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Surgical treatment of frontal sinus fractures: a retrospective evaluation of 116 cases

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ABSTRACT

There are various treatment options for frontal sinus fractures. They mainly depend on whether the anterior or posterior table and the frontal sinus outflow tract (FSOT) are affected. Our study retrospectively assessed the surgical management of 116 frontal sinus fractures in terms of the different surgical treatment options as well as the resulting complications. In our cohort, all cases of displaced anterior table fractures ($n = 73$) were treated by open reduction and fixation (ORIF). In cases of posterior table fractures ($n = 43$), cranialization, obliteration, sinus preserving measures, or no treatment were carried out. Pyomucocele was the most common complication, occurring in 8.6 % of cases. It was significantly more frequent with dislocation of the posterior table without treatment ($p = 0.003$). Cerebrospinal fluid (CSF) leakage was especially observed in combined anterior and posterior table fractures ($p = 0.012$) and in cases of accompanying centrolateral midfacial fractures ($p < 0.001$). Poor aesthetic outcome was significantly more frequent with concomitant nasoethmoidal fracture ($p < 0.001$). CSF leakage and cosmetic defects seem to depend mainly on the severity of the trauma and the accompanying injuries. Reconstruction of the posterior wall and sealing it with autologous grafts appears to be an effective method of preventing CSF leakage and pyomucocele in most cases.

1. Introduction

Treatment of frontal sinus fractures is discussed contentiously, and requires an interdisciplinary therapeutic approach tailored to the individual situation. Departments of otorhinolaryngology, neurosurgery, and maxillofacial surgery are mainly responsible. Classification and management of this type of fracture are not standardized. For fractures of the anterior table, ORIF is recommended if the fracture depth is more than 4 mm (Kim et al., 2012). In cases of displaced fracture of the posterior wall, the following treatment options are available, among others: observation, reconstruction, obliteration, cranialization, and secondary transnasal endoscopic frontal sinusotomy (Draf IIB, III procedure) (Rodriguez et al., 2008; Grayson et al., 2017).

The therapy must be individually adapted, while keeping in mind the following goals: repair of CSF leakage; preserving, restoring, or obliterating the FSOT; removal of the frontal sinus mucosa to prevent a mucocele or sinus preservation with patent frontal sinus outflow tract (FSOT); and cosmetic restoration of the frontal contour (Litschel et al., 2015). Nondisplaced fractures are best handled conservatively, without operative intervention (Rohrich and Hollier, 1992). In cases of traumatic obstruction of the FSOT, removal of the frontal sinus as a functional unit, either by obliteration or cranialization, has been recommended for decades (Rohrich and Hollier, 1992). Both procedures are increasingly under debate, as frontal sinus salvage with primary or secondary endoscopic sinusotomy has become more widespread (Grayson et al., 2017). Persistent frontal headache, cosmetic deformation, sinusitis/pyomucocele, CSF leakage, and meningitis are the most common complications after open treatment of frontal sinus injuries (Gerbino et al., 2000; Johnson and Roberts, 2021; Gossman et al., 2006; Sivori et al., 2010).

In recent years, obliteration particularly has lost its importance due to high complication rates (Rodriguez et al., 2008). Instead, cranialization has been considered as a first-choice treatment in cases of severe posterior table fracture with dura laceration and persistent CSF leakage

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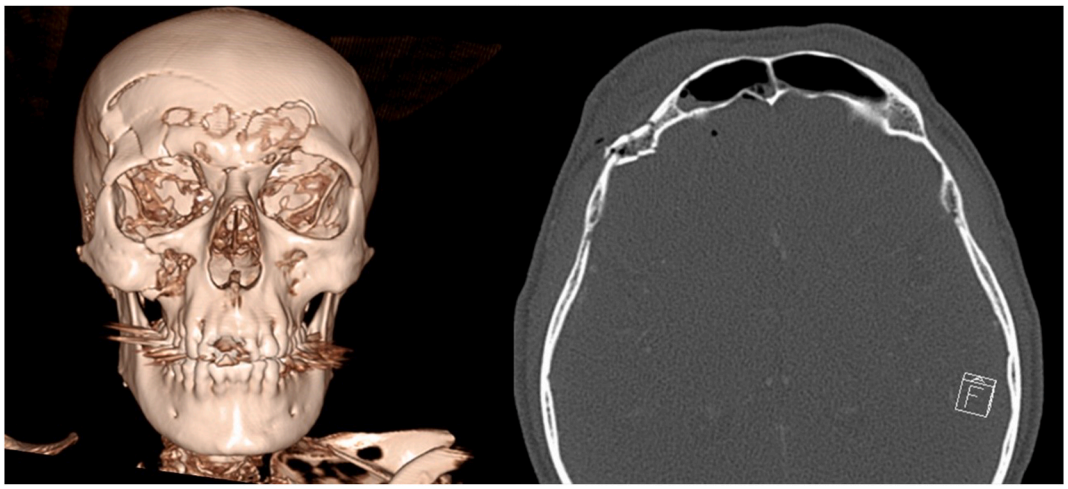

Fig. 1. CT scan of a patient with a combined anterior and posterior table fracture of the right frontal xsinus and a concomitant lateral midfacial fracture. Pneumoceles as radiographic sign for dural laceration.

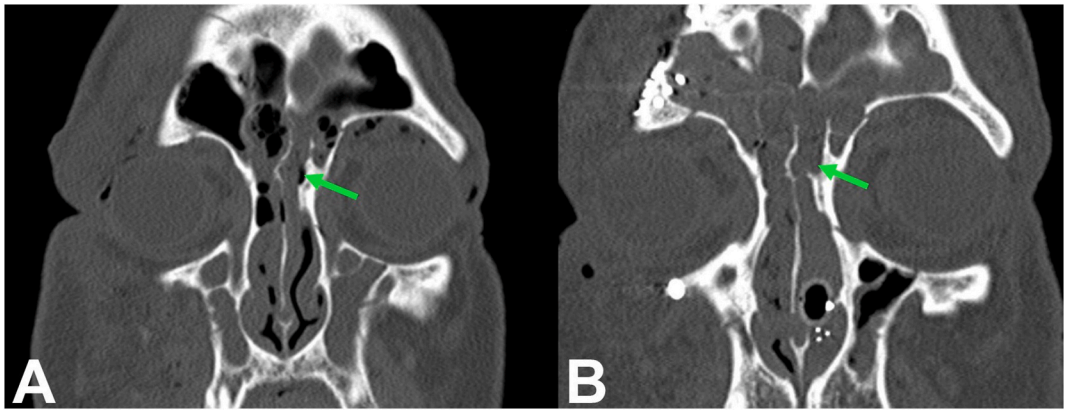

Fig. 2. Patent nasofrontal outflow tract before surgical intervention (A) and after surgical intervention (B).

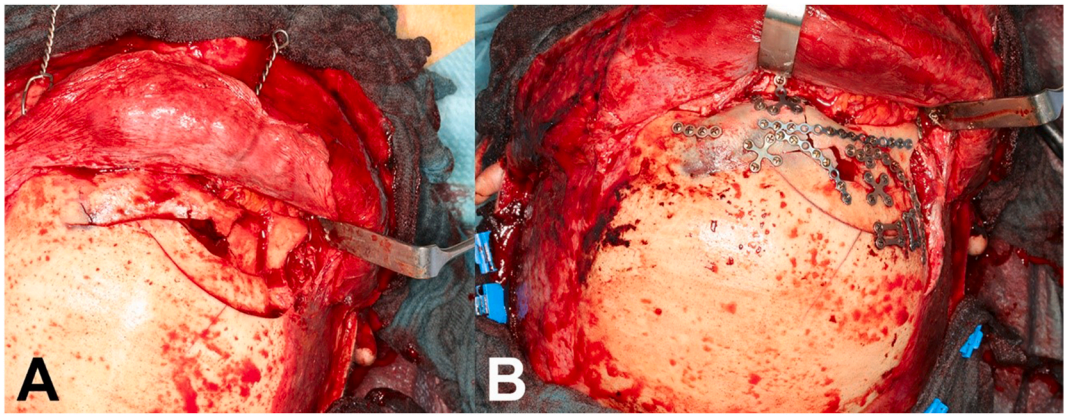

Fig. 3. Intraoperative situs before ORIF (A) and after ORIF (B).

(Calis et al., 2022). Overall, there seems to be a trend away from radical surgical interventions towards a more conservative approach.

The aim of our study was to present, retrospectively, the interdisciplinary surgical management of frontal sinus fractures in a level-1 trauma center, and to examine the different treatment approaches as well as the resulting complications.

2. Patients and methods

2.1. Data assessment

Medical records of patients undergoing surgical treatment of frontal sinus fractures at Regensburg University Hospital, between 2005 and 2020, were retrospectively assessed. Fractures of the anterior table, the posterior table, or both were enrolled. Patients with incomplete clinical

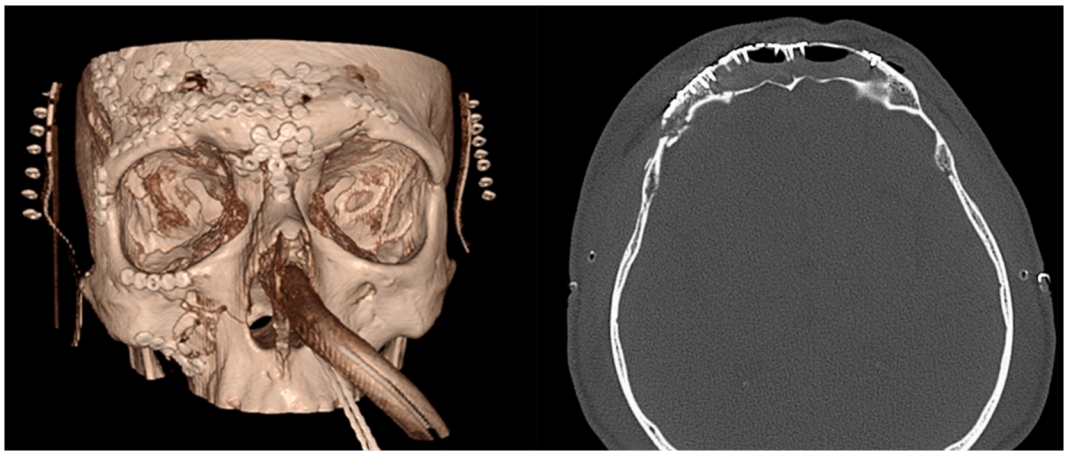

Fig. 4. CT scan after ORIF with resorption of the intracranial pneumoceles.

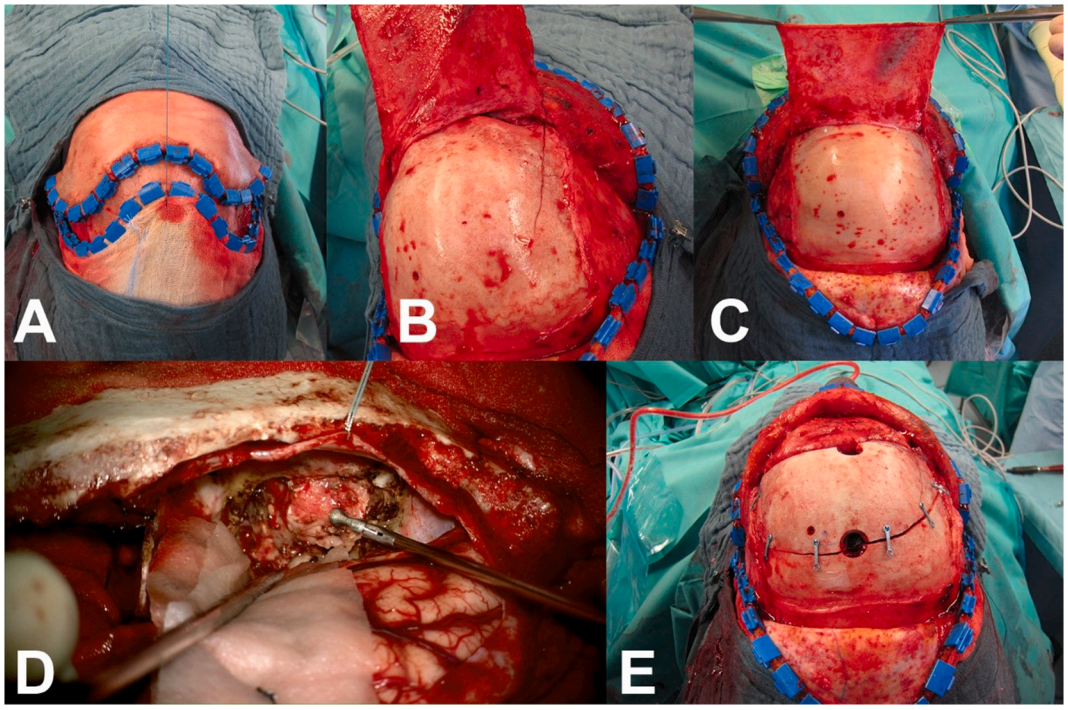

Fig. 5. Patient with a combined fracture of the orbital roof, cranial vault, frontal sinus, and skull base, undergoing a cranialization procedure: (A) coronal approach; (B) exposure of the fractures; (C) elevation of a pericranial flap; (D) obstruction of the outflow tract with temporal muscle and fascia during cranialization procedure; (E) repositioning and osteosynthesis of the frontal bone flap, with intradural insertion of the pericranial flap.

and radiological pre- and postoperative documentation were not included. The accompanying facial and cranial fractures were recorded based on the patients' records. Displacement of the anterior or posterior table and involvement of the FSOT were assessed by preoperative CT-imaging (Figs. 1 and 2). All isolated fractures of the anterior table were markedly displaced (>4 mm). CSF rhinorrhoea was detected by a beta-2-transferrin assay via nasal packages. Coronal, sub-brow/upper-eyelid, and endoscopic approaches, as well as approach via laceration if possible, were used. Osteosynthesis of the anterior table was performed with titanium plates (Synthes MatrixMIDFACE™; DePuy Synthes, Raynham, MA, USA) (Figs. 3 and 4).

2.2. Surgical techniques

Following techniques were used to treat posterior table fractures: (1) cranialization, i.e. the removal of the posterior bony wall of the frontal sinus, mucosal stripping, repair or patching of the lacerated dura, and obliteration of the FSOT (Fig. 5); (2) obliteration of the frontal sinus with abdominal fat or temporal muscle, with mucosal stripping and FSOT obliteration; and (3) sinus preservation with reconstruction of the anterior and posterior table, with preservation of the mucosa and the FSOT. Free grafts (temporal fascia or periosteal graft) or alloplastic material (TachoSil®; Corza Medical GmbH, Düsseldorf, Germany) were used for sealing of posterior table fractures to prevent ascending dura infection.

For every case it was recorded whether the FSOT was injured respectively or obstructed, and whether it was obliterated during surgical treatment. FSOT obliteration was carried out using a graft of temporalis fascia, temporalis muscle, local periosteum, or alloplastic material (TachoSil®; Corza Medical GmbH, Düsseldorf, Germany). It was also determined whether and to what extent the sinus mucosa had been removed. This involves either a complete removal of the mucosa or

Table 1
Base data.

Number of patients		116
Mean age		36.82 ± 17.27 years
Sex	Female	11 (9.5 %)
	Male	105 (90.5 %)
Etiology	Road traffic accidents	38 (32.7 %)
	Sports accidents	23 (19.8 %)
	Falls	24 (20.6 %)
	Work-related accidents	14 (12.1 %)
	Assaults	12 (10.3 %)
	Animal kicks	5 (4.3 %)
Fracture location	Anterior table	73 (62.9 %)
	Posterior table	6 (5.2 %)
	Anterior and posterior table	37 (31.9)
Dislocation of posterior table	Yes	18 (15.5 %)
	No	98 (84.5 %)
Intracranial bleeding	None	104 (89.7 %)
	Subarachnoid hemorrhage	8 (6.9 %)
	Epidural hematoma	3 (2.6 %)
	Subdural hematoma	1 (0.9 %)
Intracranial air	Yes	27 (23.3 %)
	No	89 (76.7 %)
Dura laceration	Yes	13 (11.2 %)
	No	103 (88.8 %)
FSOT injury	Yes	9 (7.8 %)
	No	107 (92.2 %)
Pre-treatment CSF leak	Yes	9 (7.8 %)
	No	107 (92.2 %)
Craniotomy	Yes	14 (12.1 %)
	No	102 (87.9 %)
Pericranial flap for anterior skull base reconstruction	Yes	7 (6.0 %)
	No	109 (94.0 %)
Post treatment complications	Sinusitis/pyocele	10 (8.6 %)
	Persisting frontal headache	6 (5.2 %)
	Poor aesthetic outcome	6 (5.2 %)
	Post-treatment CSF leak	4 (3.4 %)
Accompanying fractures	Nasoethmoidal	5 (4.3 %)
	Cranial vault	10 (8.6 %)
	Orbital wall	54 (46.6 %)
	Centrolateral midface	11 (9.5 %)
	Central midface	6 (5.2 %)
	Lateral midface	18 (15.5 %)
	Skull base	22 (19.0 %)

a partial removal. Partial removal means that the mucosa is only removed in the fractured area and left intact in the undamaged areas.

2.3. Follow-up

The follow-up course was evaluated for complications such as meningitis, frontal sinusitis, or pyomucocele, chronic post-traumatic frontal headaches, aesthetic compromises, and CSF leaks (Gossman et al., 2006; Ioannides et al., 1993; Sivori et al., 2010). Post-traumatic headache was considered chronic if it persisted for more than 3 months (Headache Classification Committee of the International Headache Society (IHS), 2018). Aesthetic compromises included contour defects and unaesthetic scarring, based on the patient's subjective perception.

The follow-up period was at least 4 years. In addition to descriptive statistics, any correlations between fracture localization, surgical treatment, injury and treatment of the FSOT, removal of the mucosa, and the complications mentioned above were established. Comorbidities that affected the results could not be identified.

Data were analyzed using SPSS (IBM SPSS, version 29.0.1.0; IBM Corp., Armonk, NY, USA). Significant differences were identified in cross-tabulation using Pearsons' chi-square test and correlations. A p-value less than 0.05 was considered significant.

3. Results

3.1. Patient data

Between 2005 and 2020, 116 patients with frontal sinus fractures were surgically treated in the Departments of Oral and Maxillofacial Surgery, Otorhinolaryngology, and Neurosurgery. Base data are shown in Table 1. The mean age was 36.82 ± 17.27 years. The majority of the patients were male (n = 105, 90.5 %). The main causes of trauma were traffic accidents (n = 38, 32.8 %), followed by falls (n = 24, 20.7 %) and sports accidents (n = 23, 19.8 %).

The dominant injury pattern was the isolated fracture of the anterior table of the frontal sinus (n = 73, 62.9 %). A fracture of both the anterior and posterior table was present in 31.9 % of cases (n = 37). In 5.2 % of cases only the posterior table was affected (n = 6). Thirty-five patients had isolated frontal sinus fractures (30.1 %), while 81 had one or more concomitant fractures (69.8 %). Subarachnoid hemorrhage (6.9 %) was the main form of cerebral bleeding. Intracranial air was documented in 27 (23.3 %) cases by CT scan. A pretreatment CSF leakage via the nose was recorded in nine (7.8 %) cases.

3.2. Treatment

The most commonly used approach for involvement of the anterior (n = 33, 45.2 %) or anterior and posterior table (n = 25, 67.6 %) was the coronal approach, followed by sub-brow incision (anterior table: n = 21, 28.8 %; anterior and posterior table: n = 5, 13.5 %) and approach via laceration (anterior table: n = 17, 23.3 %; anterior and posterior table: n = 7, 18.9 %) (Table 2). All isolated fractures of the anterior table were treated by ORIF (n = 73, 100 %). Among 37 cases with both anterior and posterior table fractures, 34 cases (91.2 %) required ORIF of the anterior table.

For treatment of the posterior table fracture, cranialization was performed in six patients (16.2 %) and obliteration of the frontal sinus in three patients (8.1 %). In 26 patients with posterior table fractures and suggested open FSOT, the sinus was preserved and the posterior wall was reconstructed and sealed with either a free fascia graft (n = 6, 14.0 %) or an alloplastic sponge sealant patch (n = 20, 46.5 %). Eight cases (18.6 %) of posterior table fractures were not treated at all. In isolated anterior table fractures a partial removal of the mucosal lining was carried out in six cases (8.3 %) and a complete removal in five cases (6.8 %). In fractures of the posterior wall (n = 43), the mucosa was completely removed in 17 cases (39.5 %, including all cases of cranialization and obliteration) and partially removed in seven cases (16.3 %). The FSOT was obliterated in a total of 11 cases (9.5 %), in nine cases as part of a cranialization or obliteration procedure. In seven cases (including all cranializations) covering of the frontal skull base was performed using a pericranial flap.

3.3. Complications

Overall post-therapeutic complications occurred in 26 cases (22.4 %) (Table 3). Ten patients (8.6 %) showed signs of frontal sinusitis or pyomucocele in the further course. This was significantly associated with posterior wall dislocation (p = 0.025), with dislocation of the posterior wall without therapy (p = 0.003), and with obliteration of the frontal sinus (p = 0.028). Poor aesthetic outcome was documented in six patients (5.1 %), and was significantly related to accompanying nasoethmoidal (p < 0.001) and centrolateral (p = 0.001) fractures.

A further six patients complained of persistent frontal headache (5.1 %), which was significantly increased in cases of accompanying cranial vault fractures (p = 0.027). Four patients had postoperative CSF leaks (3.4 %), significantly associated with untreated posterior wall (p = 0.016), skull base reconstruction by pericranial flap (p < 0.001), and

Table 2
Treatment.

Fracture localization	Approach		Treatment, anterior table		Treatment, posterior table		Removal of mucosal lining		Obliteration of FSOT
Anterior table ($n = 73$)	Endoscopic	2 (2.7 %)	ORIF	73 (100 %)	–	–	None	62 (84.9 %)	–
	Bicoronal	33 (45.2 %)					Complete	5 (6.8 %)	
	Laceration	17 (23.3 %)					Partial	6 (8.2 %)	
	Sub-brow	21 (28.8 %)							
Posterior table ($n = 6$)	Endoscopic	2 (33.3 %)	ORIF (anterior table)	5 (83.3 %)	Obliteration	0	None	2 (33.3 %)	–
	Bicoronal	2 (33.3 %)			Cranialization	0	Complete	4 (66.6 %)	
	Laceration	0			Sinus preservation	6 (100 %)	Partial	0	
	Sub-brow	2 (33.3 %)							
	Via anterior table	5 (83.3 %)							
Anterior + posterior table ($n = 37$)	Endoscopic	0	ORIF (anterior table)	34 (91.9 %)	None	8 (21.6 %)	None	17 (45.9 %)	8 (21.6 %)
	Bicoronal	25 (67.6 %)			Obliteration	3 (8.1 %)	Complete	13 (35.1 %)	
	Laceration	7 (18.9 %)			Cranialization	6 (16.2 %)	Partial	7 (18.9 %)	
	Sub-brow	5 (13.5 %)			Sinus preservation	20 (54.1 %)			

accompanying centrolateral fractures ($p < 0.001$). There was no case of meningitis or intracranial infection before or after treatment in our cohort.

Complications were also evaluated separately by fracture location (Table 4). In isolated fractures of the anterior table, overall complications were very rare (4.1 %). Removal of the sinus mucosa was not associated with increased sinusitis and pyomucoceles ($p = 0.758$). No frontal sinusitis or pyomucoceles occurred when the mucosa was completely or partially removed. Further parameters influencing the occurrence of persistent frontal headaches, reduced aesthetics, and CSF-leaks could not be identified.

In fractures of both the anterior and the posterior table, occurrence of sinusitis and pyomucocele was significantly increased for non-treatment (3/11, 46.4 %) and obliteration (2/3, 66.6 %), while no infection occurred after cranialization (0/6) and in only one case after sinus preservation (1/17, 5.9 %) ($p = 0.028$). Parameters for an increase in persistent frontal headache, poor aesthetics, or CSF leaks could not be detected. In the six isolated fractures of the posterior wall, the only complication reported was a post-therapeutic sinusitis. In 43 fractures with involvement of the posterior table, only one case of persisting frontal headache was observed.

4. Discussion

Looking at the demographic data, it was mainly men who were affected by anterior frontal sinus fractures in our cohort. This was consistent with other studies, which also showed a clear predominance of male patients in this type of fracture (Johnson and Roberts, 2021). In particular, fractures caused by assaults were exclusively found in men, whereas animal kicks were more often documented in women, mainly due to equestrian sports ($p = 0.003$).

Regarding the anterior wall, the procedure is rather clear. A displacement of the anterior table of the frontal sinus of up to 3 mm can be treated conservatively, whereas a major dislocation should be treated by ORIF to avoid contour irregularities (Calis et al., 2022). By contrast, there are various treatment options for the displaced posterior table. In our cohort, cranialization, obliteration, and sinus preservation were performed. Treatment decisions in cases of posterior table involvement were always discussed interdisciplinarily in advance. More conservative approaches, preserving the sinus, the mucosa, and the outflow tract, were more frequently used in recent years as experience with endoscopic procedures increased, providing the possibility of primary or secondary clearance of the outflow tract.

The main complications investigated were meningitis, frontal sinusitis or pyomucocele, persistent frontal headache, cosmetic defects, and CSF leaks. These were also identified as the most common complications by previous studies (Johnson and Roberts, 2021). Based on the four major complications examined, the total complication rate was 22.4 %. This is largely consistent with previous studies (Sivori et al., 2010). In our patient population, 8.6 % of patients developed pyomucoceles. The literature provides extremely varied data on the incidence of pyomucoceles. For example, Chen et al. reported only two cases of sinusitis and pyomucocele in 78 fractures, whereas Xie et al. assessed pyomucoceles in 84.6 % of frontal sinus facture patients (Chen et al., 2006; Xie et al., 2000). In our study, the occurrence of pyomucoceles was significantly associated with non-treated dislocation of the posterior table ($p = 0.003$).

Untreated displacement of the posterior table leads to malposition, trapping, or invagination of the sinus mucosa, all precursors for frontal sinusitis and pyomucoceles (Gossman et al., 2006). Many authors blame an obstruction of the FSOT with consecutive reduced ventilation of the sinus for the development of mucocele-associated frontal sinusitis (Rohrich and Hollier, 1992; Rodriguez et al., 2008). Regarding the role of the FSOT, an increased incidence of pyomucocele and frontal sinusitis was observed in cases of traumatic obliterations, without reaching statistical significance. Nevertheless, we would support the recommendation of targeted surgical intervention.

In cases of traumatic obstruction of the FSOT, Rodriguez et al. recommended obliteration or cranialization (Rodriguez et al., 2008). In our study, both obliteration of the sinus (66.6 %) and selective obliteration of the FSOT with periosteal or mucosal grafts or alloplastic material (18.2 %) were correlated with post-therapeutic pyomucocele or sinusitis. Only cranialization turned out to effectively prevent pyomucoceles, probably due to a more complete removal of the sinus mucosa and a better obliteration of dead space. This observation — in favour of cranialization over obliteration — was in line with the current literature

Table 3
Overall complications.

		Frontal sinusitis/ pyomucocele ($n = 10$)		Persisting frontal headache ($n = 6$)		Poor aesthetic outcome ($n = 6$)		CSF leak ($n = 4$)	
Gender	Female	0/11	$p = 0.284$	0/11	$p = 0.416$	1/11 (9.1 %)	$p = 0.537$	1/11 (9.1 %)	$p = 0.281$
	Male	10/105 (9.5 %)		6/105 (5.7 %)		5/105 (4.8 %)		3/105 (2.9 %)	
Fracture localization	Anterior table	3/73 (4.1 %)	$p = 0.079$	5/73 (6.8 %)	$p = 0.547$	3/73 (4.1%)	$p = 0.564$	0/73	$\mathbf{p = 0.012}$
	Posterior table	1/6 (16.7 %)		0/6		0/6		0/6	
	Anterior + posterior table	6/37 (16.2 %)		1/37 (2.7 %)		3/37		4/37 (10.8 %)	
Dislocation of posterior table	Yes	4/18 (22.2 %)	$\mathbf{p = 0.025}$	2/18 (11.1 %)	$p = 0.216$	2/18 (11.1 %)	$p = 0.216$	2/18 (11.1 %)	$p = 0.053$
	No	6/98 (6.1 %)		4/98 (4.1 %)		4/98 (4.1 %)		2/98 (2.0 %)	
Dislocation of posterior table without treatment	Yes	2/4 (50.0 %)	$\mathbf{p = 0.003}$	1/4 (25.0 %)	$p = 0.068$	0/4	$p = 0.635$	1/4 (25.0 %)	$\mathbf{p = 0.016}$
	No	8/102 (7.8 %)		5/112 (4.5 %)		6/112 (5.4 %)		3/112 (2.7 %)	
Approach	Endoscopic	2/4 (50.0 %)	$\mathbf{p = 0.022}$	0/4	$p = 0.350$	0/4	$p = 0.474$	0/4	$p = 0.656$
	Coronal	5/60 (8.3 %)		3/60 (5.0 %)		4/60 (6.7 %)		3/60 (5.0 %)	
	Laceration	2/22 (9.1 %)		0/24		2/24 (8.3 %)		1/24 (4.2 %)	
	Sub-brow	1/28 (3.6 %)		3/28 (10.7 %)		0/28		0/28	
FSOT injury	Yes	2/9 (22.2 %)	$p = 0.130$	0/9	$p = 0.466$	0/9	$p = 0.466$	1/9 (11.1 %)	$p = 0.190$
	No	8/107 (7.4 %)		6/107 (5.6 %)		6/107 (5.6 %)		3/107 (2.8 %)	
Intracranial bleeding	Yes	2/12 (16.7 %)	$p = 0.294$	1/12 (8.3 %)	$p = 0.602$	1/12 (8.3 %)	$p = 0.602$	1/12 (8.3 %)	$p = 0.327$
	No	8/104 (7.7 %)		5/104 (4.8 %)		5/104 (4.8 %)		3/104 (2.9 %)	
Intracranial air	Yes	4/27 (14.8 %)	$p = 0.190$	0/27	$p = 0.166$	2/27 (7.4 %)	$p = 0.549$	3/27 (11.1 %)	$\mathbf{p = 0.013}$
	No	6/89 (6.7 %)		6/89 (6.7 %)		4/89 (4.5 %)		1/89 (1.1 %)	
Dura laceration	Yes	2/13 (15.4 %)	$p = 0.356$	0/13	$p = 0.372$	1/13 (7.7 %)	$p = 0.663$	3/13 (23.1 %)	$\mathbf{p < 0.001}$
	No	8/103 (7.8 %)		6/103 (5.8 %)		5/103 (4.9 %)		1/103 (1.0 %)	
Craniotomy	Yes	1/14 (7.1 %)	$p = 0.834$	1/14 (7.1 %)	$p = 0.723$	1/14 (7.1 %)	$p = 0.723$	2/14 (14.3 %)	$\mathbf{p = 0.018}$
	No	9/102 (8.8 %)		5/102 (4.9 %)		5/102 (4.9 %)		2/102 (2.0 %)	
Pericranial flap	Yes	1/7 (14.2 %)	$p = 0.582$	0/7	$p = 0.524$	1/7 (14.2 %)	$p = 0.261$	2/7 (28.6 %)	$\mathbf{p < 0.001}$
	No	9/109 (8.3 %)		6/109 (5.5 %)		5/109 (4.6 %)		2/109 (1.8 %)	
Accompanying fractures	Nasoethmoidal	1/5 (20.0 %)	$p = 0.354$	0/5	$p = 0.593$	2/5 (40 %)	$\mathbf{p < 0.001}$	0/5	$p = 0.666$
	Cranial vault	2/10 (20.0 %)	$p = 0.180$	2/10 (20.0 %)	$\mathbf{p = 0.027}$	0/10	$p = 0.440$	1/10 (10.0 %)	$p = 0.235$
	Orbital wall	4/54 (7.4 %)	$p = 0.664$	2/54 (3.7 %)	$p = 0.505$	4/54 (7.4 %)	$p = 0.310$	0/54	$p = 0.057$
	Centrolateral midface	2/11 (18.2 %)	$p = 0.235$	1/11 (9.1 %)	$p = 0.537$	3/11 (27.2 %)	$p = 0.001$	3/11 (27.3 %)	$\mathbf{p < 0.001}$
	Central midface	0/6	$p = 0.440$	0/6	$p = 0.557$	1/6 (16.7 %)	$p = 0.192$	0/6	$p = 0.635$
	Lateral midface	1/18 (5.6 %)	$p = 0.614$	1/18 (5.6 %)	$p = 0.936$	0/18	$p = 0.281$	0/18	$p = 0.383$
	Skull base	3/22 (13.6 %)	$p = 0.352$	0/22	$p = 0.224$	3/22 (13.6 %)	$\mathbf{p = 0.046}$	2/22 (9.1 %)	$p = 0.107$

(Kim et al., 2024).

Another development in recent years is that conservative approaches with sinus preservation are becoming more popular. Emara et al. recommend sinus preservation with endoscopically assisted clearance of the FSOT, which appears to be a promising recent development (Emara et al., 2015). Grayson et al. considered endoscopic endonasal approaches to be superior for selected patients for maintaining both the structure and function of the sinus and minimizing early and late complications (Grayson et al., 2017). Our study did not show superiority of the endoscopic procedure, particularly in terms of CFS leaks; however, it must be noted that the endoscopic Draf III procedure was performed in cases with fracture of the anterior skull base and CSF leaks, and the limited case number did not allow for definite judgement. Aside from cranialization, sinus preservation with sealing the dura using autologous

Table 4
Complications by fracture localization.

A) Isolated fractures of the anterior table

Fractures of the anterior table ($n = 73$)			Frontal sinusitis/pyomucocele ($n = 3$)		Persisting frontal headache ($n = 5$)		Poor aesthetic outcome ($n = 3$)	
Approach	Endoscopic		1/2 (50.0 %)	$\mathbf{p = 0.007}$	0/2	$p = 0.355$	0/2	$p = 0.696$
	Coronal		0/33		2/33 (6.1 %)		2/33 (6.1 %)	
	Laceration		1/17 (5.9 %)		0/17		1/17 (5.9 %)	
	Sub-brow		1/21 (4.8 %)		3/21 (14.3 %)		0/21	
Treatment, anterior table	ORIF	Yes	3/73 (4.1 %)	–	5/73 (6.8 %)	–	3/73 (4.1 %)	–
		No	0/0		0/0		0/0	
Removal of mucosal lining	None		3/62 (4.8 %)	$p = 0.758$	5/62 (8.1 %)	$p = 0.621$	–	–
	Complete		0/5		0/5		–	
	Partial		0/6		0/6		–	
Obliteration of FSOT	Yes		0/0	–	0/0	–	0/0	–
	No		3/73 (4.1 %)		5/73 (7.4 %)		3/73 (4.1 %)	

B) Fractures of both the anterior and posterior table

Fractures of the anterior and posterior table ($n = 37$)			Frontal sinusitis/ pyomucocele ($n = 6$)		Persisting frontal headache ($n = 1$)		Poor aesthetic outcome ($n = 3$)		CSF leak ($n = 4$)	
Approach	Endoscopic		0/0	$p = 0.535$	0/0	$p = 0.781$	0/0	$p = 0.670$	0/0	$p = 0.694$
	Coronal		5/25 (20.0 %)		1/25 (4.0 %)		2/25 (8.0 %)		3/25(12.0 %)	
	Laceration		1/7 (14.3 %)		0/7		1/7 (14.3 %)		1/7 (14.3 %)	
	Sub-brow		0/5		0/5		0/5		0/5	
Treatment, anterior table	ORIF	Yes								
		No								
Treatment, posterior table	None		3/11 (36.4 %)	$\mathbf{p = 0.028}$	0/11	$p = 0.751$	0/11	$p = 0.546$	1/11 (9.1 %)	$p = 0.263$
	Obliteration		2/3 (66.6 %)		0/3		0/3		0/3	
	Cranialization		0/6		0/6		1/6 (16.7 %)		2/6 (33.3 %)	
	Sinus preservation		1/17 (5.9 %)		1/17 (5.9 %)		0/17		0/17	
Removal of mucosal lining	No		4/17 (23.5 %)	$p = 0.186$	0/17	$p = 0.250$	1/17 (5.9 %)	$p = 0.235$	2/17 (11.8 %)	$p = 0.349$
	Complete		0/10		0/10		2/10 (20.0 %)		2/10 (20.0 %)	
	Partial		3/10 (30.0 %)		1/10 (10.0 %)		0/10		0/10	
Obliteration of FSOT	No		2/26 (7.7 %)	$p = 0.235$	1/26 (3.8 %)	$p = 0.510$	2/26 (7.7 %)	$p = 0.887$	2/26 (7.7 %)	$p = 0.348$
	Yes		2/11 (18.2 %)		0/11		1/11 (9.1 %)		2/11 (18.2 %)	
Dislocation of posterior table	No		1/19 (5.3 %)	$\mathbf{p = 0.029}$	0/19	$p = 0.298$	1/19	$p = 0.515$	2/19 (10.5 %)	$p = 0.954$
	Yes		6/18 (33.3 %)		1/18 (5.6 %)		2/18		2/18 (11.1 %)	

C) Isolated fractures of the posterior table

Fractures of the posterior table isolated ($n = 6$)			Sinusitis/pyomucocele ($n = 1$)		Persisting frontal headache ($n = 0$)		Poor aesthetic outcome ($n = 0$)		CSF leak ($n = 0$)	
Approach	Endoscopic		1/2 (50.0 %)	$p = 0.301$	0/2	–	0/2	–	0/2	–
	Bicoronal		0/2		0/2		0/2		0/2	
	Laceration		–		–		–		–	
	Sub-brow		0/2		0/2		0/2		0/2	
Treatment, anterior table	Osteotomy	Yes	1/5	$p = 0.624$	0/5	–	0/5	–	0/5	–
	+ORIF	No	0/1		0/1		0/1		0/1	
Treatment, posterior table	Obliteration		–	–	–	–	–	–	–	–
	Cranialization		–		–		–		–	
	Sinus preservation		1/6 (16.7 %)		0/6		0/6		0/6	
Removal of mucosal lining	No		1/2 (50.0 %)	$p = 0.121$	0/2	–	0/2	–	0/2	–
	Complete		0/4		0/4		0/4		0/4	
	Partial		–		–		–		–	
Obliteration of FSOT	Yes		0/0	–	0/0	–	0/0	–	0/0	–
	No		1/6 (16.7 %)		0/6		0/6		0/6	

grafts also did not result in pyomucoceles. This appears to be a safe and low-complication treatment for moderately displaced posterior wall fractures.

Sivori et al. suggested chronic craniofacial pain to be the most common complication of frontal sinus fractures (Sivori et al., 2010). In our study, an incidence of only 5.2 % for chronic frontal headache could be found, with accompanying cranial vault fractures identified as the only significant contributing factor. There may be a bias here, since it is difficult for the patient to distinguish whether the pain comes from the frontal sinus or from the calvaria fracture. The same applies to the aesthetic outcome. Aesthetic compromises, mainly in the form of contour defects, occurred significantly more frequently in combination with nasoethmoidal and centrolateral fractures, leading to telecanthus, loss of nasal projection, or zygomatic prominence.

Regarding the surgical approach, access via pre-existing lacerations was not a significant factor for aesthetic self-perception compared with a bicoronary approach. Interestingly, no aesthetic limitations were observed with sub-brow access, specifically upper-eyelid incision. The upper-eyelid approach was also described by previous authors as a useful alternative in isolated fractures of the anterior wall (Bourry et al., 2019; Hakimi et al., 2011). However, treatment of the posterior wall via this approach is difficult. Nevertheless, in our cohort, seven fractures of the posterior wall were treated via this approach for sinus preservation.

Overall, pain level and aesthetic issues increased with the extent of the trauma, irrespective of approach or treatment. A significant increase in the occurrence of post-treatment CSF leaks was observed in cases where both walls of the frontal sinus were involved, in cases of dislocation of the posterior wall without treatment, and in cases of concomitant centrolateral midfacial fracture. It seems reasonable that CSF leaks are more likely to occur in extensive trauma with comminution or panfacial involvement. Nevertheless, in our collective, post-surgical CSF leakage appeared to be a rare complication, detected in only 3.4 % of our patients, and only in cases where both the anterior and posterior table were fractured. By contrast, Oslin et al. reported CSF leak

in 4.5 % of isolated anterior wall fractures and in 21.1 % of posterior table fractures, whereas Khojastepour et al. reported an overall percentage of 14.3 % (Oslin et al., 2024; Khojastepour et al., 2024).

Very few studies have clarified the relation between specific complications and specific treatment options for a displaced posterior table. According to Becelli et al., a displacement of more than 5 mm is an absolute indication for treatment (Becelli et al., 2021). But which treatment method is the right one? In our cohort, obliteration was performed in three cases. Two of these developed a pyomucocele ($p = 0.006$). During obliteration, the mucosa should be completely removed to prevent mucoceles. The occurrence of mucoceles in our cohort may therefore have been due to incomplete removal of the mucosa, which may have led to mucous retention and subsequent infection. Rodriguez et al. identified fat obliterations prone to complications due to resorption of fibrous remodeling of the fat graft (Rodriguez et al., 2008). In fact, abdominal fat was used in one of our cases of obliteration, with subsequent pyomucocele. However, other studies indicate a rarer occurrence of mucoceles after frontal sinus obliteration. For example, Hansen et al. reported a prevalence of mucoceles and revision rate of 7.5 % after this procedure (Hansen et al., 2018).

Regarding CSF leakage, the highest percentage was observed for treatment by cranialization (33 %). Choi et al. suggested that if the main indication for cranialization is to address a prolonged cerebrospinal fluid leak, then it is undetermined whether the procedure can seal the cerebrospinal fluid leak more effectively than simply prolonging the period of observation (Choi et al., 2012). Since our results could not identify any superiority of cranialization in the prevention of CSF leaks compared with sinus preservation, this would also advocate a more conservative approach and keep cranialization for gross comminution of the posterior table. However, it should be borne in mind that conservative treatment of CSF leaks can cause delayed meningitides even years later (Matschke and Tsokos, 2001; Santos et al., 2011; Giunta and Piazza, 1991).

No complications in the form of pyomucoceles or CSF leakage were found in cases with reconstruction of the posterior wall and sealing by using autologous free grafts, such as temporal fascia or mucosa grafts. Reconstruction of the posterior wall using alloplastic material showed a rate of pyomuceles of 11.1 % and a rate of CSF leakage of 5.5 %. Choi et al. put forward the hypothesis that the majority of frontal sinus fractures involving posterior table comminution, displacement, or CSF leak can be safely treated by sinus preservation without cranialization (Choi et al., 2012). Our data also showed that there was no superiority of obliteration and cranialization in avoiding CSF leak and pyomucocele, although it should be noted that cranialization in particular was performed for more severe skull-base traumas. This supports the general trend away from invasive intracranial procedures towards more conservative approaches.

Our study had some limitations. The first of these was the retrospective design, resulting in a certain loss of information and inaccuracy of the data. In addition, the number of patients was relatively low in some subgroups, for example for endoscopic treatment or obliteration. The postoperative aesthetic outcome was solely based on the subjective perception of the patient and practitioner, without a standardized procedure, for example by means of photography and scar indices. The formation of pyomucoceles or frontal sinusitis can occur even 10 years or more after the initial treatment, so the applied follow-up period of 4–15 years may have been insufficient.

Overall, the results seem to indicate that the more severe the trauma, the more pronounced the complications, regardless of the type of treatment carried out. Frontal sinus fractures are extremely complex and reported treatments are very inhomogenous. Classifications and recommendations are currently under debate, which makes objective and comparable evaluation of surgical results very difficult. Moreover, the study did not take into account that the operations were performed by surgeons with varying levels of experience, although all of them were at least consultant level.

5. Conclusion

Dislocation of the posterior wall without treatment and obliteration of the frontal sinus are both associated with an increased incidence of pyomucocele or frontal sinusitis. CSF leakage appears to be a rather rare complication and cannot always be prevented by cranialization. Preservation of the sinus, the mucosa, and the outflow tract (primary or secondary) does not result in higher complication rates and presents a reliable alternative to more invasive approaches. For localized fractures, the upper-eyelid incision can be considered as an easy-to-use, less-invasive approach. Occurrence of frontal headache, aesthetic compromise, and CSF leakage increases significantly with the extent of the injury and the accompanying fractures.

Patient consent

All involved patients or their legal guardians provided signed informed consent.

Ethical approval

The protocol was approved by the Ethics Committee of Regensburg University (protocol number 20-2008-104).

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Declarations of competing interests

The authors have no related conflicts of interest to declare.

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