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Risk of frontal sinus anterior table fractures after craniofacial trauma and the role of anatomic variations in frontal sinus size: A retrospective case-control study

Johannes Buller [a, *], Matthias Kreppel [a], Volker Maus [b], Matthias Zirk [a, 1], Joachim E. Zöller [a, 1]

[a] Department of Oral and Craniomaxillofacial and Plastic Surgery, University of Cologne, Cologne, Germany
[b] Department of Neuroradiology, University Medical Center Göttingen, Göttingen, Germany

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ABSTRACT

Introduction: Purpose of this study was to evaluate a probable risk of frontal sinus size for traumatic depressed anterior table fractures in patients with similar forehead trauma.
Methods: We conducted a retrospective case-control study with a case group of consecutive treated patients with displaced frontal sinus anterior table fractures. The control group was randomly sampled from patients who presented with a blunt forehead trauma in our institution's emergency unit. In computed tomography data sets, all patients' frontal sinus size was categorized by Guerram's classification that is defined as aplasia, hypoplasia, medium-size and hyperplasia. Odds for prevalence of the sinus types as well as sinus total width and height were compared between both groups.
Results: In total, 47 cases and 93 controls were identified. Hyperplasia in the case group had an odds ratio of 46:1 ($p < 0.001$) compared to the controls. Mean sinus width (73 mm vs. 46 mm; $p < 0.001$) and sinus height (30 mm vs. 15 mm; $p < 0.001$) were larger in the case group.
Conclusion: Depressed traumatic fractures of the anterior table are an injury with a high risk specific for enlarged frontal sinus sizes. Anatomy is the predictive factor for this mode of craniofacial trauma.

1. Introduction

Treatment of traumatic frontal sinus fractures is a topic of current investigations (Chouake and Miles, 2017; Grayson et al., 2017; Kim et al., 2017; Patel et al., 2017; Schultz et al., 2017), but there is a lack of pathologic aspects. Patients with isolated fractures of the frontal sinus anterior table can present either with fracture lines that spread along the frontal bone or with a displacement of the anterior table that leads to depression of the forehead (Garg et al., 2015). Both fracture types can be associated with combined fracture lines of the posterior table (Manolidis, 2004). Indications for surgery are resolving an aesthetic deficit (Chouake and Miles, 2017), as well as prevention of a delayed mucocele or pyelocele that might result from obstruction of the frontal recess (Jafari et al., 2015). The standard of care still remains open reduction and fixation (Gonty et al., 1999; Delaney, 2016). Therefore the bicoronal approach allows the surgeon the best overview (Gabrielli et al., 2012) but additionally, eyebrow incisions are a feasible option to reach the anterior table fragments for reduction (Hahn et al., 2017). Regarding the anatomy of this fracture site, knowledge from anthropologic studies has shown a wide range of frontal sinus size (Nambiar et al., 1999; Christensen, 2005). The individual morphologic character of the frontal sinus allows forensic postmortem identification from conventional frontal x-ray view (Quatrehomme et al., 1996) as well as computed tomography (CT) images (Ruder et al., 2012). In the field of maxillofacial trauma, isolated anterior table fractures and combined fractures of the anterior and posterior table have been shown to be associated each with large and medium-scaled frontal sinus (Buller et al., 2018). Hence, the authors hypothesized that individuals with enlarged frontal sinus might

* Corresponding author. Department of Oral and Craniomaxillofacial and Plastic Surgery, University of Cologne, Kerpener Strasse 62, 50931, Cologne, Germany. Fax: +49 221 478 7360.
E-mail address: johannes.buller@uk-koeln.de (J. Buller).
[1] Shared senior authorship.

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have a higher risk of suffering anterior table fractures from craniofacial trauma. The purpose of this study was to analyze the frontal sinus size in patients with depressed anterior table fractures and in patients with a similar trauma to the frontal bone complex. Therefore, we conducted a retrospective case–control study of CT data sets and compared the odds for the group-specific frontal sinus size.

2. Material and methods

2.1. Study design

Cases were selected from all patients in our institution's data base who were surgically treated with a traumatic displaced fracture of the frontal sinus anterior table. Diagnosis was ensured by CT or cone beam CT in 2008–2018. For the control group, we randomly sampled patients who presented in our emergency unit after sustaining a forehead trauma in 2017. Inclusion criteria for the case group were depressed isolated anterior table fractures with or without additional non-displaced fracture lines to the posterior table defined as type II and III of Manolidis' classification (Manolidis, 2004). Patients with non-displaced anterior table fractures (Manolidis type I) were excluded from the cases (Fig. 1). In the control group, inclusion criteria were hematoma or open wounds localized to the forehead section. All controls underwent CT diagnosis due to clinical signs of cerebral concussion. Exclusion criteria in both groups were displaced fractures of the posterior table (Manolidis type IV), cerebrospinal fluid leak and intracranial bleeding with subsequent need of neurosurgical intervention, and commuting fractures of the frontobasal unit (Manolidis type V). Excluded were patients with anamnestic wear of any kind of protective helmets.

2.2. Study variables

Computed tomography or cone beam CT data sets were analyzed using dedicated work stations (CT: Impax, Agfa HealthCare, Mortel, Belgium; cone beam CT: Sidexis, Sirona, Bensheim, Germany). Categorical outcome variables were defined as frontal sinus morphometric type of Guerram's classification (Guerram

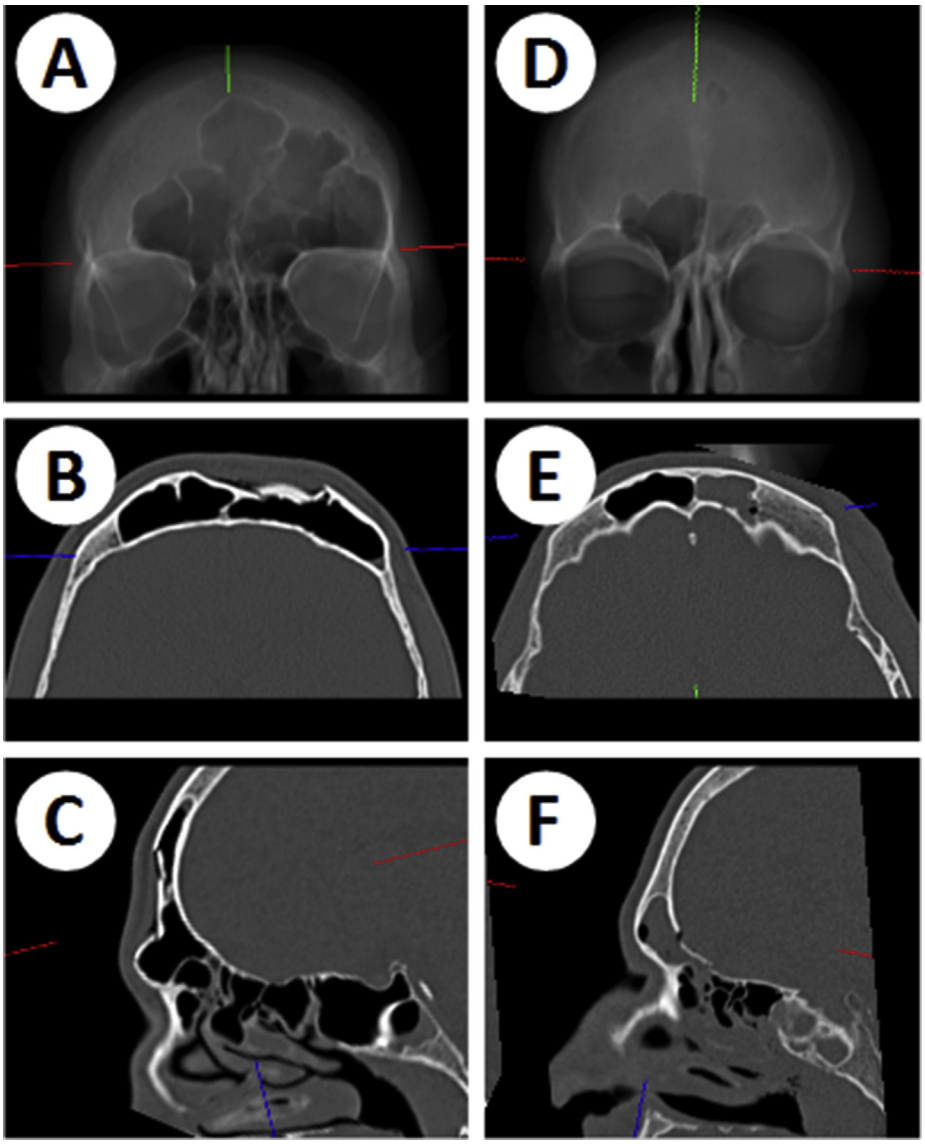

Fig. 1. Patient of the case group with an isolated depressed fracture of the anterior table (A–C); patient of the control group with a non-displaced fracture of the frontal bone (D–F); CT images are shown in reconstructed coronal x-ray view (A, D), axial (B, E) and sagittal view (C, F).

et al., 2014) that differs between frontal sinus aplasia, hypoplasia, medium size and hyperplasia (Fig. 2). Metric outcome variables were frontal sinus width and height (Fig. 3). Covariates of interest were age, sex and trauma causes that were collected from patient files. Cause of fracture was assigned to a low and high velocity impact group based on knowledge about strength of traumatic forces from physical and forensic research: motor-vehicle accidents, falls from above standing height (Sharkey et al., 2012), and kicks to the forehead (Fife et al., 2013) were considered as high-velocity trauma up from 10 m/s. Low velocity was defined as forehead trauma with 4 m/s to 8 m/s, that is approximated for falls from ground level as from stairs (Hamel et al., 2013; Hajiaghamemar et al., 2015) and from bicycle (Kurt et al., 2017), head to head collisions (McIntosh et al., 2000), and fist hits (Fife et al., 2013).

2.3. Statistics

Data analysis was performed in statistics software SPSS 23 (IBM Corp., Armonk, NY). To identify potential influence of baseline characteristics of the sampled controls on sinus size we calculated the correlation coefficients of Pearson (*phi*) and Spearman (*rho*). Predictive variables were compared between both groups using a t test for continuous variables and two-sided chi-square test for categorical variables. Odds ratios were calculated for outcome variables. Statistical significance for all tests was set at $p < 0.05$.

3. Results

From the retrospective data bank analyses, 47 cases and 93 controls were identified. In the case group, patients were predominantly male (93%) and younger (mean age 33 years) compared to the control group (Table 1). Testing the assumption of predictive correlations to the frontal sinus size revealed neither significance in the control group for sex (*rho* = −0.11; p = 0.3 for width; *rho* = −0.16; p = 0.16 for height) nor for age (*phi* = 0.08; p = 0.45 for width; *phi* = 0.01; p = 0.89 for height). Thus, a potential influence of the difference in age and sex between both groups on the appearance of sinus size was discarded. Etiology of the forehead trauma is shown in Table 2. Matching the traumatic acts to the approximated velocity of traumatic impact on the forehead, there was no statistical difference between both study groups with low velocity impact as the major cause (cases 92% vs. controls 85%; p = 0.275). Additionally, incidences of concussion did not differ between both study groups (p = 0.45). Non-displaced fracture lines of the posterior table had a prevalence of 6% (n = 3) in the case group. In the control group, non-displaced fractures of the frontal bone presented in 29% (n = 27); of those, the fracture lines were restricted to the anterior table in 7%, combined anterior and posterior table in 9%, and to the frontal bone beside the frontal sinus in 13%. Prevalence of Guerram's sinus types are shown in Table 3. Calculating the odds of hyperplastic sinus type in patients with depressed anterior table fractures compared to the controls revealed a ratio of 46 to1 ($p < 0.001$). The odds ratio of presence of medium-sized frontal sinus type in the case group was 0.04 to 1 compared to the controls ($p < 0.001$). There was neither hypoplasia nor aplasia of frontal sinus in the case group. Metric sinus size showed significant higher mean values for height ($p < 0.001$) and for width ($p < 0.001$) in the case group (Table 4).

4. Discussion

Anatomic variety of the bi-lobed frontal sinus has initially been described in forensic studies of x-ray images (Yoshino et al., 1987).

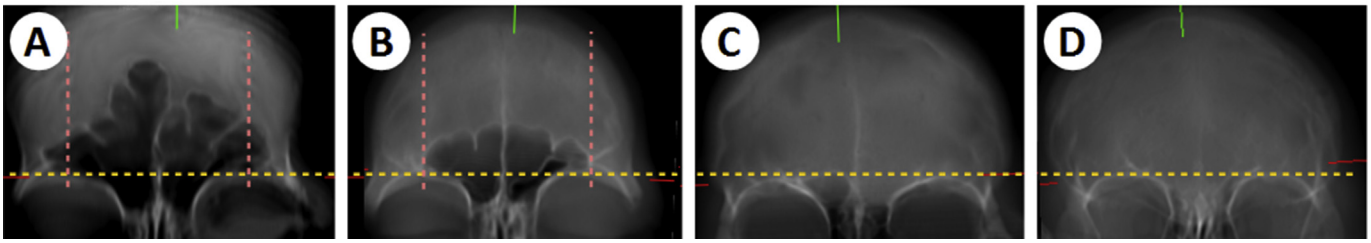

Fig. 2. Guerram's classification (Guerram et al., 2014) of frontal sinus size by using Schmittbuhl and Le Minor's supraorbital line (SOL; yellow dotted) as reference (Schmittbuhl and Le Minor, 1998) and the additionally introduced midorbital reference line (MOL; red dotted); sinus types: hyperplasia, sinus extent lateral to MOL (A); medium-size, sinus extent within MOL and above SOL (B); hypoplasia, sinus extent below SOL (C); and aplasia, no radiologic sign of frontal sinus (D); CT images are shown in reconstructed coronal x-ray view.

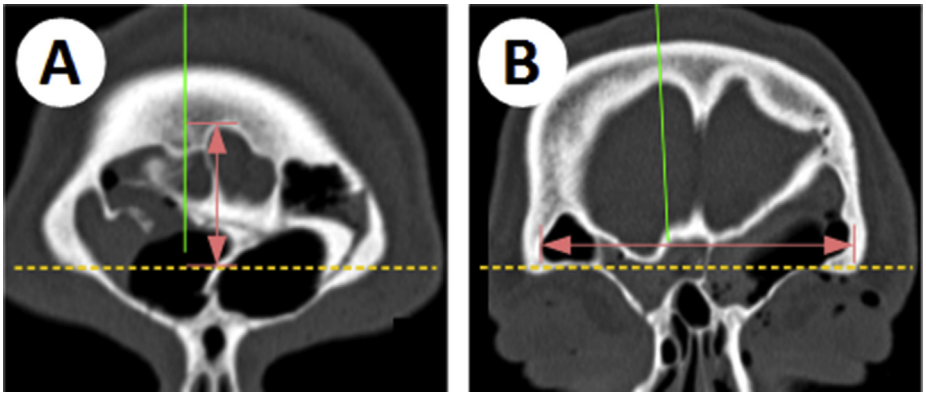

Fig. 3. Measurements of maximum frontal sinus height (A) and width (B); reference for height is the supraorbital line (Schmittbuhl and Le Minor, 1998); CT images in coronal view.

Table 1
Study cohort's characteristics.

Variables	Case group	Control group	P value
	n (%)		
Sample size; n	47	93	
Age, yr (Mean, ±SD)	32.9 (±12.8)	51.5 (±19.7)	<0.001[a,c]
Sex			
Female	3 (6.4)	32 (34.4)	<0.001[b,d]
Male	44 (93.6)	61 (65.6)	
Intracranial involvement			
Brain concussion	47 (100)	86 (92.5)	0.45
Epidural haematoma	0 (0.0)	2 (2.2)	
Subarachnoidal haematoma	0 (0.0)	3 (3.2)	
Epidural air	0 (0.0)	2 (2.2)	

[a] T test.
[b] Chi-squared test.
[c] Note: No correlation appeared between the control's age and metric sinus size calculating Person's coefficient; $p > 0.05$.
[d] Note: No correlation appeared between the control's sex and metric sinus size calculating Spearman's coefficient; $p > 0.05$.

Table 2
Etiology of forehead trauma.

Trauma cause	Case group	Control group
	n (%)	
Total sample size; n	47	93
Fall		
Ground level	4 (8.5)	35 (37.6)
Bicycle	7 (14.9)	20 (21.5)
Stairs	4 (8.5)	6 (6.5)
Elevated position	2 (4.3)	4 (4.3)
Assault		
Fist hit	19 (40.4)	13 (14.0)
Kick	1 (2.1)	2 (2.2)
Hit from object	0	1 (1.1)
Sports		
Soccer	4 (8.5)	0
Boxing	1 (2.1)	1 (1.1)
Horse kick	0	2 (2.2)
Hit against hard object	3 (6.4)	3 (3.2)
Motor vehicle accident	1 (2.1)	5 (5.4)
Other	1 (2.1)	1 (1.1)

With ongoing research, measurements of frontal sinus size using CT and cone beam CT improved analyzing the frontal sinus morphology (Tatlisumak et al., 2008; Flanigan et al., 2016; Stokovic et al., 2018). Guerram's proven method allows categorizing of the frontal sinus morphology from the coronal view (Guerram et al., 2014). For the maxillofacial surgeon, the crucial point for treatment decision after forehead trauma is a displacement of the anterior table (Ioannides and Freihofer, 1999; Manolidis, 2004; Dalla Torre et al., 2014; Garg et al., 2015). We hypothesized that a largely pneumatized frontal sinus is a predictor of depressed fractures of the anterior table after craniofacial trauma.

Table 4
Metric outcome of frontal sinus size.

Variables	Case group	Control group	P value[a]
	Mean, (±SD)		
Frontal sinus width	73.4 (±12.1)	46.0 (±14.8)	<0.001
Frontal sinus height	30.2 (±7.8)	14.7 (±9.0)	<0.001

[a] Paired t test.

Our primary finding was a more than 40 fold increased probability of hyperplastic frontal sinus in the case group, whereas the odds of medium sized types were 25 fold lower. Further results were a significant increased mean sinus width for the cases with a twofold higher sinus height. These findings indicate the higher likelihood of depression fracture of the anterior table in patients with large scaled frontal sinus. There was absence of hypoplastic frontal sinus type in the cases cohort, whereas in our control group hypoplastic and aplastic variants showed comparable rates to published data. Nikolova et al. reported a prevalence for aplasia and hypoplasia of 4% in 137 cadaver skulls (Nikolova et al., 2018).

Regarding the etiologies of both study groups, violent acts were the leading causes within the cases and ground level falls were most frequent in the control group. Remarkably, violent acts that cause maxillofacial trauma account for an overall rate of 39% in Europe, and among these, fractures of the frontal bone have the lowest rate with 1% (Boffano et al., 2015). In both study groups, falls from bicycles without protection from helmets were similar. To ensure comparability, the impact of the traumatic force velocity that caused the forehead injuries in our study cohort was analyzed with regard to several investigations that have recently been published (McIntosh et al., 2000; Sharkey et al., 2012; Fife et al., 2013; Hamel et al., 2013; Hajiaghamemar et al., 2015; Kurt et al., 2017). This leads to two results. First, considering the impact velocity that caused the fracture in our study showed that both groups were comparable. Consequently, we discarded an influence from trauma mode on presence of a fracture in the case group. Second, anterior table fractures are commonly considered as results of high-energy impact although for combined anterior and posterior table fractures a more increased energy is assumed (Delaney, 2016). In detail, high-velocity trauma from motor-vehicle accidents and falls from elevated positions have been described to be the major causes in more than 50% (Gerbino et al., 2000; Manolidis, 2004; Bell et al., 2007). In contrast, the most frequent mode of the cases in our investigation is represented by the low-velocity impact group in more than 90%. This imbalance could be explained with a higher rate of severe traffic accidents in development countries while bicycle falls and interpersonal violence are increasing in industrial nations (Lee, 2009). None of the patients in the case group sustained from intracranial injury except brain concussion. Hence we can state that depressed fractures of the anterior table are not dedicated solely to a high velocity impact. We appoint that the

Table 3
Morphologic outcome of frontal sinus type.

Sinus type	Case group	Control group	Odds ratio[a] (95% CI)[c]	P value[d]
	n (%)			
Total sample size; n	47	93		
Aplasia	0 (0.0)	2 (2.2)	n.a.[b]	0.311
Hypoplasia	0 (0.0)	6 (6.5)	n.a.[b]	0.075
Medium size	6 (12.8)	73 (78.5)	0.04 (0.02–0.11)	<0.001
Hyperplasia	41 (87.2)	12 (12.9)	46.12 (16.15–131.75)	<0.001

[a] Note: Odds ratios were calculated for the prevalence of a sinus type within cases compared to the controls.
[b] Not applicable due to abscence of sinus type in the case group.
[c] Confidence interval.
[d] Chi-squared test compared the row-associated sinus type to all other types.

frontal sinus anatomy remains the primary variable to influence the fracture risk from similar entities of blunt trauma. Interestingly, the authors of a current study hypothesized that a large sized frontal sinus lead to brain protection by working as an energy absorbing element in forehead trauma (Yu et al., 2014). Yu et al. interpreted a lower probability of radiologic signs of brain contusion in patients with large frontal sinus that sustained a fracture of the frontal sinus to support their hypothesis. With regard to our results, we suggest the significant higher odds of depressed fractures after predominantly low velocity impact on large-scaled sinus might be the more fitting explanation for Yu's findings.

Considering the clinical relevance of our results means, the surgeon who is confronted with the reconstruction of depressed anterior table fractures must be aware of the special selection of patients which sustained from these fracture patterns. For those patients the need of adequate postoperative covering with molded thermoplastic shields may be proposed (Kim et al., 2010). Furthermore, with regard to the cases with fractures during sports activities the wear of protective devices such as face masks (Cascone et al., 2008) for close-contact disciplines, e.g. boxing and soccer should be considered for athletes who recovered from frontal sinus injury.

5. Conclusion

We conclude that in depressed fractures of the frontal sinus anterior table, blunt force impact with low velocity prevails as trauma cause. Our data imply that frontal sinus size is the physiologic predictor for these fractures. Thus, individuals with huge frontal sinus have an increased risk for a displaced anterior table fracture after craniofacial injury.

Financial disclosure

There are no financial disclosures or commercial interests from any authors.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jcms.2019.01.018.

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