Orbital floor fracture repair: the endonasal approach*

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Abstract
To avoid the dangers associated with lower eyelid approaches to the orbital floor and to improve visualization, we propose an endoscopic procedure for orbital floor fracture reduction and osteosynthesis using endonasal access via the medial maxillary sinus wall. The technique of endoscopic, endonasal transantral surgery is described, together with a retrospective analysis of 17 patients who had undergone this surgical procedure in the Department of Otorhinolaryngology, University of Regensburg, between July 2013 and June 2016. Fractures without infraorbital margin involvement were successfully repaired and enophthalmos and/or diplopia were corrected in all cases.
The endonasal approach described here allows orbital floor fractures to be repaired without injury to the eyelid apparatus. Visualization, in particular across the orbital floor as far as the palatine process, appears to be superior to that achieved with other approaches. The increased time required for the procedure and the difficulties of manipulation within a confined space are offset by rapid wound healing without ocular swelling and a minimal risk of complications.

Key words: orbital floor fracture repair, endonasal, prelacrimal endoscopic approach to maxillary sinus

Introduction
Orbital floor fractures are common injuries for which there is a range of established surgical approaches, alongside conservative management in a small number of cases.
Entrapment of extraocular muscles constitutes an indication for immediate correction [(1)]. Prompt correction within 2 weeks is indicated in cases of exophthalmos greater than 2 mm or where ocular motility is limited. Surgery is further considered to be indicated in persistent diplopia as well as in hypesthesia of the skin due to damage of the infraorbital nerve [(1)]. Conservative management appears to be possible in cases where diplopia resolves spontaneously [(2)]. Thaller and Yvorchuk showed that 82% of patients suffered from sequalea following conservative treatment. Only 9% out of 396 orbital floor fractures were left with diplopia and 3% with enophthalmos in patients having had surgery for orbital floor fractures [(3)]. Axial and coronal CT imaging is strongly recommended as a key component of preoperative planning [(1)].
Alongside techniques involving subciliary and infraorbital access, the established methods also include the transconjunctival approach, which is the most common choice for orbital floor fracture repair [(4)]. Various studies have shown good outcomes in terms of diplopia, infraorbital numbness, ectropion and cellulitis for both the transconjunctival and the subciliary approaches [(5,6)]. Aside from good visualization, one of the advantages of these approaches is that scarring is cosmetically acceptable; the disadvantages include the likelihood of postoperative eyelid malposition with entropion or ectropion in some 5% of cases [(7)].
The literature contains reports of the endoscopic repair of orbital floor fractures but these refer to procedures involving reduction rather than reconstruction [(7)]. The current prevailing consensus that not only reduction but also specific stabilization of the fractured orbital floor should be provided especially for more extensive fractures is not reflected in these procedures. Therefore, despite improved fracture visualization, the traditional techniques are not widely accepted. The incorporation of stabilization of the fracture into the endonasal technique should address a major shortcoming of this surgical option.
We set out to overcome these problems using a novel technique for the repair of orbital floor fractures. The endonasal prelacrimal

endoscopic approach has the potential to avoid some of the disadvantages of the established surgical techniques, in particular, manipulations involving the eyelid apparatus. Although implant placement is rather more challenging in technical terms, the excellent visualization afforded ensures very good outcomes. The results obtained using endonasal access via the maxillary sinus are presented below.

Materials and methods

Inclusion and exclusion criteria

We allowed all fractures limited to the orbital floor for this technique with no regard of size and shape. No fractures of the inferior rim nor fractures of the anterior wall were included. We would not operate on patients suffering from inflammatory or infectious disease of the sinuses in order to prevent implant colonisation. Traumatic injury to the infraorbital nerve that requires decompression is obviously not suitable for endonasal surgery as there is no access to the nerve´s canal or foramen, respectively.
To date there is no experience in cases when patients had had surgery of the maxillary sinus beforehand, mainly with distortion of the anterior and lateral nasal wall inferior to the turbinate. We feel that fractures of the orbital floor as part of severe trauma to the midface, particularly compartment syndrome of the orbit and fractures of the optic canal need to be assessed in well documented standard techniques. We did not include children so far.

Preoperative assessment

We have the patient examined by an ophthalmologist in terms of proptosis, exclusion of visual loss, and extent of diplopia on a regular basis. CT scans in high resolution technique are considered mandatory in all cases.
We do not administer antibiotic prophylaxis longer than the duration of the operation. As recommended in the guidelines on midface trauma we start with cephalosporine half an hour prior to onset of surgery. No antibiotic prophylaxis longer than this is advised in accordance with up to date guidelines.

Endoscopic endonasal surgical technique

Prelacrimal access [8, 9] to the maxillary sinus was achieved by a curved incision from the lateral wall of the nasal cavity via the piriform aperture as far as the nasal floor. The inferior turbinate was elevated medially and the nasolacrimal duct was exposed. The frontal process of the maxilla was removed with a chisel and, where necessary, a drill. An incision was made into the antral mucosa which was detached from the roof of the maxillary sinus. Where possible, this was re-attached after fracture reduction or osteosynthesis had been completed. At that point the fracture could be visualized in its full extent. As far as possible, fracture reduction was performed using the existing bone

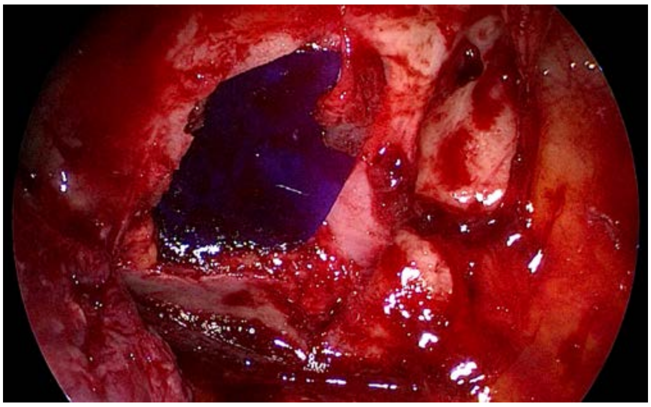

Figure 1. Fracture repair using polydioxanone sheet (PDS™).

fragments. In larger fractures or severely comminuted fractures where this cannot be done, it is recommended that loose fragments be removed prior to inserting an implant tailored to the individual orbital floor contours.
In accordance with up to date literature [10, 11] decision on the type of implant material depends on fracture size and shape. Smaller fractures within the scope of type „large fracture size" [1] were fixed by wedging of the fragments. Fragments of sufficient size that are capable to bridge the defect of the orbital floor are essential. Commuted fractures with multiple fragments i.e. more than three, do not suit this method.
Larger fractures without too big a dislocation of orbital content were reconstructed using PDS sheets. We were pleased with reinforcement of the orbital floor whenever the pressure test to the globe proved positive (Figure 1).
Very large defects and comminuted fractures were fixed with titanium mesh or titanium-reinforced polyethylene (Medpor™). This type of reconstruction suits all classes of fractures and all sizes that do not exceed the orbital floor (Figures 2 and 3).
The fracture edges were undermined with double-angled instruments. Implant insertion also served to lift orbital contents that had prolapsed into the maxillary sinus.
The implant rested either on bony edges posteriorly and anteriorly or on the posterior shelf if the dorsal edge was not easily accessible. The medial and lateral edges were of secondary importance. The orbital floor contours were checked and, if necessary, the implant was adjusted (Figure 4).
A forced duction test was used to demonstrate the free mobility of the globe, and the stability of reconstruction was checked endoscopically while applying appropriate external pressure to the globe. In all cases the implant was sealed with Tachosil™ collagen fleece as an onlay graft on the maxillary sinus roof.
Once the procedure had been completed, the mucosal wound in the area around the lateral nasal wall was closed with three 5x0 Vicryl interrupted sutures. Nasal packing was not required.
Our patients underwent surgery within 14 days after trauma (earliest time of surgery: 1 day after trauma; latest time of sur-

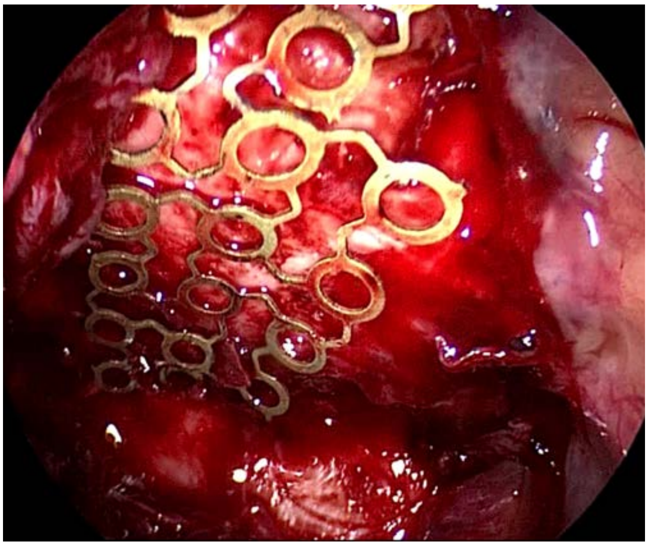

Figure 2. Fracture repair using titanium mesh.

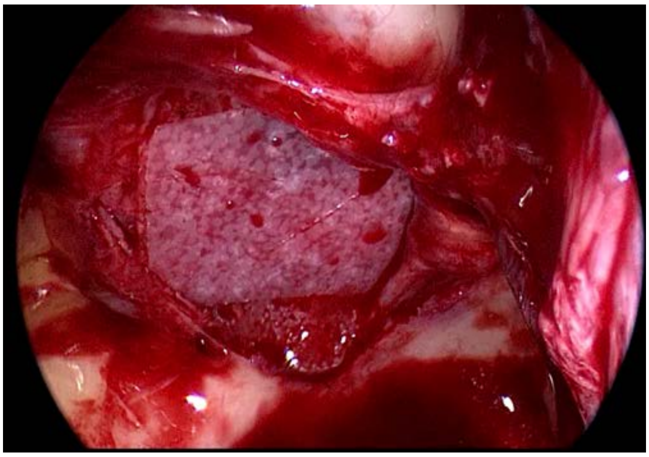

Figure 3. Fracture repair using titanium-reinforced porous polyethylene (Medpor™).

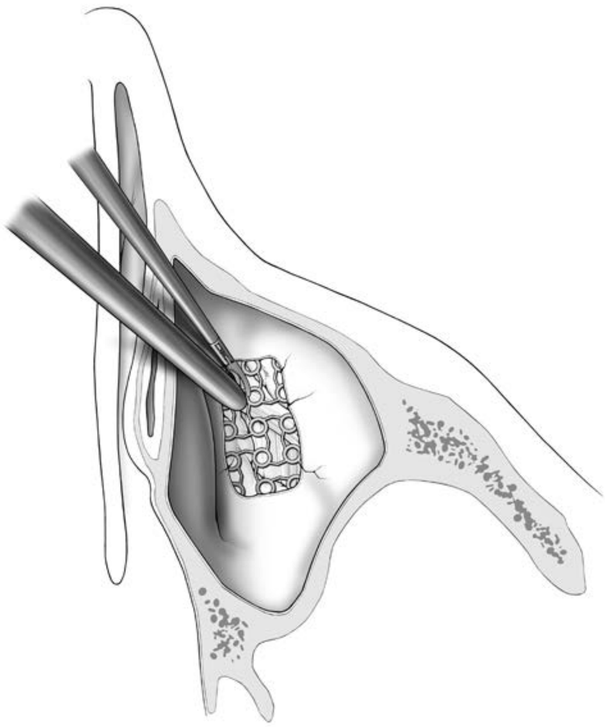

Figure 4. Endoscopic view onto the defect of the orbital floor from inside the maxillary sinus. Fracture repair has already been accomplished by titanium mesh.

gery: 14 days after trauma). Repair was scheduled to take place within 2 weeks so as to avoid the sometimes serious problems associated with secondary repair [12]. As has been widely reported in the published literature, considerable difficulties with reduction and correction are bound to occur in cases where the fracture has become partially consolidated.

Results

During the period from July 2013 to June 2016 the technique described here was used in a total of 17 patients who had sustained an orbital floor fracture. The clinical characteristics of our patients are presented in Table 1. Implants were made from titanium in 5 patients, Medpor™ in one patient, and PDS sheets in 8 patients. Fracture fragments were simply repositioned in 3 patients.

In terms of postoperative complications one female patient developed sensory disturbance in the territory supplied by the infraorbital nerve. Revision on day 1 after surgery was able to correct this problem which was thought to have been caused by compression of the infraorbital nerve by the implant. In response to questioning after surgery, two patients who had been free of any sensory disturbance preoperatively and in the early postoperative period reported paresthesia in the territory supplied by the second branch of the trigeminal nerve. Other symptoms, such as eyelid margin malposition, epiphora, diplopia or loss of visual acuity did not occur. Two patients were not available for follow-up in person, but symptoms were ruled out on the basis of telephone enquiries.

Deviations of sagittal globe position manifesting as exophthalmos or enophthalmos in our patients are presented as numerical measurements obtained with a Hertel mirror exophthalmometer (Table 2). Preoperative right-left differences in corneal apex were corrected in all cases.

Due to our limited experience so far, there is no difference in wound healing and risk of complications dependent on the type of reconstruction material. Wound healing was solely a matter of mucosa at the lateral nasal wall in all cases depicted here. They turned out to be uneventful but one case. One patient experienced sinusitis of the maxillary sinus bearing the alloplastic implant (Medpore-Titanium mesh) 13 months postoperatively. For maximum security, the alloplast was removed, the infection

Table 1. Demographic and clinical characteristics of the patient sample.

Pat.	Age (years)	Gender (M / F)	Injured orbit (R / L)	Trauma mechanism	Defect dimensions in mm (length x width x depth)	Time of surgical repair after trauma
1	34	F	R	Affray, punch	22 x 21 x 16	10 days
2	50	F	R	Fall	21.1 x 17.1 x 28.3	9 days
3	75	F	L	Fall	25.6 x 19 x 15.7	3 days
4	56	F	R	Fall	29.5 x 10.9x 10.7	7 days
5	22	M	L	Affray	15.4 x 18.6 x 6.8	12 days
6	74	F	L	Fall at home	27.4 x 18.6 x 10.6	1 day
7	28	F	R	Fall while drunk	29.4 x 27.9 x 12.2	11 days
8	88	F	R	Fall at home	15.9 x 13.3 x 15.4	4 days
9	22	F	R	Drunk, cause of injury unclear	16.4 x 20.7 x 7.3	9 days
10	34	F	L	Fall while drunk	22.3 x 15.1 x 13.5	7 days
11	54	F	L	Road traffic accident	11.5 x 7.9 x 5.3	13 days
12	63	F	R	Assault on bar owner	24.4 x 18 x 17.9	5 days
13	45	F	L	Domestic violence	-	14 days
14	37	M	L	Affray	29.7 x 24 x 17.9	4 days
15	49	F	R	Fall onto ski pole	18.8 x 13.4 x 10.8	1 day
16	31	M	L	Fall from bicycle	22.9 x 13.8 x 11.7	13 days
17	48	F	R	Fall	25.9 x 15.5 x 10.4	4 days

of the sinus resolved within a few days. No malposition of the globe could be observed.

Discussion

All patients included in this retrospective study underwent surgery within two weeks after trauma. The most favorable outcomes are achieved after initial edema and hematoma have subsided and before the fracture has consolidated. Orbital emergencies are repaired immediately [4, 13, 14]. This modus operandi is consistent with the German Guideline on the repair of orbital floor fractures [15] and is in agreement with current recommendations in the international literature [16, 17].

The indication for surgery was established in all patients on the basis of clinical parameters. The main symptoms were posterior displacement of the globe (enophthalmos) followed by diplopia and prolapse of orbital tissue into the maxillary sinus. Functional and aesthetic deficits are likely to occur if surgical correction is not performed in such cases [5].

We measured each defect and related our findings to the normal orbital floor area in order to demonstrate which fracture type is suitable for the technique presented here. Like other authors, we consider fracture size to be an important criterion when selecting the material to be used for reconstruction. However, fracture size and shape were not determining factors for choosing the endonasal technique. All fracture types that were confined to the orbital floor excluding the inferior rim of the orbit were suitable for the technique presented here. However, the indication for surgical intervention was not inferred solely on the basis of CT diagnosis [18, 19], the importance of which nevertheless remains undisputed (Figure 5).

According to the classification proposed by Shah et al., all the fractures measured in our study qualified as 'large', although dislocation was not taken into account [19]. This is intended to illustrate that the technique presented here is suitable not only for minor trauma but for fractures of all sizes. The fractures presented had mean dimensions of 22.4 mm (length calculated from sagittalplane in CT scans), 17.2 mm (width in coronal plane) and 13.2 mm (depth in coronal plane) and maximum dimensions of up to 29.7 mm (length), 27.9 mm (width) and 28.3 mm (depth) (Table 1). In fact, once it has been decided to use an implant and provided that the infraorbital margin is not involved, it is immaterial from a technical standpoint whether the fracture involves the entire orbital floor or only a part. Fracture size was only a determining factor when selecting the material to be used for reconstruction.

Alloplastic and autologous implants are available for the repair of orbital floor fractures [20]. Defect size, surgeon experience and preference as well as economic considerations all contribute

Table 2. Hertel mirror-exophthalmometer measurements (mm) after surgical repair.

Patient	Left eye	Right eye
1	18	19
2	19	19
3	19	18
4	19	19
5	17	17
6	16	18
7	21.5	21.5
8	-	-
9	20	20
10	16	17
11	10	11
12	20	20
13	-	-
14	22	21
15	20	20
16	19	20
17	15	15

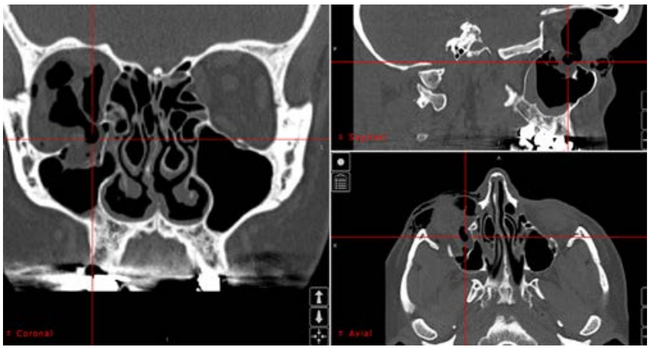

Figure 5. Multiplanar CT scan of severe orbital trauma with isolated fracture of the orbital floor prior to endonasal reconstruction.

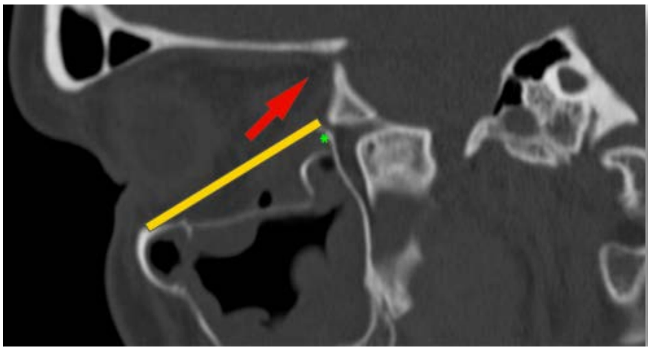

Figure 6. Fracture involving the posterior part of the orbital floor. The asterisk indicates the posterior shelf for seating the implant. Proximity to optic nerve (arrow).

to decision-making in favor of a particular type of implant [21]. In three of our patients, smaller fractures with larger fragments were able to be repaired with locally available bone fragments, i.e. without alloplastic implants. Checks were made in all cases to ensure that the resulting orbital floor was of stable construction. We prefer autologous material because the risk of infection is lowest and the results are favorable [22].

If the fragments were too small, unperforated polydioxanone (PDS) sheets (0. 25 mm thick) were used. Recent studies also show stable results when perforated PDS sheets are used, with no major differences noted by comparison with repairs using titanium mesh [23].

Very extensive fractures were repaired using individually-sized titanium mesh and in one case we used preformed, polyethylene-coated titanium [24].

Rationale for the endoscopic, endonasal technique

Visualization of fractures located posteriorly is obscured in approaches via the eyelid because the orbital floor ascends from antero-caudal to posterior. From this it follows that visualization is poorest in the immediate vicinity of the optic nerve. In order to manipulate fracture fragments satisfactorily, it is necessary to lift the contents of the orbit and this represents a source of stress and danger for the globe and the optic nerve [25] (Figure 6). The curved geometry of the orbital floor is also referred to as a 'lazy S' shape. This accounts for the risk – with transfascial and transconjunctival approaches – of pushing the implant horizontally underneath the posterior fracture edge and hence into the lumen of the maxillary sinus [26]. There is also a risk that an overly long implant will tilt upwards and come into contact with the free edge of the optic nerve. By the time the patient is able to draw attention to the problem after awakening from anesthesia, it may already be too late to correct it. Cases of blindness have been reported [26, 27].

The endoscopic view from the maxillary sinus toward the orbital floor helps to ensure that these errors do not occur. The implant can be tailored precisely to the natural anatomical form, thus avoiding asymmetrical differences compared with the contralateral side. In the past, repeated efforts have been made to introduce endoscopic techniques although the main emphasis has been on monitoring reduction outcomes by endoscopy. Fracture reduction was still performed using a transpalpebral approach with repair by osteosynthesis. The exceptions are techniques in which no implant was used. In a retrospective analysis involving 11 patients from 1999 Ikeda et al. described fracture repair with an antral balloon [30]. An endonasal approach was selected, and the advantages identified were improved visualization and fewer complications [28, 29]. Aside from the visualization advantage, supporting the orbital floor with balloons inserted from the maxillary sinus or with ointment packing is now no longer recommended [12, 30]. Farwell and Persons have described endoscopic repair via a transantral approach, citing the avoidance of eyelid complications as the chief advantage [7]. However, despite the improvement in visualization and the lower incidence of eyelid complications, widespread acceptance has not yet been achieved [29, 31]. Moreover, in classic techniques as stated above additional morbidity i.e. scarring within the buccal mucosa, damage to the infraorbital nerve and oroantral fistula has to be considered [32].

The downward prolapse of orbital contents into the maxillary sinus inevitably entails the possibility of enophthalmos. A reliable estimate of the clinical relevance of this phenomenon is generally only possible once the trauma-induced swelling has subsided. Pronounced soft-tissue injury may delay primary repair [13]. Furthermore, access through edematous swollen soft tissue or through hematoma is problematic in terms of wound healing. The risk of impaired wound healing or of unfavorable scar formation must be borne in mind. The transantral approach is not constrained by these issues. Moreover, fracture reduction can be performed, at least in circumstances of preseptal swelling. An increase in intra-orbital pressure that potentially jeopardizes the function of the globe is the only possible contraindication for any method equally.

Naturally, because there is no incision wound involving the conjunctiva or lower lid, there is no risk of eyelid malposition or malfunction.

Access can be achieved swiftly and is technically straightforward. It yields perfect visualization of the fracture zone.

In all our cases endonasal wound healing was unproblematic and rapid. This is consistent with experiences reported in routine endonasal surgery [33].

Dislocation of the implant in a sagittal direction is not possible with the transantral approach. The stability and integrity of the reconstruction can be easily checked on endoscopic inspection using a pulse test.

The transnasal approach requires some skills in FESS (functional endoscopic sinus surgery) standard technique. Bimanual manipulation seems somewhat difficult as the corridor to the sinus is very narrow. There is little space for "four-hands-two-minds" (two surgeons). To our experience, the approach itself via the lateral nasal wall anterior to the lacrimal duct provides the following benefits: it is a fast and straightforward procedure and heals rapidly and reliably. Handling within the cavity of the maxillary sinus may turn out to be technically demanding when positioning the implant. Repositioning the orbital fat may be tricky as well. When the implant is put into place however, adjusting it to the shape of the orbital floor is easy as overview is perfect and comprehensive. In standard techniques bimanual surgery is carried out compared to endoscopic technique. Operation time is shorter which is worthy in times of increasing economic requests.

Taking an overall view of the advantages and disadvantages, the technique presented here would appear to be a useful addition to the existing range of surgical options for the repair of orbital floor fractures. For the future, improvements to the materials used for osteosynthesis should facilitate manipulation inside the maxillary sinus.

Authorship contribution

TK: idea, conception, data collection, interpretation, manuscript; HJ: interpretation, manuscript; WH: interpretation, manuscript; RW: interpretation, manuscript; VV: conception, data collection, interpretation, manuscript; All authors read and approved the final manuscript.

Conflict of interest

None

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