 70 % remained unchanged, and 5 % even showed deteriorated vision acuity ($p<0.05$; Fig. 4a). Concerning visual field impairment of all patients with AC, 47 % of patients improved, 47 % did not change, and 6 % deteriorated. Correspondingly, patients without AC only improved in 24 %, remained unchanged in 52 %, and deteriorated in 24 % of cases. Yet, change in visual filed did not reach statistical significance ($p=0.16$; Fig. 4b).

Extent of resection

We also evaluated whether residual tumor is a risk factor for failed postoperative visual improvement. Patients with STR showed improvement in vision acuity in 54 %, remained unchanged in 42 %, and deteriorated in 4 % of cases. In contrast, patients with GTR showed a lower rate of postoperative improvement of 29 % and those patients remained unchanged in 71 % of cases. However, we were not able to show statistical significance ($p=0.16$). Even in those cases, where a tumor invasion into the optic canal was expected on the images but not the prominent sign intraoperatively, the surgeon felt a certainty by opening the falciforme ligament and being able to inspect the canal.

Recurrent tumor surgery

Four patients in this series underwent a second surgery for recurrent meningioma. All four patients showed unchanged vision acuity and visual field. Another three patients underwent radiation therapy prior to surgery. Out of these, one patient showed unchanged, one patient improved, and another patient showed deteriorated vision acuity but also visual field.

Further neurological deficit

Out of the 46 patients, 12 (26 %) suffered from preoperative cranial nerve (CN) deficit including trigeminal dysesthesia, diplopia, and hypacusis. During postoperative follow-up, 11 patients (24 %) presented with persisting CN dysfunction. In terms of oculomotor nerve function (CN III, IV, VI), five patients showed a preoperative palsy; three recovered after

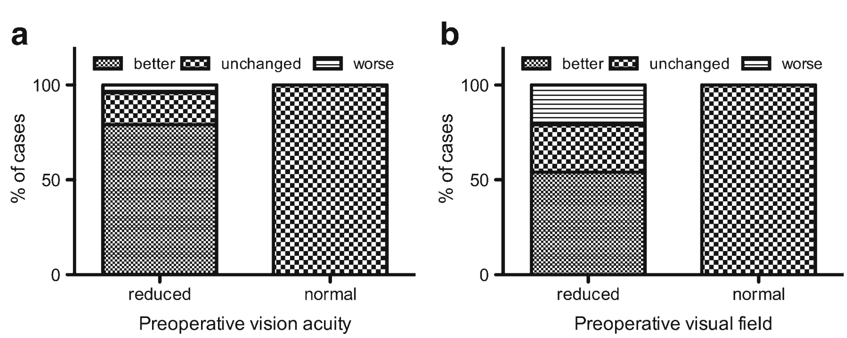

Fig. 3 **a** In patients with preoperative impaired vision acuity, 79 % showed significant improvement while all patients without preoperative visual deficit remained equal ($p<0.0001$). **b** Out of all patients with visual field impairment, 54 % improved and all patients without preoperative visual field impairment remained unchanged ($p<0.001$)

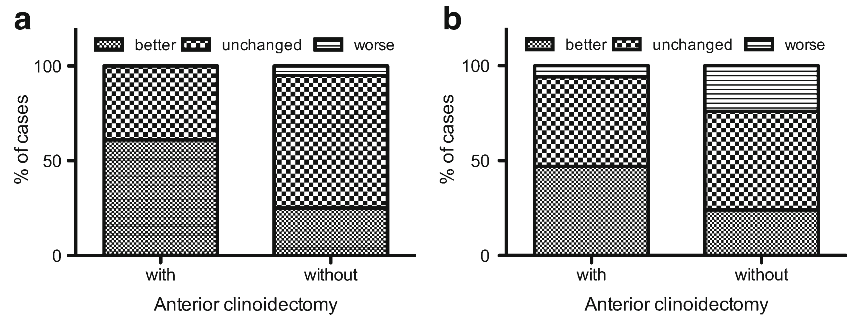

Fig. 4 Patients with anterior clinoidectomy (AC) showed significantly improved visual acuity (**a**; $p<0.05$), whereas changes in visual field showed a trend towards better improvement with AC but failed to reach statistical significance (**b**; $p=0.16$)

surgery and resolved completely during follow-up, while two patients remained unchanged. Moreover, six patients showed a new deficit of oculomotor nerve function (CN III, IV, VI) from which five recovered completely during follow-up.

With regard to surgery-related complications, we observed two cases of secondary acute subdural hemorrhages, one CSF fistula, three chronic subdural hematomas, one patient with symptomatic epilepsy, and one case of meningitis. On long-term follow-up, one patient with acute secondary subdural hemorrhage remained apallic, while none of the other patients suffered from long-term sequelae. Additionally, symptomatic epilepsy did not recur under antiepileptic medication. Moreover, two patients suffered from intraoperative laceration of the right ICA. In one of these cases (meningioma WHO grade II), a primary suture with consecutive endovascular stenting was used without ischemia or neurological sequelae. Yet, the other patient suffered from consecutive stroke of the right anterior territory of the middle cerebral artery after surgical clipping of the ICA to control bleeding despite some degree of crossflow. However, neither of the patients suffered from paresis or further sequelae on long-term follow-up.

By drilling of the AC itself, we did not encounter any complications such as laceration of the ICA or optic nerve.

Discussion

During microsurgical resection of meningiomas in and around the optic canal, the eminent issue is to achieve, as possible, a Simpson grade II resection but without any surgically related impairment of function of the optic nerve. The hypothesis of the study was that wide bony and soft tissue decompression of the optic nerve might be the crucial step in the surgical strategy providing preservation of optic nerve function.

Surgical strategy

In this study, three categories of optic canal opening were distinguished. No opening at all, optic canal unroofing, which was mainly performed from intradurally after intradural tumor resection, and wide bony decompression including anterior clinoidectomy, which was preferentially performed extradurally, respectively. The decision of whether to perform an optic canal decompression of various extend was primarily upon the evaluation of the images, not the status of visual function. Clear intracanalicular tumor extension or optic canal narrowing due to hyperostosis in sphenoorbital meningiomas justified optic canal opening. Therefore, the distribution of patients who underwent AC was statistically independent of the preoperative visual status. The positive result in the early years motivated us to indicate optic canal decompression more liberally. Our primary intention is the complete resection of the meningioma not invading the cavernous sinus. GTR was achieved in 46 % of patients, depending upon tumor invasiveness and location. These data are highly comparable to other previous studies [6, 14]. The anterior clinoid process may be tumor-invaded, in those cases, anterior clinoidectomy may play a crucial role in reducing tumor recurrence [6, 9]. Within a mean follow-up of 25 months, we only observed one patient with recurrent WHO grade II tumor after Simpson grade III resection of a meningioma of the anterior clinoid process who underwent repeated surgery.

We also evaluated whether residual tumor is a risk factor for failed postoperative visual improvement. Despite failing to reach a statistically significant level, patients with STR showed a trend towards better postoperative visual improvement compared to patients with GTR. In combination with the impact of AC on visual outcome, this trend might be a sign that not the extent of resection but direct optic nerve decompression is the major factor for improved postoperative visual outcome. Moreover, this trend alerts us that too aggressive tumor reduction might cause iatrogenic injury to the optic nerve and therefore influence visual outcome in a negative way.

Timing and the surgical details of optic canal decompression is still under discussion among skull base surgeons [6, 7, 9]. The vast majority of studies recommended early extradural AC and optic canal decompression in order to achieve the best visual recovery. This recommendation is mainly based on the understanding that an early released optic nerve can be handled safer during consecutive tumor resection

[7, 9, 14]. Moreover, 270° optic nerve bony decompression including extradural AC enlarges the surgical approach to the opticocarotid angle with superior exposure of the branches of the carotid artery, in particular the ophthalmic artery.

However, resection of the tumor next to the optic nerve primarily depends on the exact tumor location in relation to the optic nerve and thereby the optic canal. Tumor medioinferior to the optic nerve, near or in the optic canal, or between the optic nerve and the carotid artery can only be seen after slight dislocation of the optic nerve, if the optic nerve has not already been dislocated by the tumor itself. After wide opening of the optic canal including anterior clinoidectomy, as well as incision of the falciform ligament and the dura of the optic canal, this dislocation of the optic nerve, especially from medial to lateral, does not result in compression against bone, i.e., the anterior clinoid process. Thus, AC causes a higher intraoperative mobility and reduced sensitivity to intraoperative manipulation independent of the tumor location. Moreover, postoperative swelling of the optic nerve might cause less perfusion deficit when the optic nerve is not confined by the anterior clinoid process. Nonetheless, extensive irrigation during drilling has to be advocated, as it is crucial to prevent thermal injury to the optic nerve and its vasculature [4, 6, 7, 13].

Endoscope-assisted microsurgery has been described for the resection of tumor reaching into the optic canal. The surgeons of the herein presented patients felt a certainty by opening the falciforme ligament and being able to inspect the optic canal. The anatomical narrowness of the canal with additional tumor obstructing the canal is not the best requisite for the endoscopic inspection.

Anterior clinoidectomy and vision recovery

Prior to surgery, 57 % had a deficit in visual acuity, which improved significantly in 79 % of this group of patients. Fifty-three percent of patients underwent anterior clinoidectomy, 23 % optic canal unroofing, and 24 % any bony decompression. Postoperative changes in vision were significantly related to the preoperative visual function. While all patients with normal preoperative vision remained unchanged, in patients with impaired vision, surgery caused an improvement in 70 % and deterioration in 10 % of patients ($p<0.0001$). In patients with anterior clinoidectomy, vision improved in 61 % of patients while it improved in only 25 % of patients without anterior clinoidectomy ($p<0.05$).

This study provides statistical evidence that patients who underwent AC showed a higher rate of postoperative visual recovery than patients without AC ($p<0.05$; Fig. 4a). Yet, we have to note that we are not able to finally prove that AC is an independent factor for postoperative visual improvement. However, our data strongly suggests this fact.

Involvement of the optic canal can occur in a wide variety of anterior and middle fossa skull base meningiomas [1, 6, 14]. Like in our series, these tumors therefore already impair visual function in 35 to 70 % of patients depending on the cited series [6, 9, 13]. Thus, the overall surgical result is not only defined by the extent of meningioma resection but also by the extent of optic nerve decompression through unroofing of the optic canal and AC [1, 10, 13, 14].

Despite that tumor extension within the optic canal and its resection are frequently reported to be an indicator of poor prognosis due to imminent nerve ischemia, our study clearly shows that extensive decompression of the optic nerve is effective in improving visual outcome in the majority of patients [9]. A major cause for the improved nerve function may be the improved perfusion of the vasa nervorum after wide bony decompression. The intracranial portion of the optic nerve receives its blood supply from perforating vessels of the internal carotid artery or directly from the superior hypophyseal artery; the intraorbital portion from the ophthalmic artery [4, 10]. Both sources are not extensively endangered during extradural drilling.

In this series, preoperative visual status but not the duration of vision impairment were shown to be predictors of improved visual outcome. In former series, age and tumor size were also shown to be prognostic factors [4, 11, 13].

Adverse events of extensive bony decompression

Despite an aggressive surgical strategy with extensive bony decompression, we observed a low rate of surgery-related complications or co-morbidities, which is highly comparable with previous reports [1, 9]. The major potential hazard of anterior clinoidectomy is the laceration of the carotid artery, which may require occlusion of this vessel. This complication has not been encountered during drilling. Another potential risk is winding of tissue on the drill. To avoid this, we implemented the pure extradural optic canal decompression and anterior clinoidectomy. Opening of the sphenoid sinus carries the risk of a CSF fistula. The free pericranial flap replacing the falciform ligament did prevent this sequel in our series.

Conclusions

To achieve the optimal visual outcome in microsurgically resected meningiomas involving the optic nerve, wide bony decompression of the optic canal including anterior clinoidectomy might be advocated. This report supports the more aggressive bony decompression in such tumors and adds another mosaic in this controversially discussed issue.

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Conflict of interest None.

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