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Original Research Article

ASSOCIATION OF FRONTAL SINUS PNEUMATIZATION AND INTRACRANIAL INJURY ON COMPUTED TOMOGRAPHY IN HEAD TRAUMA

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ABSTRACT

Background: Head injury is a leading cause of morbidity and mortality in trauma patients. Frontal sinuses (FS) are air filled structures in the skull that can provide protection to the surrounding structures. Such an effect may be influenced by the variations in the sinus volume. Objectives: To evaluate the effect of the extent of FS pneumatization to the findings of intracranial injury on CT.

Materials and Methods: A retrospective study was conducted among patients admitted to the Department of Neurosurgery between September 2021 and August 2023. The participants included all patients referred for CT scan with indication of head injury in the study hospital during the study period. After recruitment, FS volume was measured in Non-contrast CT of the brain; fractures and other associated facial or intracranial injuries were determined from the imaging reports and data on other variables were obtained from the medical records department. The data was then analyzed with a significance level of $p<0.05$.

Results: The study included 120 participants with a mean age of 35.93±11.91 years and involved a slightly higher proportion of females (52.5%). The different variables collected during admission showed that most participants (59.2%) reported a moderate traumatic brain injury (Glasgow Coma Scale score of 9–12) followed by 40.8% of participants with mild traumatic brain injury (Glasgow Coma Scale score of 13-15). The results showed that the mean FS volume was highest among patients who presented with a Marshall score of 2 with 1.55±1.44 cm3 and the difference in scores was found to be statistically significant ($p=0.016$). The difference of FS volume among patients with and without contusion, traumatic subarachnoid hemorrhage (tSAH), subdural hematoma (SDH) was found to be statistically significant ($p<0.05$).

Conclusion: The results of the present study help conclude that higher FS volume can have a protective affect during craniofacial injuries.

Keywords: Trauma, Frontal Sinus, Computer Tomography, Intracranial injury, Outcome.

INTRODUCTION

The frontal sinuses (FS) are two funnel-shaped pneumatic chambers located between the outer and inner tables of the frontal bone. A bony septum divides the two frontal sinuses; it is rarely found in the midline.[1] In the fourth month of intrauterine life, frontal sinuses begin to protrude from the area of the frontal recess of the nose. They are either absent or rudimentary at birth. Only during the second year of life do they start to grow and become noticeable and mature at the age of seven or eight.[2] There is a significant difference in the frontal sinus volume between different people. The adult sinus has a maximum capacity of 37 cc and a typical size of about 10 cc. It is well known that the frontal

sinus's pneumatization varies greatly.[1] Previous research has carefully examined the many differences in the morphological features linked with frontal sinuses and has revealed that these variations vary depending on gender and age.[3,4,5] Additionally, it has been noted that the frontal sinus's anatomy varies throughout climate zones and among populations with various racial or cultural backgrounds.[6]

In traumatic brain injury (TBI), frontal sinus fractures account for 5–15% of all face fractures. Complications from frontal sinus fractures include meningitis, cerebritis, and leakage of the CSF.[7] Frontal pneumocele is an unusual complication secondary to the previous head trauma. Pneumoceles most commonly affect the frontal sinus leading to a facial deformity.[8]

According to one study, patients who suffered head trauma had a higher frequency of brain contusions when they had frontal sinuses with 33% less volume. Greater frontal sinus pneumatization, according to the authors' theory, would enable more direct force transmission to the brain during head trauma.[9] The frontal sinus was also thought to form a "crumple zone" in a study by Celikar M et al., suggesting that this zone served as a protective area for the brain, distributing and absorbing energy following head trauma.[10] According to a different study, TBI has been detected in as many as 83% of frontal sinus-related craniofacial fractures. Research is currently ongoing to determine the risk factors for TBI at presentation and ongoing symptoms in these patients.[11]

In summary, the available evidence suggests that greater frontal sinus pneumatization is associated with a decreased risk of intracranial injury in patients who sustain head trauma. This may be due to the ability of the pneumatized sinus to transmit forces more directly to the brain during impact. The present study hypothesized that the paranasal sinuses provide a protective effect with regard to brain trauma which has been proposed in the literature. The protective effect of these sinuses on the brain was analyzed based on CT calculation of the sinus volume.

MATERIAL AND METHODS

A retrospective study was conducted among patients admitted in Trichy SRM Medical College Hospital and Research Centre with head trauma. The study was conducted between September 2021 and August 2023 after obtaining clearance from the Institutional Human Ethics Committee (TSRMMCH & RC/ 2023- IEC No: 160). The study included all patients referred for CT scan with indication of head injury during the study period. Patients below 16 years of age at the time of presentation, patients with penetrating injury, previous head trauma, history of craniofacial surgery, suboptimal CT images due to artifacts and lesions categorized under Marshall CT scores V and VI were excluded from the study.

Procedure: After patient recruitment, frontal sinus volume was measured in Non-contrast CT of the brain; fractures and other associated facial or intracranial injuries were determined from the imaging reports. Necessary clinical data was acquired from the Neurosurgery case records in the medical records department.

Statistical Analysis: Data analyses was carried out using SPSS statistical package IBM version 26.0. Mean and standard deviation or median and interquartile range was used to describe normally distributed and skewed continuous variables, respectively. Categorical variables will be reported as proportions. Univariate and multivariate analysis was be used to identify and to account for confounding variables. ANOVA was applied to evaluate the association between frontal sinus volume and the clinical variables after adjusting for potential confounders including age, gender, and GCS at admission. All tests were two-tailed with a significance level of $p<0.05$.

RESULTS

Demographic details of the participants

The table 1 shows that the present study included 120 participants with a mean age of 35.93±11.91 years and involved a slightly higher proportion of females (52.5%). The different variables collected during admission showed that most participants (59.2%) reported a moderate traumatic brain injury (Glasgow Coma Scale score of 9–12) followed by 40.8% of participants with mild traumatic brain injury (Glasgow Coma Scale score of 13-15). Severe traumatic brain injury (Glasgow Coma Scale score less than 8) was not reported in this study (Figure 1). Data related to the injuries showed that most of the participants were admitted due to road traffic accident (64%) and it was also reported that fracture of the orbital roof (16%), maxillary sinus (15%) and orbital floor (14%) were the most common associated fractures (Figure 2 and 3). Most of the participants presented with contusions (79.2%) with the absence of extradural hemorrhage (95.8%), subdural hemorrhage (80%) and subarachnoid hemorrhage (70%). A midline shift of 1-5 mm was observed among 49.2% and effaced cisterns were observed in 46.7% participants. 15.8% of the patients needed surgical interventions. Rest of the patients (84.2%) were treated conservatively. Duration of stay was found to be 1 to 5 days among 37.5% participants and above 10 days among 35% participants. [Table 1]

Association between frontal sinus fracture and contusion

Table 2 shows that with regard to the left frontal sinus, 21 patients without a fracture suffered from contusions while 74 patients with a fracture suffered from a contusion. The number of patients without

contusions were 13 without incidence of fracture and 12 with fracture. This difference was found to be statistically significant with p=0.003. Results on the right frontal sinus showed that 23 patients without fracture suffered from contusion while 72 patients with a frontal sinus fracture suffered from a contusion. Eight patients without a fracture did not suffer from a contusion while 17 patients who suffered from a fracture had a contusion. However, analysis showed that this difference was not statistically significant (p>0.05)

Association of frontal sinus volume with Marshall score

The results showed that the mean frontal sinus volume was highest among patients who presented with a Marshall score of 2 with 1.55±1.44 cm^3 followed by 1.08±0.35 cm^3 for score 4, 1.07±0.46 cm^3 for score 3 and 0.87±0.23 cm^3 for score 1. This difference was found to be statistically significant (p=0.016). [Table 3]

Association of FS volume with variables of interest

Table 4 depicts the association of FS volume with variables that indicated intracranial insults and outcome and the results showed that the difference between FS volume among patients with contusion (4.54±3.03 cm^3) and without contusion (6.99±4.05 cm^3) was statistically significant (p=0.001). Patients who presented with traumatic subarachnoid hemorrhage (tSAH) had a mean FS volume of 3.51±1.32 cm^3 while those without tSAH incidence had a mean FS volume of 5.71±3.79 cm^3 with this difference also being statistically significant (p=0.001). Similarly significant difference (p=0.018) was observed with regard to presence (3.58±1.53 cm^3) and absence (5.42±3.64 cm^3) of subdural hematoma (SDH). However, this difference was not observed among mean FS volume with regard to extradural hematoma (EDH), Intraventricular hemorrhage (IVH) and prolonged length of stay (p>0.05).

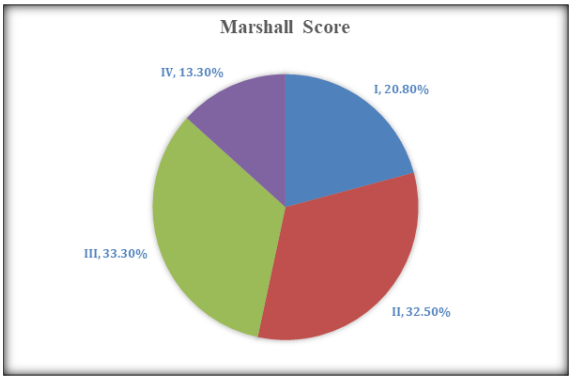

Figure 1: Distribution of Marshall score

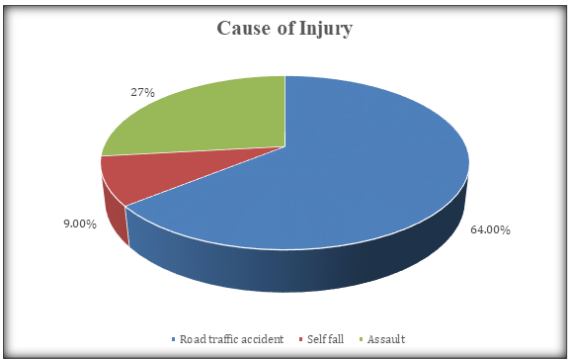

Figure 2: Distribution of cause of injury

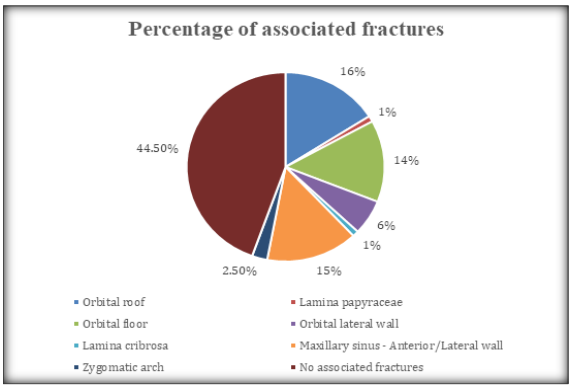

Figure 3: Distribution of associated fractures

Table 1: Demographic details of study participants

Age	**35.93±11.911**
Gender	
Male	**57(47.5%)**
Female	**63(52.5%)**
GCS-Admission	
Mild	**49(40.8%)**
Moderate	**71(59.2%)**
Severe	**00(0.00%)**
Contusion	
Absent	**25(20.8%)**
Present	**95(79.2%)**
EDH	
Absent	**115(95.8%)**
Present	**5(4.2)%**
SDH	
Absent	**96(80.0%)**
Present	**24(20.0%)**
SAH	
Absent	**84(70.0%)**
Present	**36(30.0%)**
Intra-Ventricular Extension	

Absent	**111(92.5%)**
Present	**9(7.5%)**
Midline shift	
Absent	**45(37.5%)**
1 to 5 mm	**59(49.2%)**
More than 5mm	**16(13.3%)**
Cisterns	
Normal	**64(53.3%)**
Effaced	**56(46.7%)**
Management	
Conservative	**101(84.2%)**
Surgical	**19(15.8%)**
Days Stay	
1 to 5 Days	**45(37.5%)**
6-10 Days	**33(27.5%)**
Above 10 Days	**42(35.0%)**
Death	
Survived	**120(100%)**
Patient dead	**00(0.00%)**

Table 2: Association between side of frontal sinus fracture and incidence of contusion

Left Frontal sinus			
	Contusion		**p-value**
	With Contusion	**Without Contusion**	
No Frontal Sinus Fracture	**21**	**13**	**0.003***
Frontal Sinus Fracture	**74**	**12**	
Right Frontal sinus			
No Frontal Sinus Fracture	**23**	**8**	**0.429**
Frontal Sinus Fracture	**72**	**17**	

Table 3: Association of FS volume with Marshall Score

Marshall Score	**FS volume ± SD (cm3)**		**p-value**
	Mean	**Std. Deviation**	
1	**0.865**	**0.226**	**0.016***
2	**1.547**	**1.442**	
3	**1.071**	**0.455**	
4	**1.081**	**0.354**	

Table 4: Association of FS volume with intracranial insults, interventions, and patient outcomes

Variable of Interest (VOI)	**FS volume (cm3) in patients with VOI**	**FS volume (cm3) in patients without VOI**	**p-value**
Contusion	**4.54±3.03**	**6.99±4.05**	**0.001***
tSAH	**3.51±1.32**	**5.71±3.79**	**0.001***
SDH	**3.58±1.53**	**5.42±3.64**	**0.018***
EDH	**5.60±0.00**	**5.03±3.47**	**0.716**
IVH	**5.15±0.52**	**5.04±3.53**	**0.926**
Prolonged length of stay	**5.62±0.52**	**4.74±2.97**	**0.182**

DISCUSSION

A serious public health concern, traumatic brain injury (TBI) is frequently caused by high-velocity head trauma. In TBI, frontal sinus fractures are frequent, accounting for up to 15% of all facial fractures. Serious side effects include meningitis, cerebritis, and leakage of cerebrospinal fluid (CSF) can result from these fractures.[7,12] It is interesting to note that new research raises the possibility that the degree of frontal sinus pneumatization influences the likelihood and seriousness of intracranial damage after head trauma. Patients with greater frontal sinus volumes had worse outcomes, according to the most recent study by Celiker et al. This link was determined to be statistically significant (p=0.005). Greater frontal sinus pneumatization would enable more direct force transmission to the brain during head trauma according to the author.[10] The risk factors for TBI at presentation and persistent symptoms in patients with these disorders are still being studied because of these divergent viewpoints. Examining the correlation between the level of frontal sinus pneumatization and the incidence of intracranial damage in individuals with head trauma was the aim of this investigation. Comprehending this correlation may yield significant understanding of the biomechanics of brain trauma and guide management of the condition.

The mean age of the study participants was 35.93±11.91 years and involved a slightly more proportion of females (52.5%). This gender distribution is contrasted by a previously conducted studies wherein most of the patients with fractures involving the FS region were male but this different was small.[14,15] The mean age reported was also

close to that of a previously conducted study among patients with FS fractures (39.9±19.6 years).[15]

The different variables collected during admission showed that most participants reported a moderate (59.2%) level of consciousness based on the GCS. This was different from a previously conducted study were most of the participants reported a mild GCS score on admission.[15] Data related to the injuries showed that most of the participants were admitted due to road traffic accident (64%). This etiology is found to vary between different studies.[14,15] It was also reported that fracture of the orbital roof (16%), maxillary sinus (15%) and orbital floor (14%) were the most common associated fractures. This can be explained by the close proximity of these structures to the FS.

Most of the participants presented with contusions (79.2%) with the presence of extradural hemorrhage (4.2%), subdural hemorrhage (20%) and subarachnoid hemorrhage (30%) being low. A midline shift of 1-5 mm was observed among 49.2% and effaced cisterns were observed in 46.7% participants. A previously conducted study reported that intracranial hemorrhage was observed in about 35% patients which was close to that obtained in the present study.[14] The frequency was however found to vary from that of another study.[15]

When comparing the side of the FS fracture that led to contusions, it was found that in the left FS, 21 patients without a fracture suffered from contusions while 74 patients with a fracture suffered from a contusion. The number of patients without contusions were 13 without incidence of fracture and 12 with fracture. This difference was found to be statistically significant with p=0.003. The right FS did not show a similar significant difference (p>0.05). This is a novel finding that needs to be studied further for variation among FS fracture patients.

The results showed that the mean frontal sinus volume was highest among patients who presented with a Marshall score of 2 with 1.55±1.44 cm3 and lowest for score 1 with 0.87±0.23 cm3. The difference between means was found to be statistically significant (p=0.016). This result is contrasted by results obtained in a previously conducted study which reported that there was a significant difference between the FS volume with regard to patient mortality but larger volume was associated with higher level of mortality (p=0.005).[10] However, the comparison study used a lower sample size (30) when compared to the present study (120) while using a regression analysis, which may restrict the generalizability of the results. The results of another previously conducted study showed that lower FS volumes were associated with higher Marshall score (p=0.0024).[15] However, the results of the present study show varied results with the Marshall score 4 being closer to the higher mean FS volume. This could be explained by the low availability of patients with Marshall score 4 in the present study which can skew the results. This variation can be explained by the different causes of FS fractures between the studies.

The association of FS volume with variables that indicated intracranial insults and outcome and the results showed that the difference between FS volume among patients with contusion (4.54±3.03 cm3) and without contusion (6.99±4.05 cm3) was statistically significant (p=0.001). Patients who presented with traumatic subarachnoid hemorrhage (tSAH) had a mean FS volume of 3.51±1.32 cm3 while those without tSAH incidence had a mean FS volume of 5.71±3.79 cm3 with this difference also being statistically significant (p=0.001). Similarly significant difference (p=0.018) was observed with regard to presence (3.58±1.53 cm3) and absence (5.42±3.64 cm3) of subdural hematoma (SDH). However, this difference was not observed among mean FS volume with regard to extradural hematoma (EDH), Intraventricular hemorrhage (IVH) and prolonged length of stay (p>0.05). A previously conducted study reported that cerebral contusion was seen in 44.6% of the study patients and it was significantly associated with lower FS volume (p=0.022) independent of potential confounders. The study also observed that lower FS volume was associated with incidence of tSAH, SDH and longer length of stay, However, the latter variable did not show a statistically significant association in the present study.[15] The mean FS volumes and the subsequent variables help reinforce the hypothesis that higher FS volume can help in protecting the surrounding structures when high impact forces are imparted onto these facial regions.

A study using finite element modeling showed that the frontal sinus volume influences the distribution of impact stress in the frontal area. It was discovered that in cases with hyperplastic sinuses, the anterior sinus wall displayed the highest level of fragility, while in situations with hypoplastic and underdeveloped sinuses, the posterior wall/inner plate displayed more fragility. According to the authors, fully formed frontal sinuses may have a protective function by absorbing impact energy and causing the anterior sinus wall to distort and destroy, protecting the posterior wall and intracranial contents.[13] This has been corroborated by the results of a study conducted by Kim I et al which reported that patients with FS fractures involving only the anterior wall showed satisfactory postoperative recovery, with no clinical or radiological complications. In case of extensive damage, both anterior and posterior were affected but even then the outcome was usually manageable.[14] From this result, it can be inferred that the anterior wall absorbs most of the damage before the forces are transferred to the posterior wall which can be associated with worsened outcomes.

The drawbacks of the present study include the retrospective nature of the study which can affect the generalizability of the results. The lack of regression analysis also can be a weakness as it can

help in understanding the effect of specific variables. However, the strengths of the present study include the sample size and the inclusion of multiple variables that are studied which can help in better understanding the protective role of the FS in intracranial injury. The clinical implications of the study include the understanding of the defensive aspects of FS volume and the major role it can play in assessing intracranial damage.

CONCLUSION

The results obtained in the present study help conclude that higher FS volume can help provide protection to the surrounding structures during conditions that can cause intracranial injury. The increased volume can help absorb the detrimental forces and help in reducing the incidence of damage to the brain.

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