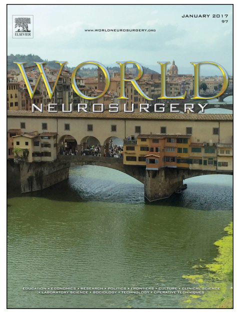

Surgical treatment of intraorbital lesions

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Surgical treatment of intraorbital lesions

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Orbital tumor, skull base surgery, surgical technique, approach, neuro-oncology

Running title

Intraorbital lesions

Abstract

Background: Resection of pure intraorbital tumors is challenging due to immediate vicinity to the optic apparatus. We report our experience with different intraorbital tumors and discuss classic approaches and obstacles.

Methods: A retrospective case series at a tertiary neurosurgical center of patients who underwent surgery for intraorbital tumors between 06/2007 – 01/2020 was performed.

Results: We included 34 patients (median age 58, range of 18-87 years, 55.9% [19/34] female, 44.1% [15/34] male). Preoperative proptosis was observed in 67.6% (23/34), visual impairment in 52.9% (18/34), diplopia in 41.2% (14/34) and ptosis in 38.3% (13/34). Intraconal tumors were found in 58.8% (20/34). Most common lesions were cavernous hemangiomas in 26.5% (9/34) and metastases in 14.7% (5/34). Gross total resection rate was 73.5% (25/34). Planned biopsy was performed in 14.7% (5/34). Median follow-up time was 15.5 months (range 0-113). 23.5% (8/34) underwent a supraorbital approach, 52.9% (18/34) a pterional approach, 14.7% (5/34) a lateral orbitotomy, 5.9% (2/34) a transnasal approach and one patient (2.9%) underwent a combined approach (transnasal/lateral orbitotomy). Excluding planned biopsies, gross total resection was achieved in 80.0% (12/15) with a pterional, 100% (7/7) with a supraorbital approach, 80.0% (4/5) with a lateral orbitotomy, 100% (1/1) via a transnasal and a combined approach, respectively. Complication rate requiring surgical intervention was 11.8 % (4/34).

Conclusion: Considering the low operative morbidity and satisfying functional outcome, gross total resection of intraorbital lesions is feasible. We support the use of classic transcranial and transorbital approaches. More invasive and complicated approaches were not needed in our series.

INTRODUCTION

Treatment of neoplasms involving the orbit might be challenging as impairment of intraorbital structures can result in an important reduction of quality of life. When planning an optimal surgical treatment strategy, one has to take various factors into account. Primary lesions, originating from orbital structures have to be distinguished from secondary lesions penetrating into the orbit and metastatic neoplasm[1]. Tumors can be intra-, extraconal or intracanalicular depending on the location according to the muscle cone and the optic canal[2]. About two thirds of orbital neoplasms are benign with higher incidences of malignant tumors in elderly patients[2, 3].

To access intraorbital lesions, two major approaches exist, with various extensions and technical nuances: the transorbital rand the extraorbital approach (including classical skull base approaches such as pterional or supraorbital)[2, 4-8]. More recently, the transnasal endoscopic technique allows exposure of the orbit in selected cases. Sometimes, combined approaches are required.

In this manuscript we present outcome and adverse events in a large contemporary cohort of primary intraorbital lesions and discuss surgical advantages and disadvantages of transorbital, extraorbital and transnasal endoscopic approaches.

MATERIAL AND METHODS

Study design and outcome parameters

We performed an observational retrospective single-center case series study. Patients who underwent surgery for intraorbital tumors between June 2007 and January 2020 were included. The clinical records of patients were analyzed according to surgical approach, pre- and postoperative neurological and ophthalmological status, Karnofsky Performance Status Scale (KPSS) and adverse events during follow up visits. Extent of resection was determined by pre- and postoperative T1 ± contrast agent 3.0 T MRI sequences.

Statistics

Statistical analysis was performed using the software STATA (version 13.1, 2011, StataCorp, College Station, Texas, USA). Normal distribution was assumed according to the central limit theorem. Data in text and graphs are shown as median (mdn.) with interquartile range

(IQR) or mean ± standard deviation (SD). A p value $\leq .05$ was considered significant and indicated by "*", p values $\leq .01$ were indicated by "**", and values $\leq .001$ by "***".

Ethics approval

The local ethics committee of the Technical University Munich, School of Medicine (231/20 S-EB) (Ethikkommission der Fakultät für Medizin der Technischen Universität München), approved our study. We conducted it in accordance with the ethical standards of the 1964 Declaration of Helsinki and its later amendments [9].

The requirement for written informed consent was waived by the ethics committee (Ethikkommission der Fakultät für Medizin der Technischen Universität München).

Surgical approaches

Transcranial extraorbital approaches

This group consisted of pterional, frontolateral, and the smaller supraorbital approaches (Fig. 1). These "workhorses" approaches have been published and trended over recent years[10-13]. We use either a myocutaneous flap or a subfascial dissection to preserve frontal facial branches. A commonly known craniotomy is performed. The sphenoid wing is partially drilled to expose the frontal and temporal dura. An orbital osteotomy and excision of the adjacent orbital roof are performed if frontal lobe retraction is required; otherwise, the orbital rim can be left intact. The superior orbital fissure is opened and the orbital roof resected to expose the periorbita. The amount of bone removal depends on the tumor location. Extradural optic canal decompression may be performed for intracanalicular lesions. In most cases, the tumor can be separated from neuromuscular structures in the periorbital fat. If the osseous orbital defect is large, titanium mesh is used to prevent postoperative enophthalmos.

For the more minimal invasive supraorbital approach[10, 14, 15], an eyebrow incision is performed. The supraorbital nerve must be detected; it defines the medial edge of the incision and the craniotomy. The fat pad and muscle are reflected posteriorly. The supraorbital rim is exposed. A single burr hole is made on or medial to the keyhole. Navigation may be used to avoid opening of the frontal sinus. In case of intradural resection, the dura is opened in a U-shaped fashion based on the orbital rim. The frontal lobes may be mobilized away from the cranial base using appropriate techniques such as opening of the optico-carotid cisterns by splitting the anterior Sylvian fissure, dissecting the optico-carotid arachnoid membranes and releasing cerebrospinal fluid.

Lateral orbitotomy

In our series, we did perform a lateral orbitotomy if indicated. Tumors that involve the lateral orbit, orbital apex, middle fossa, and cavernous sinus can be operated via this technique[5, 6, 16-18]. A curvilinear skin incision is made, beginning in the lateral upper brow, extending to the mid-lateral orbit, and then posterior for about 3 cm from the lateral canthus. The lateral canthus is removed by blunt and sharp dissection. The orbital rim is removed and the lateral orbital wall drilled down. The periorbita is opened and the tumor exposed. The exposure can be extended posteriorly all the way to the orbital apex. A traction suture can be placed under the lateral rectus muscle distally to identify the muscle more easily under the periorbita. A periorbital incision is made, avoiding the lateral rectus muscle. When the tumor is identified, it is dissected using sharp and blunt microsurgical techniques.
(Fig. 2).

Endoscopic transnasal approach

The transnasal endoscopic approach is possible for intraconal lesions located inferiorly and medially to the optic nerve. Tumor manipulation must be carried out very carefully, as full control is not given due to limited exposure. After sphenoethmoidectomy, a maxillary antrostomy is performed to expose the floor of the orbit (Fig. 3). The middle turbinate is resected, and medial maxillectomy after swinging of the inferior turbinate can be performed to completely expose the inferior and medial orbit. The medial part of the lamina papyracea and the floor of the orbit are removed [19-21] (Fig. 4). Afterward, the periorbita is sharply opened. For intraconal lesions located inferiorly and medially, the dissection corridor is between the medial and inferior rectus muscles. These muscles should be identified.

RESULTS

Patient population

34 patients underwent resection for primary intraorbital lesions and were analyzed. (*patient characteristics see* Table 1).

Postoperative outcome

Median follow-up time was 15.5 [0-113] months. Surgery-related mortality was 0%. (*Detailed postoperative outcome see* Table 2).

One patient with a solitary fibrous tumor underwent a combined technique including a transnasal approach and a lateral orbitotomy. Excluding planned biopsies, GTR was achieved in 80.0% (12/15) with a pterional approach, 100% (7/7) with a supraorbital approach, 80.0% (4/5) with a lateral orbitotomy, 100% (1/1) via a transnasal approach and a combined approach, respectively. Prior to surgery, 52.9% (18/34) had visual impairment and 11.8% (4/34) had amaurosis of the affected eye. Vision improved in 41.2% (14/34) after surgery. One of four patients suffering from amaurosis improved. Only one patient without preoperative visual deficit deteriorated after surgery.

Total adverse event rate requiring surgical intervention was 11.8%, with none of these patients experiencing a permanent neuro-ophthalmological deficit. One patient (2.9%) operated through a frontolateral approach for a metastasis developed a symptomatic epidural hematoma, 5.9% (2/34) developed a postoperative abscess, and one patient (2.9%) needed revision due to massive postoperative proptosis and amaurosis caused by postoperative hemorrhage via orbitotomy.

DISCUSSION

Extent of resection, clinical and neuro-ophthalmological outcome

In the present series, good clinical outcome and high rates of GTR (73.5%) or STR (11.8%) were achieved using straight forward extra- or transorbital approaches. These results are in line with comparable cohorts [10, 15, 17, 18, 22]. Our numbers are in line with the prior reports, considering that comparison of these individual orbital lesions can be difficult. Hassler et al. reported no postoperative deficits in treatment of 58 vascular lesions with 44 cases of cavernous malformations, in which they advocated early surgical treatment to avoid neuroophthalmological deficits in further course [15]. In another series, they could achieve GTR in all of 19 cases using tailored extraorbital approaches. Interestingly, Hejazi and Hassler compared clinicopathological and radiological findings of orbital and cerebral cavernous malformations. In contrast to the cerebral ones, orbital cavernous malformations showed non-degenerated well-developed vessel walls and were covered by a hard and compact capsule [17].

Visual complications in our series were few and neuro-ophthalmological outcome excellent. Postoperative visual improvement occurred in 41.2% (14/34), also in one of the four patients with preoperative amaurosis. Our findings suggest GTR via classic approaches in order to remain and improve visual outcome. Sing et al. could prospectively show the preoperative impact on visual function of orbital tumors and the relevance of surgical resection in their prospective study [23]. As good neuro-ophthalmological outcome with GTR can be achieved and deterioration is rare, we advocate a surgical strategy to prevent neural injury especially in cavernous hemangiomas and other benign intraorbital lesions, as previously described [15, 17, 23].

Choosing a suitable approach

Treatment strategy for orbital tumors should always respect the individual's anatomy, clinical presentation, and the patient's baseline characteristics. To facilitate the choice of an appropriate approach, the main decision the surgeon has to make is whether to approach the lesion via an extra- or transorbital approach. Anterior lesions can be targeted via a transorbital approach, while lesions of the posterior third of the orbit are well managed through extraorbital approaches[2, 5, 6]. Size of the tumor, goal of the surgery (biopsy, optic decompression, GTR), and the characteristics of the tumor must be considered when choosing the right technique. Extraorbital approaches enable superior visualization of intraorbital tumors through the orbit roof and its lateral wall[24]. Lateral located intraconal lesions can be feasible targeted by a lateral orbitotomy. Lesions located more inferiorly, for example, could be targeted by a transconjunctival approach whereas involvement of the optic canal, orbital apex and superior orbital fissure may be operated by an extraorbital approach. Superior medial, intraconal lesions can be approached supraorbitally [25]. As we focused on pure intraorbital tumors, no greater variations of the classic workhorse approaches were necessary.

Transcranial extraorbital approaches

The pterional/frontolateral approach is the classic workhorse approach proposed by Dandy[26] in 1922, with later further refinements and modifications[27-31]. One advantage of this approach is the satisfactory view of the superior and lateral aspects of the posterior orbit, the optic canal, the superior orbital fissure, and a panoramic view of the orbital apex. No other orbito-cranial approaches provide such exposure. By focusing on the Sylvian fissure and providing access to the sphenoid ridge, cranio-orbital lesions with intradural invasion can also be feasibly targeted. The exposure is primarily achieved by removing the sphenoid wing to expose the superior orbital fissure as well as the posterior and lateral orbit. In the present cohort, postoperative visual improvement occurred in 41.2% of cases. In particular, tumorous involvement of the orbit/optic structures emphasizes the advantage of the posterior view by this approach. Optic canal decompression intra- or extradurally can be performed if necessary [32, 33]. As a minimized modification, the keyhole concept was first advocated and described by Perneczky et al.[31] in 1998. Further authors reported feasibility of that approach [34]. Hassler et al. showed satisfactory results with the extradural supraorbital approach in 20 patients with no cosmetic issues, size of craniotomy was no relevant limitation [10]. Prior reports also advocate these extraorbital techniques in case of extraorbital tumor growth [13, 15, 18]. Tumors medial and basal to the optic nerve should not be operated on via these approaches. Tumors of the superior orbital fissure and the cavernous sinus are best approached extradurally.

Transorbital approaches

The lateral orbitotomy is an indispensable approach for resection of orbital tumors and accessing vascular pathologies. Krönlein first described the lateral orbitotomy in 1889 for exposure of the temporal orbital compartment[35]. Intraconal tumors located dorsally, basally, and laterally to the optic nerve can be easily targeted by this technique[31, 36, 37]. In a series of 85 cases of hemangiomas, resected via lateral orbitotomy in 71 cases, the approach turned out to be efficacious, with only three patients experiencing postoperative visual impairment[38]. Schick and Hassler reported successful treatment of orbital lymphomas in 15 cases with no complications using a lateral orbitotomy [18]. Several modifications have been proposed, such as the Berke-Reese approach, with a more direct access to the orbit through a smaller, straight, horizontal cut made lateral to the orbit, or the Stallard-Wright lateral orbitotomy, avoiding the lateral canthotomy through a curvilinear incision beginning above the eyebrow and moving downward aslant into the temporal area[39, 40]. Lateral orbitotomies through upper lid crease incisions with limited canthotomy to minimize cosmetic complications are performed as well. Tumors of the orbital apex or located medial to the optic nerve should not be operated on via this approach [25]. Maroon and Kennerdell described an anterior medial orbitotomy recommended for biopsies and the removal of tumors of the medial intraconal space [41]. With their techniques it is still necessary to sever the medial rectus muscle close to its insertion site to achieve enough ocular bulb motility for lateral retraction. In contrast, Hassler presented a microneurosurgical transconjunctival approach for the removal of retrobulbar intraconal cavernoma advocating for the removal of cavernomas located in the basal, inferomedial, and lateral aspect of the orbit [25, 42]. Further reports showed satisfactory results with that technique, which, if unexperienced, is to be performed interdisciplinary [18, 25]. However, this approach obviates the need for bone resection and subsequent reconstruction, making it a less traumatic approach with no visible scar. Nevertheless, the transconjunctival approach is not indicated for larger-sized tumors because of the limited surgical corridor. In our series, we did not have the necessity to perform an anterior transorbital approach as tumor locations allowed as to perform our more well-experienced techniques. An interdisciplinary procedure was not necessary as well. Further modifications and alternatives such as the total lateral orbitotomy or the medial micro-orbitotomy have been described in detail[31].

Endoscopic transnasal approaches

Endoscopic approaches were only used in three cases: In one case of highly suspected lymphoma, a biopsy was performed endoscopically; in another case, endoscopic resection was paused and switched to a transorbital approach as the tumor (solid fibrous tumor) turned out to be inaccessible and unfavorable for endoscopy. Successful endoscopic resection was performed in one case with optimized tumor position close to the lamina papyracea located inferiorly and medially.

However, we do not use endoscopic approaches regularly for orbital tumors, as the limitations, disadvantages, and higher morbidity outweigh the benefits[19, 20]. The endoscopic technique involves a few limitations, such as the steep angle required to reach the lateral orbit, the lack of binocular vision, and the subsequent lack of depth perception. One of the major complications of using this approach is cerebrospinal fluid leak.

To sum it up, the evolution to fewer distressing procedures for the removal of pure intraorbital tumors is going on since the important notes and results beginning from Dandy to Hassler, Margalit and further authors [2, 42, 43]. Nowadays, the surgical technique can be tailored according to the individual tumor localization, thanks to high resolution imaging. Most of the orbit's regions or quadrants can be reached and overseen with different, safe operative approaches, avoiding sacrifice of the orbital contents. Based on our results we think that, only if the tumor is extensively invading extraorbital structures of periorbital anatomy or the anatomy is grossly altered, extra- or transorbital approaches might need to be extended or further modification. The transnasal endoscopic technique is a simple and suitable option for planned biopsies of inferomedial lesions or in combination with other approaches in case of a tailored approach in large tumor masses. Nowadays, with superior preoperative visualization due to high resolution imaging, a valid choice of approach can be made during presurgical planning. Most of the orbit's regions can be reached and overseen with different, yet standard approaches, avoiding risk to the orbital structures. There is not a superior or „one fits all" approach to primary orbital lesions, yet, based on our series, we think a „few fit most" concept of using standard approaches allows a very good outcome with high learning curve in the majority of cases. With this concept of standardization, we believe, more neurosurgical colleagues can provide good care of patients with these rare lesions.

Histopathological considerations

Analogue to our series, orbital cavernous hemangioma is the most common orbital tumor in adults and appears as a well-defined intraconal mass (Fig. 5). McNab et al. analyzed anatomical locations of those lesions in 104 patients and could show that they tend to occur in the intraconal space (87%) and lateral to the optic nerve (47%) [44]. A further study of cavernous hemangiomas in 39 patients by Rootman et al. showed that 33% of patients presented with optic nerve dysfunction. They also showed that 75% of the lesions were situated in the intraconal space, with optic nerve compression in 54% [45]. Kloos et al. reported four cases of apical pear-shaped cavernous hemangiomas partially removed leading to postoperative hemorrhage and visual loss [46]. By performing transcranial techniques and achieving GTR, such complications may be reduced. As mentioned before, the preferred approach and techniques depends mainly on the location.

Several series in the past two decades have shown an increased prevalence in the number of orbital metastases compared to earlier studies [47]. We experienced such lesions in 14.7% being the second largest histopathological entity in our series. The clinical presentation may vary, but the onset tends to be short and progressive early [48]. However, the appearance of an orbital metastasis is not always characteristic independent of the histological type, since it may present as a well-defined mass, a diffuse lesion in the intra- or extraconal space or may inducing hypo- or hyperostosis [47, 49].

Orbital solitary fibrous tumor, a rare spindle cell tumor, may present as a well-defined intra- or extraconal mass mimicking cavernous hemangiomas, schwannomas, meningiomas or fibrous histiocytoma. Immunohistochemistry is the major diagnostic tool to differentiate it from aggressive hemangiopericytoma [44]. Le et al. reported four cases of orbital solitary fibrous tumor without recurrence after GTR indicating the importance of surgical treatment [50].

Regarding inflammatory and malignant lesions, another analysis showed that malignant neoplasms of the eye socket occurred in 24% whereas inflammatory lesions occurred in 4% [51], we detected inflammatory lesions in 5.9%. Interestingly, in Caucasian populations, the percentage of patients with malignant lymphoma is 5–15%,whereby in the elderly population that percentage increases up to 24% [52, 53]. In further studies of Liu et al. and Shields et al. concerning orbital tumors, non-malignant tumors occurred most frequently, in line with our findings [52, 54].

Optic nerve sheath meningiomas represent a challenging subgroup of tumors. Surgical resection is indicated to prevent intracranial spreading and invasion to the contralateral optic nerve. Loss of vision after resection of such a meningioma is almost a rule due to the ischemic injury to the nerve for interruption of pial vessels incorporated into the growth pattern of those lesions. In rare instances, however, preservation of vision or even vision improvement after resection have been reported [55, 56].

Study Limitations

As this was a retrospective case series, it was not possible to determine causalities with respect to clinical outcome. Nevertheless, we implemented detailed clinical examination, including scores on functional performance, and a standardized follow-up protocol based on a certified neuro-oncological board into our clinical workflow. By focusing on mainly pure intraorbital lesions (primary and metastatic), we aimed to avoid case heterogeneity—with a slight reduction of sample size. Of course, heterogeneity of pathology is not negligible, but due to focusing on the surgical techniques and approaches, we decided to not exclude certain entities.

CONCLUSIONS

Considering the low operative morbidity and satisfying functional outcome, complete resection of intraorbital lesions is safe and feasible. GTR is advocated maintaining neuro-ophthalmological functionality by choosing the right and tailored approach. Lateral orbitotomy is advocated for lateral intraconal located lesions, a transconjunctival approach may be considered for medial, basal, extra and intraconal lesions, whereas a transnasal endoscopic approach can be discussed alternatively. An extraorbital pterional/frontolateral approach should be prepared in case of intracranial involvement or tumor location in the apex and the optic canal. In addition, tumors of the superior orbital fissure are candidates for a supraorbital approach. Very good outcome can be achieved using few standard approaches according to patient's individual anatomy.

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REFERENCES

1. Laws E. *The Diagnosis and Management of Orbital Tumors*. Futura P Co; 1988.
2. Margalit N, Ezer H, Fliss DM, Naftaliev E, Nossek E, Kesler A. Orbital tumors treated using transcranial approaches: surgical technique and neuroophthalmogical results in 41 patients. 2007;23(5):E11. doi:10.3171/foc-07/11/e11
3. Maroon JC, Kennerdell JS. Microsurgical Approach to Orbital Tumors. *Neurosurgery*. 1979;26(CN_suppl_1):479-489. doi:10.1093/neurosurgery/26.CN_suppl_1.479
4. Adkins W. Maxillectomy with preservation of orbital function. *Surg Forum*. 1976;27:548-550.
5. Bejjani G, Cockerham K, Kennerdel J, Maroon J. A reappraisal of surgery for orbital tumors. Part I: extraorbital approaches. *Neurosurg Focus*. 2001;10(5):E2.
6. Cockerham KP, Bejjani GK, Kennerdell JS, Maroon JC. Surgery for orbital tumors. Part II: transorbital approaches. 2001;10(5):1. doi:10.3171/foc.2001.10.5.4
7. Nakamura M, Roser F, Struck M, Vorkapic P, Samii M. Tuberculum sellae meningiomas: clinical outcome considering different surgical approaches. *Neurosurgery*. Nov 2006;59(5):1019-28; discussion 1028-9. doi:10.1227/01.NEU.0000245600.92322.06
8. Sekhar LN, Nanda A, Sen CN, Snyderman CN, Janecka IP. The extended frontal approach to tumors of the anterior, middle, and posterior skull base. *J Neurosurg*. Feb 1992;76(2):198-206. doi:10.3171/jns.1992.76.2.0198
9. World Medical Association Declaration of Helsinki: ethical principles for medical research involving human subjects. *Jama*. Nov 27 2013;310(20):2191-4. doi:10.1001/jama.2013.281053
10. Hassler W, Schick U. The supraorbital approach—a minimally invasive approach to the superior orbit. *Acta Neurochirurgica*. 2009/06/01 2009;151(6):605-612. doi:10.1007/s00701-009-0301-x
11. Schick U, Hassler W. Surgical management of tuberculum sellae meningiomas: involvement of the optic canal and visual outcome. *J Neurol Neurosurg Psychiatry*. Jul 2005;76(7):977-83. doi:10.1136/jnnp.2004.039974
12. Hassler W, Zentner J. Surgical treatment of olfactory groove meningiomas using the pterional approach. *Acta Neurochir Suppl (Wien)*. 1991;53:14-8.
13. Hassler W, Zentner J. Pterional Approach for Surgical Treatment of Olfactory Groove Meningiomas. *Neurosurgery*. 1989;25(6):942-947. doi:10.1227/00006123-198912000-00014
14. Esposito G, Dias SF, Burkhardt J-K, et al. Selection Strategy for Optimal Keyhole Approaches for Middle Cerebral Artery Aneurysms: Lateral Supraorbital Versus Minipterional Craniotomy. *World Neurosurgery*. 2019/02/01/ 2019;122:e349-e357. doi:https://doi.org/10.1016/j.wneu.2018.09.238
15. Schick U, Hassler W. Treatment of deep vascular orbital malformations. *Clinical Neurology and Neurosurgery*. 2009/12/01/ 2009;111(10):801-807. doi:https://doi.org/10.1016/j.clineuro.2009.08.004
16. Mortazavi MM, Brito da Silva H, Ferreira M, Jr., Barber JK, Pridgeon JS, Sekhar LN. Planum Sphenoidale and Tuberculum Sellae Meningiomas: Operative Nuances of a Modern Surgical Technique with Outcome and Proposal of a New Classification System. *World Neurosurg*. Feb 2016;86:270-86. doi:10.1016/j.wneu.2015.09.043
17. Hejazi N, Hassler W, Offner F, Schuster A. Cavernous malformations of the orbit: a distinct entity? *Neurosurgical Review*. 2007/01/01 2007;30(1):50-55. doi:10.1007/s10143-006-0055-3
18. Schick U, Lermen O, Unsold R, Hassler W. Treatment of primary orbital lymphomas. *Eur J Haematol*. Mar 2004;72(3):186-92. doi:10.1046/j.0902-4441.2003.00192.x
19. Arai Y, Kawahara N, Yokoyama T, Oridate N. Endoscopic transnasal approach for orbital tumors: A report of four cases. *Auris Nasus Larynx*. Jun 2016;43(3):353-8. doi:10.1016/j.anl.2015.10.009
20. Chhabra N, Wu AW, Fay A, Metson R. Endoscopic resection of orbital hemangiomas. *International Forum of Allergy & Rhinology*. 2014;4(3):251-255. doi:10.1002/alr.21267

21. Hagemann J, Roesner J, Helling S, et al. Long-term Outcome for Open and Endoscopically Resected Sinonasal Tumors. *Otolaryngol Head Neck Surg*. May 2019;160(5):862-869. doi:10.1177/0194599818815881
22. Margalit N, Ezer H, Fliss DM, Naftaliev E, Nossek E, Kesler A. Orbital tumors treated using transcranial approaches: surgical technique and neuroophthalmogical results in 41 patients. *Neurosurg Focus*. 2007;23(5):E11. doi:10.3171/foc-07/11/e11
23. Singh D, Pushker N, Bajaj MS, Saxena R, Sharma S, Ghose S. Visual function alterations in orbital tumors and factors predicting visual outcome after surgery. *Eye*. 2012/03/01 2012;26(3):448-453. doi:10.1038/eye.2011.308
24. Nanda A, Patra DP, Savardekar AR, Mohammed N, Narayan V, Bir SC. Surgery of Tuberculum Sellae Meningioma: A Technical Purview on Pterional Approach. *J Neurol Surg B Skull Base*. Apr 2018;79(Suppl 3):S265-S266. doi:10.1055/s-0038-1625945
25. Schick U, Dott U, Hassler W. Surgical treatment of orbital cavernomas. *Surg Neurol*. Sep 2003;60(3):234-44; discussion 244. doi:10.1016/s0090-3019(03)00136-8
26. Dandy WE. Prechiasmal intracranial tumors of the optic nerves. *American Journal of Ophthalmology*. 1922;5(3):169-188.
27. Housepian EM. Surgical treatment of unilateral optic nerve gliomas. *Journal of neurosurgery*. 1969;31(6):604-607.
28. Hamby W. Pterional approach to the orbits for decompression or tumor removal. *Journal of neurosurgery*. 1964;21(1):15-18.
29. LOVE JG, DODGE HW. Transcranial removal of intraorbital tumors. *AMA archives of surgery*. 1953;67(3):370-380.
30. MacCarty CS, Brown DN. Orbital tumors in children. *Neurosurgery*. 1965;11(CN_suppl_1):76-93.
31. Abou-Al-Shaar H, Krisht KM, Cohen MA, et al. Cranio-Orbital and Orbitocranial Approaches to Orbital and Intracranial Disease: Eye-Opening Approaches for Neurosurgeons. Review. *Frontiers in Surgery*. 2020-February-07 2020;7(1)doi:10.3389/fsurg.2020.00001
32. Schick U, Dott U, Hassler W. Surgical management of meningiomas involving the optic nerve sheath. *J Neurosurg*. Dec 2004;101(6):951-9. doi:10.3171/jns.2004.101.6.0951
33. Kennerdell JS, Maroon JC, Malton M, Warren FA. The management of optic nerve sheath meningiomas. *American journal of ophthalmology*. 1988;106(4):450-457.
34. Cheng C-M, Noguchi A, Dogan A, et al. Quantitative verification of the keyhole concept: a comparison of area of exposure in the parasellar region via supraorbital keyhole, frontotemporal pterional, and supraorbital approaches. *Journal of neurosurgery*. 2013;118(2):264-269.
35. Kronlein R. Zur pathologie und behandlung der dermoidcysten der orbita. *Beitr Klin Chir*. 1888;4:149.
36. Carta F, Siccardi D, Cossu M, Viola C, Maiello M. Removal of tumours of the orbital apex via a postero-lateral orbitotomy. *Journal of neurosurgical sciences*. 1998;42(4):185.
37. Goldberg RA, Shorr N, Arnold AC, Garcia GH. Deep transorbital approach to the apex and cavernous sinus. *Ophthalmic Plastic & Reconstructive Surgery*. 1998;14(5):336-341.
38. McNab AA, Wright JE. Cavernous haemangiomas of the orbit. *Australian and New Zealand journal of ophthalmology*. 1989;17(4):337-345.
39. Berke RN. A modified Krönlein operation. *AMA Archives of Ophthalmology*. 1954;51(5):609-632.
40. Stallard H. A plea for lateral orbitotomy: with certain modifications. *The British journal of ophthalmology*. 1960;44(12):718.
41. Kennerdell JS, Maroon JC, Malton ML. Surgical Approaches to Orbital Tumors. *Seminars in Ophthalmology*. 1989/01/01 1989;4(4):209-218. doi:10.3109/08820538909060142

42. Hassler W, Schaller C, Farghaly F, Rohde V. Transconjunctival approach to a large cavernoma of the orbit. *Neurosurgery*. May 1994;34(5):859-61; discussion 861-2. doi:10.1227/00006123-199405000-00011

43. DANDY WE. RESULTS FOLLOWING THE TRANSCRANIAL OPERÁTIVE ATTACK ON ORBITAL TUMORS. *Archives of Ophthalmology*. 1941;25(2):191-216. doi:10.1001/archopht.1941.00870080015001

44. Honavar SG, Manjandavida FP. Recent Advances in Orbital Tumors—A Review of Publications from 2014-2016. *The Asia-Pacific Journal of Ophthalmology*. 2017;6(2):153-158. doi:10.22608/apo.201736

45. Rootman DB, Heran MK, Rootman J, White VA, Luemsamran P, Yucel YH. Cavernous venous malformations of the orbit (so-called cavernous haemangioma): a comprehensive evaluation of their clinical, imaging and histologic nature. *Br J Ophthalmol*. Jul 2014;98(7):880-8. doi:10.1136/bjophthalmol-2013-304460

46. Kloos R, Mourits D, Saeed P, Mourits M. Orbital apex cavernous hemangioma – beware of the pear! *Acta Ophthalmologica*. 2013;91(4):e328-e329. doi:https://doi.org/10.1111/aos.12052

47. Valenzuela AA, Archibald CW, Fleming B, et al. Orbital metastasis: clinical features, management and outcome. *Orbit*. 2009;28(2-3):153-9. doi:10.1080/01676830902897470

48. Amemiya T, Hayashida H, Dake Y. Metastatic orbital tumors in Japan: a review of the literature. *Ophthalmic Epidemiol*. Feb 2002;9(1):35-47. doi:10.1076/opep.9.1.35.1718

49. Goldberg RA, Rootman J, Cline RA. Tumors metastatic to the orbit: a changing picture. *Surv Ophthalmol*. Jul-Aug 1990;35(1):1-24. doi:10.1016/0039-6257(90)90045-w

50. Le CP, Jones S, Valenzuela AA. Orbital solitary fibrous tumor: a case series with review of the literature. *Orbit*. Apr 2014;33(2):145-51. doi:10.3109/01676830.2013.853806

51. Markowski J, Jagosz-Kandziora E, Likus W, et al. Primary orbital tumors: a review of 122 cases during a 23-year period: a histo-clinical study in material from the ENT Department of the Medical University of Silesia. *Med Sci Monit*. Jun 16 2014;20:988-94. doi:10.12659/msm.890433

52. Shields JA, Shields CL, Scartozzi R. Survey of 1264 patients with orbital tumors and simulating lesions: The 2002 Montgomery Lecture, part 1. *Ophthalmology*. May 2004;111(5):997-1008. doi:10.1016/j.ophtha.2003.01.002

53. Ohtsuka K, Hashimoto M, Suzuki Y. A review of 244 orbital tumors in Japanese patients during a 21-year period: origins and locations. *Jpn J Ophthalmol*. Jan-Feb 2005;49(1):49-55. doi:10.1007/s10384-004-0147-y

54. Liu Y, Ma J-R, Xu X-L. Transcranial surgery through pterional approach for removal of cranio-orbital tumors by an interdisciplinary team of nurosurgeons and ophthalmologists. *International journal of ophthalmology*. 2012;5(2):212.

55. Schick U, Dott U, Hassler W. Surgical management of meningiomas involving the optic nerve sheath. *Journal of Neurosurgery*. 01 Jan. 2004 2004;101(6):951-959. doi:10.3171/jns.2004.101.6.0951

56. Montano N, Lauretti L, D'Alessandris QG, et al. Orbital Tumors: Report of 70 Surgically Treated Cases. *World Neurosurg*. Nov 2018;119:e449-e458. doi:10.1016/j.wneu.2018.07.181

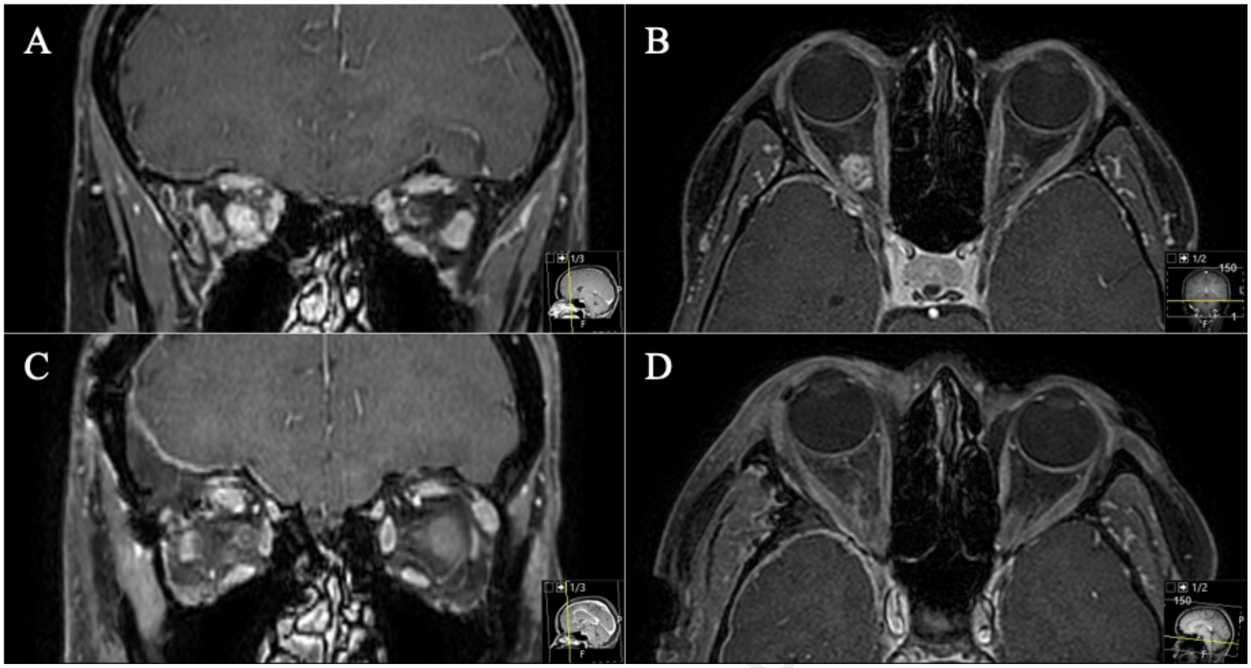
mdn. age (years)		58	[18-87]
Sex	**female**	19	(55.9%)
	male	15	(44.1%)
mdn. preoperative KPSS (%)		90	[70-100]
Preoperative deficits			
Proptosis		23	(67.6%)
Visual affection		18	(52.9%)
Amaurosis		4	(11.8%)
Diplopia		14	(41.2%)
Ptosis		13	(38.3%)
Headache		8	(23.5%)
Oculomotor nerve palsy		9	(26.5%)
Trochlear nerve palsy		1	(2.9%)
Abducens nerve palsy		3	(8.8%)
Histopathology			
Meningioma WHO grade I		2	(5.9%)
Metastasis		5	(14.7%)
Cavernous hemangioma		11	(32.4%)
Schwannoma WHO grade I		2	(5.9%)
Inflammatory lesion		2	(5.9%)
Other *)		12 *1 case per entity*	(35.3%) *(2.9%)*
Intraconal		20	(58.8%)
Extraconal		14	(41.2%)
Approach			
Supraorbital keyhole		8	(23.5%)
Pterional/frontolateral		18	(52.9%)
Lateral orbitotomy		5	(14.7%)
Transnasal endoscopic		2	(5.9%)
Combined approach (transnasal + lat. orbitotomy)		1	(2.9%)
total		34	

Table 1: Demographics, clinical presentation, histopathology anatomical localization and surgical approach. *) pathologic entity “other” (one each): Aspergilloma, cholesterol granuloma, fibrosis, Langerhans Cell Histiocytosis, leiomyosarcoma, lymphangioma, lymphoma, neurofibroma, pleomorphic adenoma, solid fibrous tumor, cylindrical cell

carcinoma. Data shown as n = number (%). Mdn. = median [interquartile range]. KPSS = Karnofsky Performance Status Scale.

Extent of resection		
GTR	25	(73.5%)
STR	4	(11.8%)
Biopsy only	5	(14.7%)
Postoperative outcome		
KPSS	90	(70-100%)
Follow-Up (months)	15.5	(0-113)
Proptosis	4	(11.8%)
Ptosis	4	(11.8%
Enophthalmos	1	(2.9%)
Corneal arrosion	1	(2.9%)
Oculomotor nerve palsy	5	(14.7%)
Trochlear nerve palsy	2	(5.9%)
Abducens nerve palsy	4	(11.8%)
Visual improvement	14	(41.2%)
Visual decline	1	(2.9%)
Adverse events (necessitating surgical intervention)	4	(11.8%)
Epidural hematoma	1	(2.9%)
Abscess	2	(5.9%)
Intraorbital hemorrhage	1	(2.9%)
total	n = 34	

Table 2: Postoperative outcome. Data shown as n = number (%). Mdn. = median [interquartile range]. GTR=gross total resection, STR=subtotal resection, KPSS= Karnofsky performance status scale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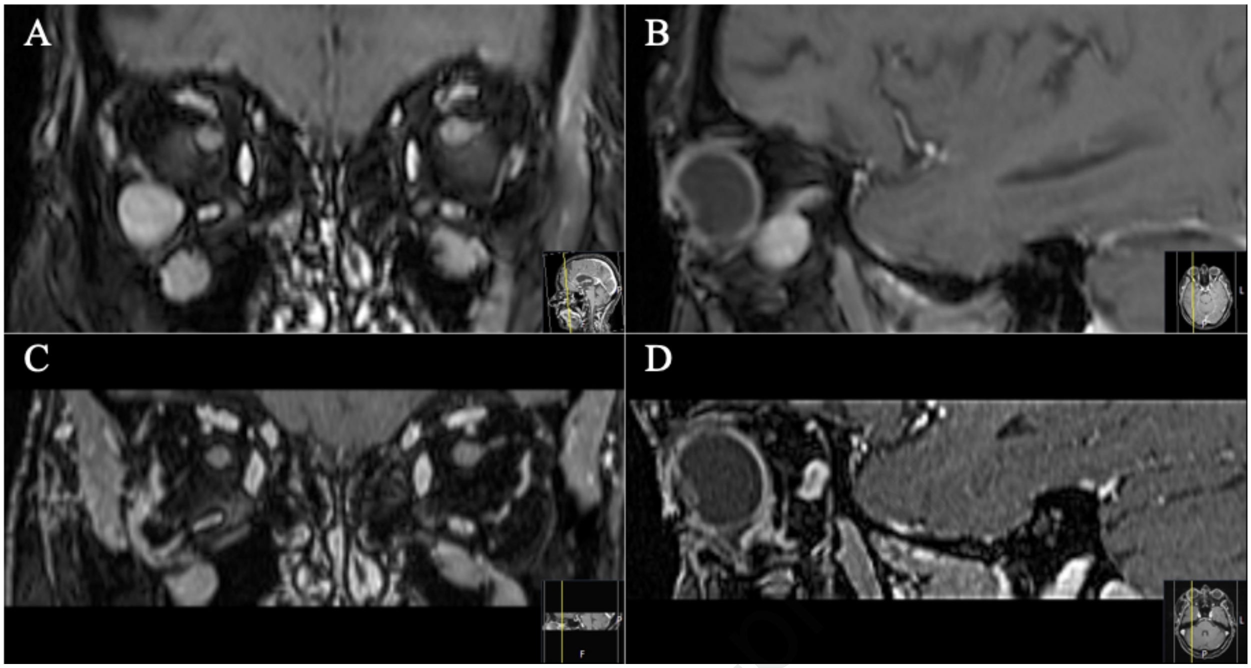
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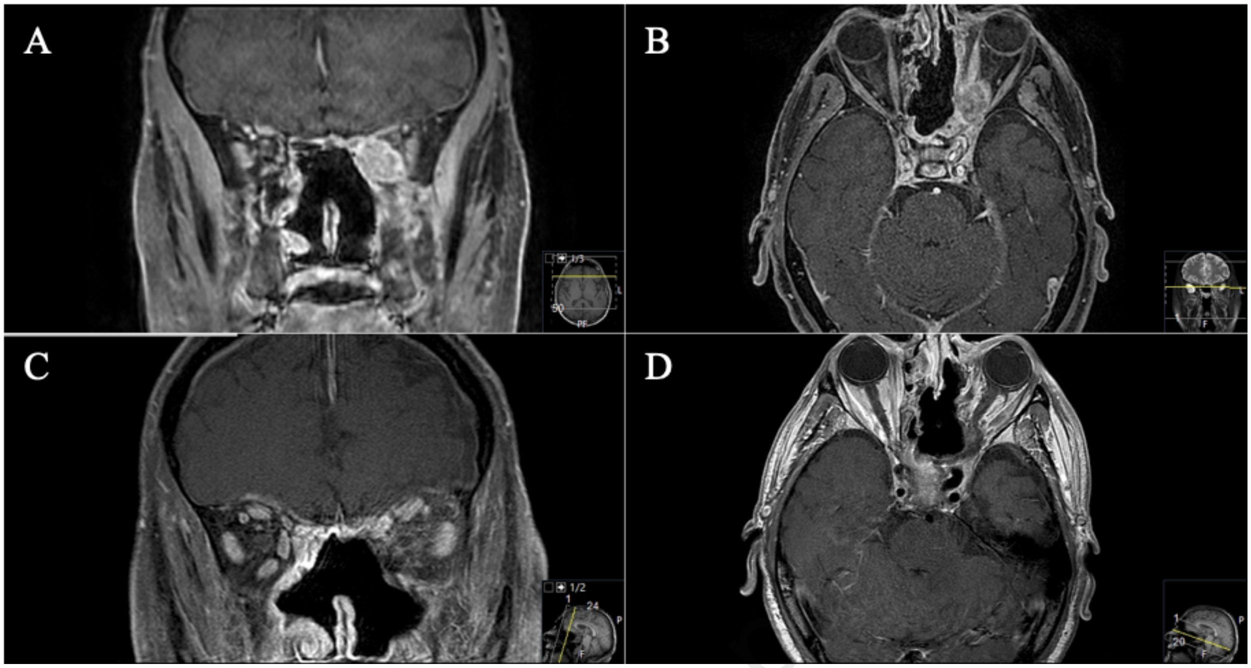
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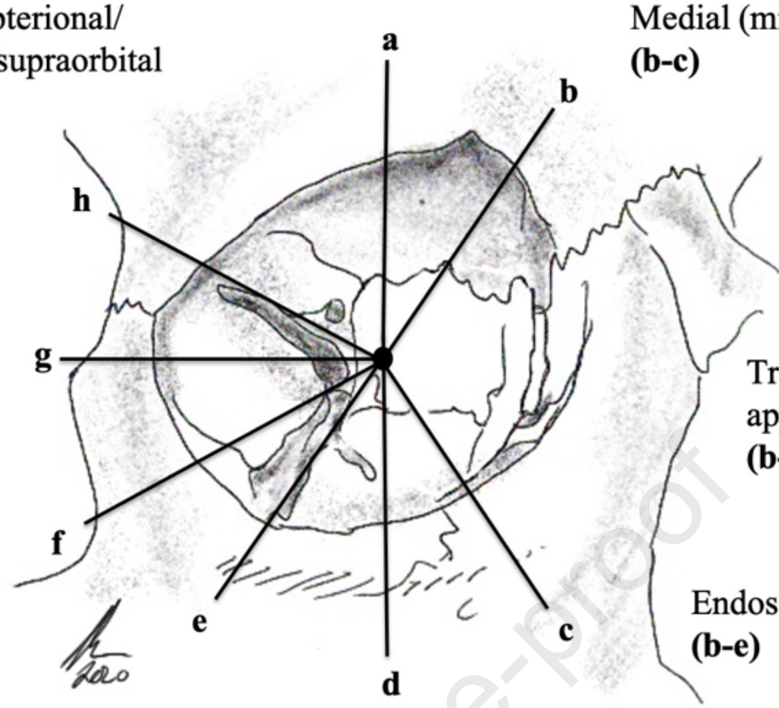
D

Extraorbital pterional/
frontolateral/supraorbital
(g-b)

Medial (micro-)orbitotomy
(b-c)



Lateral
orbitotomy
(f-h)

Transconjunctival
approach
(b-d)

Endoscopic transnasal
(b-e)

Additionally
zygomatic osteotomy
(d-f)

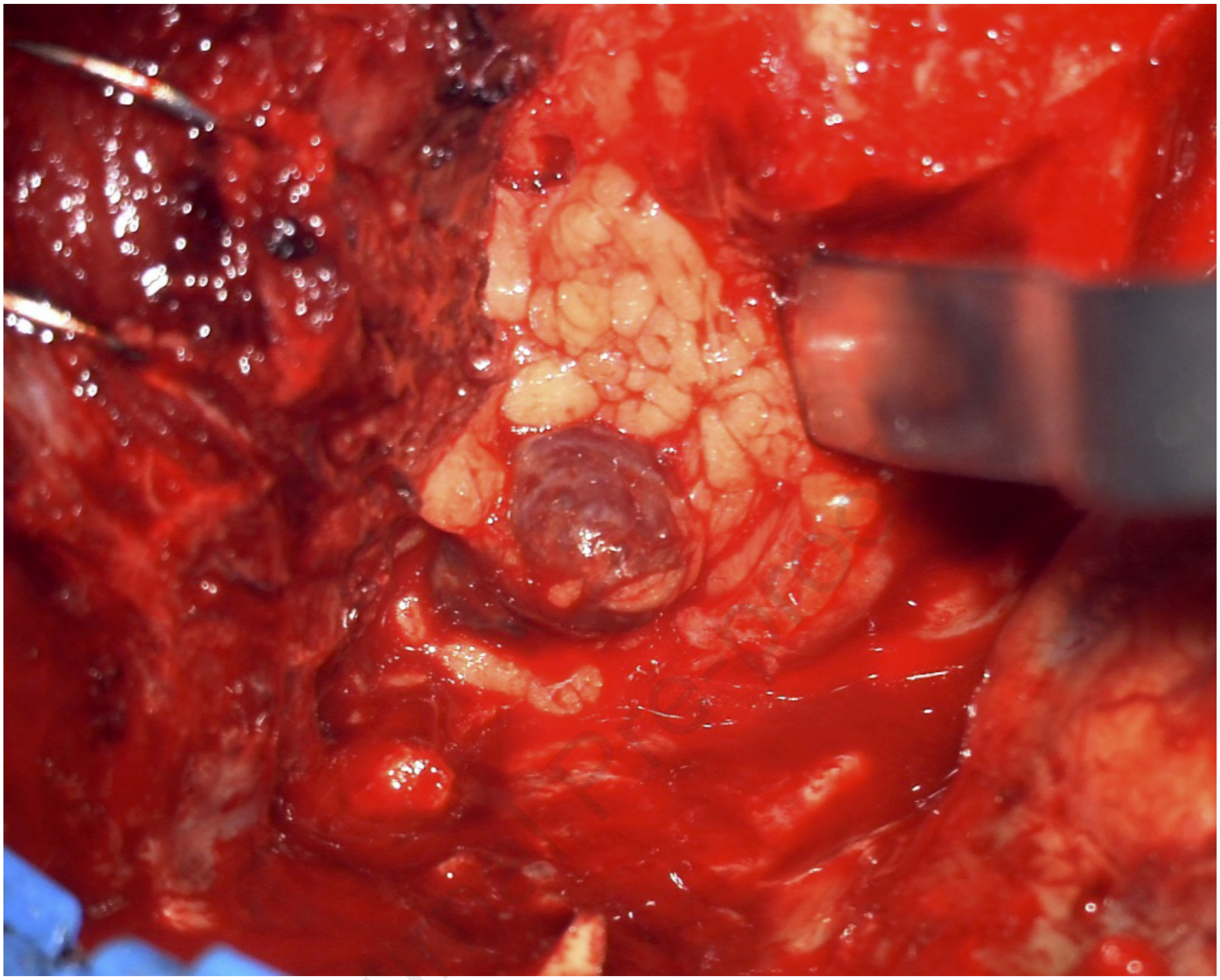


FIGURE CAPTIONS

Fig. 1: A 32-year-old female patient presented with intermittent right visual impairment and oculomotor nerve palsy for several weeks. ***A*** Preoperative coronal and ***B*** axial T1-weighted gadolinium-enhanced MRI showing a space-occupying intraconal tumor with displacement of the optic nerve. ***C*** Postoperative coronal and ***D*** axial MRI control indicating complete resection via a pterional approach. Postoperatively, the patient did recover from the visual decline; the incomplete oculomotor nerve palsy remained but improved as well. Intraoperative and histopathological findings revealed a cavernous hemangioma.

Fig. 2: A 74-year-old female patient presented with progressive proptosis and new visual field deficits. The lesion had already been known for six years, and annual clinical and imaging controls had been performed since then. ***A*** Preoperative coronal and ***B*** axial T1-weighted gadolinium-enhanced MRI showing a right orbital extraconal tumor. ***C*** Postoperative coronal and ***D*** axial MRI control indicating GTR via a lateral orbitotomy. Postoperatively, the patient recovered from the visual field deficits and proptosis. Intraoperative and histopathological findings revealed a schwannoma WHO grade I.

Fig. 3: A 78-year-old male patient presented with proptosis and rapid visual decline on the left side. Prior to admission, a transnasal biopsy was performed by otorhinolaryngologists, which revealed a cylindrical cell carcinoma. ***A*** Preoperative coronal and ***B*** axial T1-weighted gadolinium-enhanced MRI showing an irregularly enhancing left orbital intraconal lesion with vicinity to the cavernous sinus. ***C*** Postoperative coronal and ***D*** axial MRI control indicating GTR via transnasal endoscopic medial maxillectomy. Postoperatively, the patient recovered rapidly from visual decline but developed a permanent ptosis. Due to tumor adherence and narrow working space, more manipulation was necessary. Postoperatively, space-occupying hemorrhage occurred, possibly causing partial oculomotor nerve injury.

Fig. 4: Illustration demonstrating how extraorbital, transorbital and transnasal approaches provide complete access to the orbit.

Fig. 5 Intraoperative exposure of an intraorbital cavernous hemangioma located laterally in the intraorbital fat. A frontolateral approach was performed.

Authors' contributions

Conceptualization: Amir Kaywan Aftahy

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Writing - review and editing: Melanie Barz, Arthur Wagner, Philipp Krauss, Chiara Negwer, Bernhard Meyer, Jens Gempt

Supervision: Chiara Negwer, Bernhard Meyer, Jens Gempt

GTR	gross total resection
IQR	interquartile range
KPSS	Karnofsky Performance Status Scale
Mdn	median
SD	standard deviation
STR	subtotal resection

Conflicts of interest

Jens Gempt (JG) and Bernhard Meyer (BM) work as consultants for Brainlab (Brainlab AG, Feldkirchen).

In addition, BM works as a consultant for Medtronic, Spineart, Icotec, Relievant and Depuy/Synthes. In these firms, BM acts as a member of the advisory board. Furthermore, BM reports a financial relationship with Medtronic, Ulrich Medical, Brainlab, Spineart, Icotec, Relievant and Depuy/Synthes. He received personal fees and research grants for clinical studies from Medtronic, Ulrich Medical, Brainlab, Icotec and Relievant. All this happened independently of the submitted work. BM holds the royalties/patent for Spineart.

All named potential conflicts of interest are unrelated to this study.

There are no further conflicts of interest regarding the other authors.