Treatment of Frontal Sinus Fractures: A Systematic Review and Meta-analysis

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Purpose: There is still no consensus about the best treatment for frontal sinus fractures (FSFs). Thus, the aims of this study were to answer the following questions: 1) what treatment of FSFs has the lowest rate of postoperative complications? 2) does sinus preservation using observation produce a lower complication rate? 3) are FSFs with nasofrontal outflow tract (NFOT) injury associated with greater complication rates following different treatment options when compared to those patients without NFOT involvement?

Methods: A systematic review and meta-analysis were performed based on PRISMA that included several databases with specific keywords, a reference search, and a manual search for suitable articles. Randomized clinical trials, controlled clinical studies, retrospective studies and case series that estimated complications rate after different treatments options for FSFs were included. The predictor variable was treatment groups, including observation, ORIF, cranialization and obliteration. The outcome variable was complication rate and correlation between complication rate and presence/absence of NFOT. A weighted complication rate/proportion using a random effect model, or risk ratio (RR) with a 95% confidence interval (CI), was performed to construct forest plots. Data analysis was done using a comprehensive meta-analysis.

Results: A total of 2,911 patients with FSFs enrolled in 23 studies were included in this study. The weighted complication rate for different treatment was as follows: observation (7%), ORIF (9.4%), obliteration (10.6%), and cranialization (11%). Nonsurgical treatment decreased the complication rate by 2.1 times (low quality evidence, RR = 2.1, CI: 1.13 to 3.9, P = .000) when compared to surgical treatments for FSFs. CR for fractures with NFOT was 8 % (55/619) compared to a complication rate of 5% (18/353) for fractures without NFOT with insignificant difference (very low quality evidence, RR = 1.7, CI: 0.75 to 4.1, P = .158).

Conclusions: FSFs vary in their severity and treatments. The more severe fractures, the higher the complication rate, no matter how they were treated.

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Frontal sinus fractures (FSFs) are unique and infrequent craniofacial trauma. They account for about 5% of all facial fractures. Similar to other facial fractures, FSFs are caused by road traffic accidents, assaults, falls or sport injuries. The management of these fractures could be as simple as observation or as extensive as cranialization or obliteration of the frontal sinus. The classification of FSFs into anterior table, posterior

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table or both tables is typically used. However, this classification does not suggest the appropriate treatment options.

The management of FSFs is usually based on the anticipation of early or late complications. The possible complications include orbital infection, meningitis, brain abscess, muco/pyocele and/or frontal bone deformity. These complications are related to the extension of the injury to the surrounding vital structures (brain and eyes), the integrity of the frontal sinus outflow track, sinus-brain communication and the displacement of the fractured bone. The controversies in the management of FSFs is the question of whether any kind of treatment would prevent or cause such complications.

At the time of writing this systematic review, there is no consensus on the optimal treatment of FSFs. Several systematic reviews and meta-analyses have been published.[1-3] However, a real meta-analysis using a pooled analysis has not been done. Additionally, there has been no systematic review and meta-analysis comparing complication rates for different treatment modalities. Nor has there been a systematic review and meta-analysis comparing surgical to nonsurgical treatment or comparing sinus preservation versus sinus obliteration or cranialization. Finally, there is no meta-analysis comparing complications for different treatments of FSFs in cases where the nasofrontal outflow tract (NFOT) has been injured versus those without involvement of the NFOT.

Based on the literature, we hypothesize the following: 1) there is no difference in the rate of postoperative complications using different treatments (including observation, open reduction and rigid fixation of the anterior table, obliteration and cranalization) for FSFs; 2) observation (nonsurgical) treatment with sinus preservation will significantly decrease the incidence of postoperative complications when compared to surgical treatment options without sinus preservation such as osteoneogenesis, obliteration and cranialization; 3) the incidence of postoperative complications following different treatments (observation, ORIF, canalization and obliteration) for patients with FSFs with involvement of the NFOT would be associated with greater postoperative complication rate when compared to those patients with FSFs without involvement of the NFOT.

The specific aims of this systematic review and meta-analysis were to: 1) estimate weighted proportion rates of postoperative complications for different treatment options of FSFs; 2) compare surgical and conservative treatments for FSFs; 3) compare complication rates using different treatments for cases of FSFs with and without NFOT involvement.

Methods

PROTOCOL AND REGISTRATION

This study was also registered in the International Prospective Register of Systematic Reviews (PROSPERO) with No. CRD42021248476.[4] This review was done based on Preferred Reporting Items for Systematic reviews and Meta Analyses (PRISMA) statement for reporting systematic reviews[5] (Online supplementary File 1)

FOCUSED QUESTIONS

The research clinical questions were

1. What treatment of FSFs has the lowest rate of postoperative complications?
2. Does sinus preservation using observation or ORIF with reconstruction of displaced anterior/posterior tables produce a lower complication rate when compared to cranialization and sinus obliteration?
3. Are FSFs with NFOT injury (confirmed by computed tomography (CT)) associated with greater complication rates following different treatment options when compared to those patients without NFOT involvement?

SEARCH STRATEGY

The electronic search strategy was done on October 2020 on 3 major databases (PubMed, EMBASE and Cochrane central library). (Online supplementary File 2).

SELECTION CRITERIA

The following inclusion criteria were adopted based on the following PICOS criteria: (P) Patients: Patients with FSFs with or without NFOT injury. (Ia) Intervention: different treatments for FSFs namely observation (serial computed tomography and/or clinical evaluation), ORIF of anterior table with sinus preservation (duct and mucosal preservation with anterior wall reconstruction), sinus obliteration (complete removal of sinus mucosa; burring the sinus walls to eliminate mucosal invaginations; plugging the nasal frontal ducts; and filling the sinus cavity with fat, muscle, bone, or alloplasts) and cranialization (sinus cavity is stripped of mucosa by burring the walls, the ducts are sealed, and the cavity is preserved). (Ib) Intervention: surgical treatment without sinus preservation (osteoneogenesis, obliteration and cranialization). (Ic) Intervention: FSFs with CT confirmation of NFOT injury. (C) Comparator: nonsurgical (observation) treatment and FSFs without CT confirmation of NFOT injury. (O) Outcomes: Primary outcome: incidence of postoperative complications. (S) Study design: all clinical studies including

randomized controlled trials, controlled clinical studies, cohort studies (prospective or retrospective) and case series reporting different treatment option details and complication rates that were directly related to FSFs. (T) Time: adequate follow-up period (at least 1 year) with CT.

EXCLUSION CRITERIA

The following exclusion criteria were applied: (1) animal or in vitro studies, (2) review papers, (3) studies that did not investigate the outcomes of interest and (4) studies that do not expressly report type of surgical treatments and number of postoperative complications.

DATA EXTRACTION

Data were extracted independently by 2 authors using a previously prepared data extraction form. The following information was extracted from each study: author, type of study, male to female ratio, mean age, total patients, type of treatment(s), complications, average follow-up (years).

RISK OF BIAS IN THE STUDIES INCLUDED

Assessment of risk of bias was done by methodological index for non-randomized studies (MINORS).[6]

CONFIDENCE OF EVIDENCE

To assess confidence of evidence for all analyses, GRADE (Grading of Recommendations Assessment, Development and Evaluation) system was used.[7]

SUMMARY OF MEASURES AND SYNTHESIS OF RESULTS

Outcome variable was the number of complications following treatment of FSFs. Predicator variables were different treatment of FSFs including: observation, ORIF, sinus obliteration and cranialization. Additional predictor variables were observation (conservative) treatment with sinus preservation, and surgical options such as obliteration or cranializations and incidence of complications following different treatments in case of concomitant or intact NFOT injuries.

The number of postoperative complications following different treatments for FSFs was pooled using event rate or proportion with corresponding 95% confidence intervals (95% CIs). Risk ratio (RR) with corresponding 95% confidence intervals (95% CIs) was calculated to compare number of postoperative complications following observation (conservative) treatment versus surgical treatment and FSFs with NFOT injury versus without.

Owing to variations in follow-up periods between the included studies, a random effect model was applied even when there was no significant heterogeneity (I^2 <50%). The statistical unit was incidence of

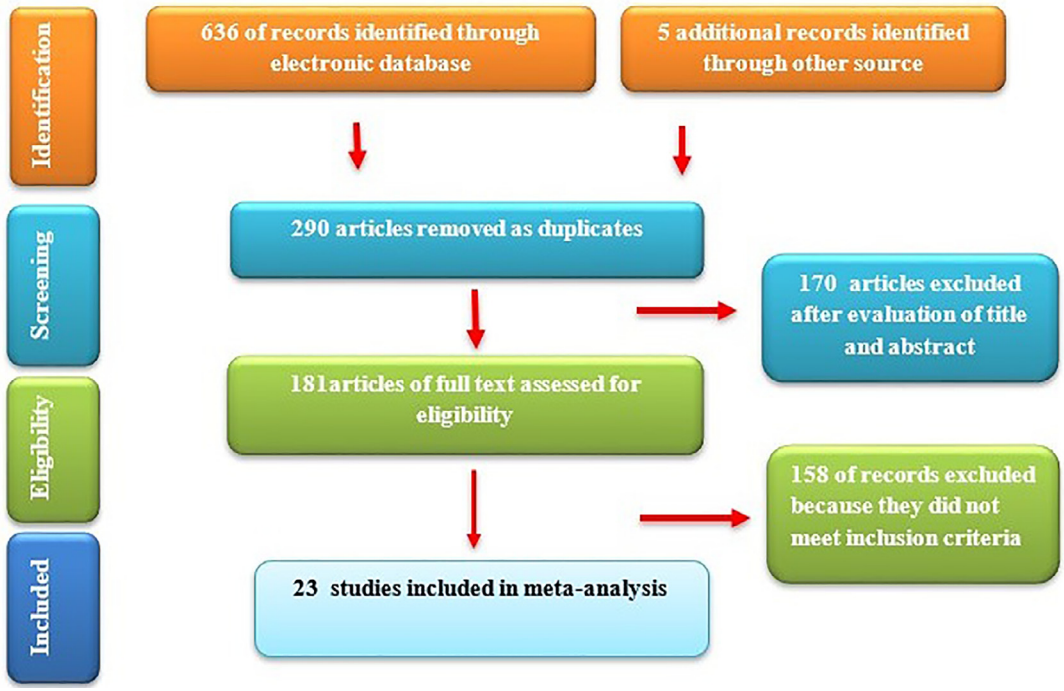

FIGURE 1. Flow chart for screening process based on PRISMA.

complication, not the number of patients, as there were patients with 2 or more complications. The meta-analysis was conducted using Comprehensive meta-analysis Version 2.[8]

Results

LITERATURE SEARCH OUTCOME

Twenty-three studies were included in the final review and underwent meta-analysis (Fig 1).[9-31]

DESCRIPTION OF THE STUDIES INCLUDED

Twenty-three studies were included in this systematic review and meta-analysis. All of them are retrospective[9,10,12-23,26,27,30] except 4 are prospective[24,28,29,31] and 1 is randomized clinical trial.[25] Most of the included studies have a follow-up more than a year and mainly assessed the outcome of each intervention in terms of complication rate. Few studies failed to report complete data[9-11] The included studies involved 2,911 patients who sustained a frontal bone fracture among other injuries. Most of the patients were male and the age ranged from 6 to 93 years. The most common causes of the injury were motor vehicle accidents, assaults and falls. Observation was the most common intervention for non-displaced fracture. Open reduction and internal fixation with sinus preservation were done for most displaced anterior table with intact nasofrontal duct. Obliteration and cranialization was done for displaced or comminuted posterior table fractures with injured nasofrontal duct. Most of the studies reported the outcome as the complication rate of each intervention.[9,11,13,15,17-23,25,28,29,31] Some studies reported the complications as surgical or observation without mentioning the type of surgery[27,30] (Online supplementary File 3).

QUALITY ASSESSMENT OF THE STUDIES INCLUDED

Seven studies showed moderate risk of bias,[10,16–18,23,28] 12 studies a high risk of bias[11-14,15,19-22,24,26,27] and 4 a low risk of bias[14,25,29,31] when assessed by MINORS tool. (Online supplementary File 4)

RESULTS OF THE OUTCOME VARIABLES

A. *Prevalence of postoperative complications following different treatments using proportion (weighted event rate)*

1. *Observation, proportion of complications, % (weighted event rate)*
   Nine studies including 912 patients with non-/minimally-displaced FSFs underwent observation treatment such as medications, serial CT and/or clinical evaluation.[13,14,18,20,21,27–30] There was significant heterogeneity among the studies, with I^2 = 83% (P = .000). The proportion of complications after observation was 7 % (CI: 3.1 to 15.1%) (Fig 2)
2. *ORIF of anterior table fractures, proportion of complications, % (weighted event rate)*
   Seven studies including 370 patients with displaced anterior table fractures underwent ORIF with sinus preservation.[13-15,17,18,21,22] The follow-up ranged from 1 month to 9.5 years. The proportion of complications after observation was 9.4% (CI: 5.2 to 16.6%) (Fig 3)
3. *Sinus obliteration, proportion of complications, % (weighted event rate)*
   Eight studies including 343 patients with displaced, comminated anterior/posterior table fractures underwent obliteration of frontal sinus using different materials.[9,10,14,18–21,25] The follow-up ranged from 1 month to 7.8 years . The proportion of complications after observation was 10.6 % (CI: 7.5 to 14.6%) (Fig 4)
4. *Cranialization, proportion of complications, % (weighted event rate)*
   Eleven studies including 550 patients with displaced, comminuted anterior/posterior table fractures underwent cranialization of the frontal sinus.[10,13,14,16,18–23,29] The follow-up ranged from 1 month to 20 years. The proportion of complications after observation was 11 % (CI: 8.4 to 14.3%) (Fig 5)
5. *Sinus preservation (observation, endoscopic assisted ORIF), proportion of complications, % (weighted event rate)*
   Fourteen studies including 1,343 patients with non-displaced/displaced comminuted anterior/posterior table fractures underwent observation or ORIF with or without endoscopic assistance.[14,15,17,18–22,24,27,28,30,31] The follow-up ranged from 1 month to 7.8 years. The proportion of complications after observation was 7% (CI: 4.2 to 11.5%) (Fig 6)

B. *Observation conservative treatment versus surgical interventions, overall complications rate, risk ratio*
   Two thousand three hundred fifteen patients in 11 studies having FSFs receiving surgical intervention including ORIF, obliteration or cranialization (n = 1146) and observation conservative treatment (n = 1169) were compared.[13,14,18–23,26,29,30] The follow-up ranged from 1 month to 20 years. There was no significant heterogeneity among the studies, with I^2 = 67% (P = .004). Nonsurgical treatment decreased the complication rate by 2.1 times

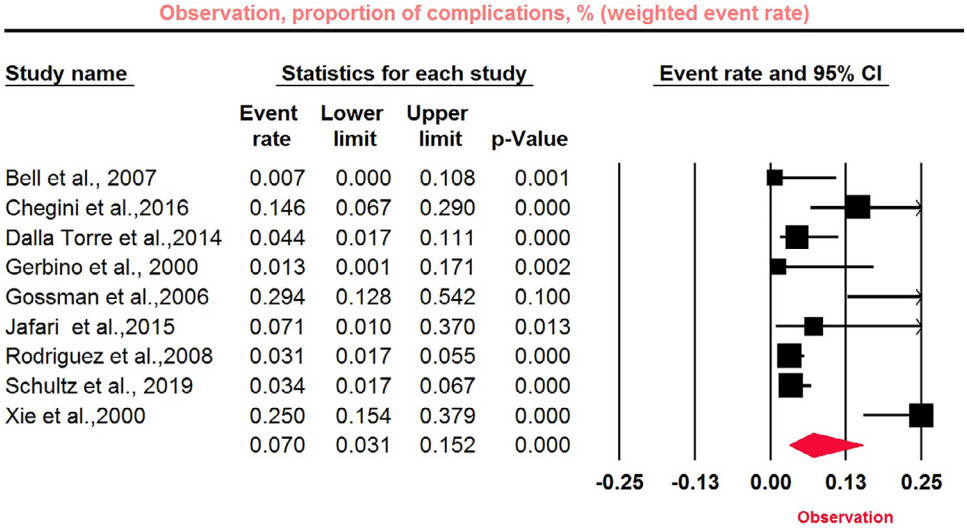

FIGURE 2. Observation, proportion of complications, % (*weighted event rate*).

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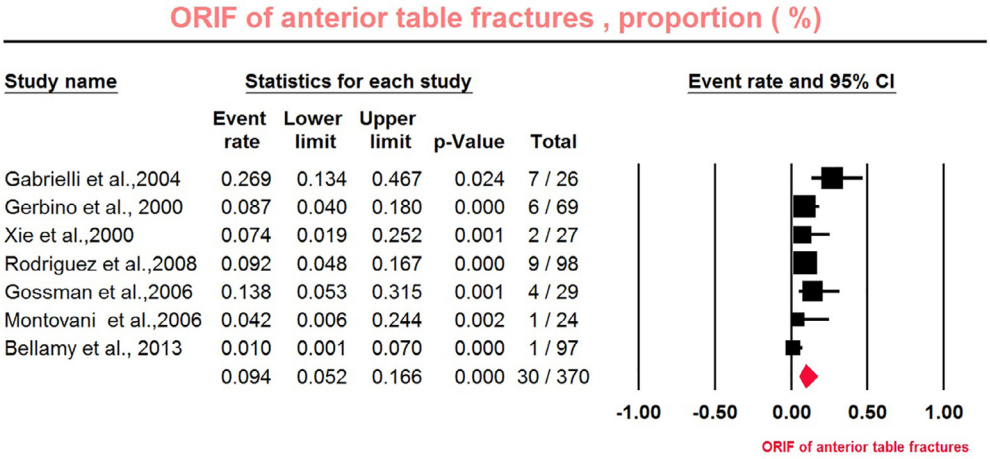

FIGURE 3. ORIF of anterior table fractures, proportion of complications, % (*weighted event rate*).

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(low quality evidence, CI: 1.13 to 3.9, $P = .000$) when compared to surgical treatments for FSFs (Fig 7).

C. *FSFs with versus without NFOT injury, overall complications rate, risk ratio*

Two studies composed of 994 patients compared different treatments with respect to complication rate when FSFs were associated with ($n = 640$) or without ($n = 354$) NFOT injuries.[14,21] There was an obvious decrease in prevalence of postoperative complications after various treatment for patients having FSFs without concomitant NFOT injury when compared to FSFs with involvement of FSFs. The complication rate following different treatments (observation, cranialization, obliteration and ORIF) for fractures with NFOT was 8% (55/619) compared to a complication rate of 5% (18/353) for fractures without NFOT. However, this reduction did not reach a level or significance (very low-quality evidence, RR = 1.78, CI: 0.75 to 4.1, $P = .185$). The RR was 1.78, indicating that FSFs with NFOT injury increase the incidence of postoperative complication by 1.78 times when compared to FSFs without NFOT injury (Fig 8).

Subgroups analyses based on correlations between type of treatment, NFOT involvement and postoperative complications

Observation: Four hundred nine patients in 2 studies underwent observation as sole treatment of non- or minimally-displaced FSFs.[14,21] Of the 409 patients,

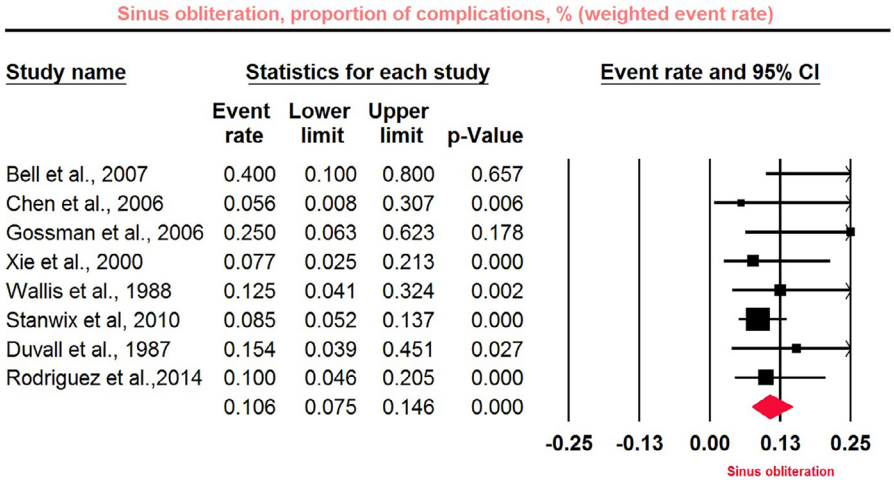

FIGURE 4. Sinus obliteration, proportion of complications, % (*weighted event rate*).

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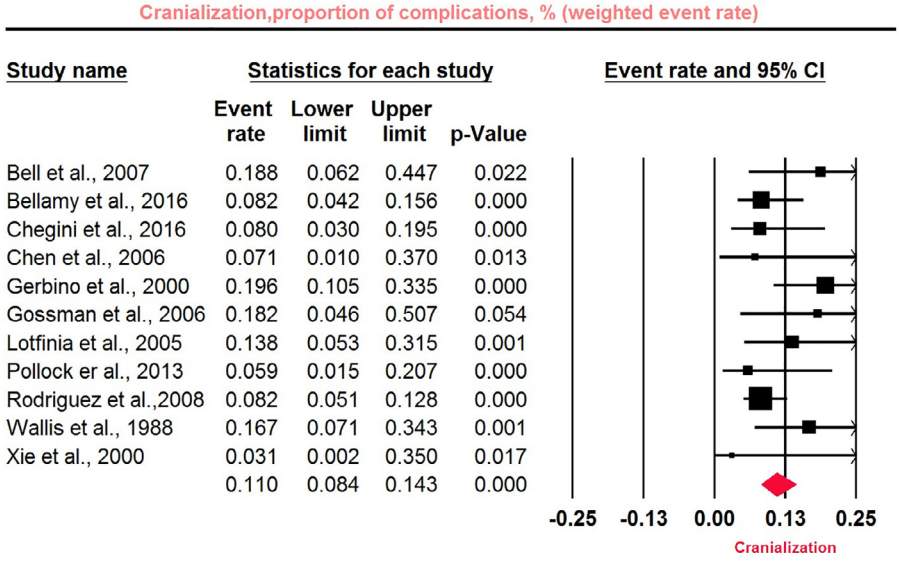

FIGURE 5. Cranialization, proportion of complications, % (*weighted event rate*).

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139 were and 270 were not associated with NFOT injury. When there was NFOT injury the complication rate was 8.6% (12/139), while when there was no NFOT injury, the complication rate was 4.8% (13/270). The presence of NFOT injury following observation increased the complication rate by 1.8 (very low quality evidence, CI: 0.37 to 8.6). However, no statistically significant difference was found between them (Fig 8).

ORIF: One hundred twenty-five patients in 2 studies underwent ORIF of displaced FSFs. Ninety had NFOT injury and 39 did not have NFOT injury.[14,21], When there was NFOT injury the complication rate was 9.7% (9/90), while when there was no NFOT injury the complication rate was 5.1% (2/39). The presence of NFOT injury following ORIF increased the complication rate by 1.31 (very low quality evidence,CI: 0.244 to 7.06) compared to those without NFOT injury managed by observation. This was not a statistically significant difference (Fig 8).

Obliteration: Two hundred fifteen patients in 2 studies underwent obliteration using different materials for displaced FSFs. One hundred eighty-four had NFOT injury and 31 did not have NFOT injury.[14,21] When there was NFOT injury the complication rate was 9.2% (17/184), while when there was no NFOT injury the complication rate was 3.2% (1/31). The presence of NFOT injury following sinus obliteration increased the complication rate 2.3 times (very low quality evidence, CI: 0.39 to 13.4), when compared to FSFs without

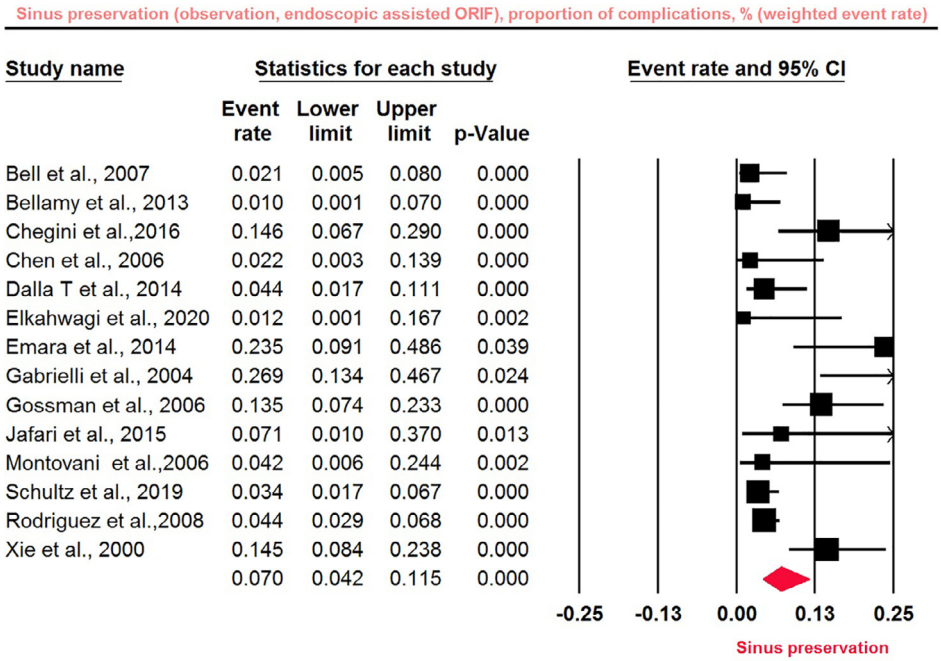

FIGURE 6. Sinus preservation (*observation, endoscopic assisted ORIF*), proportion of complications, % (*weighted event rate*).

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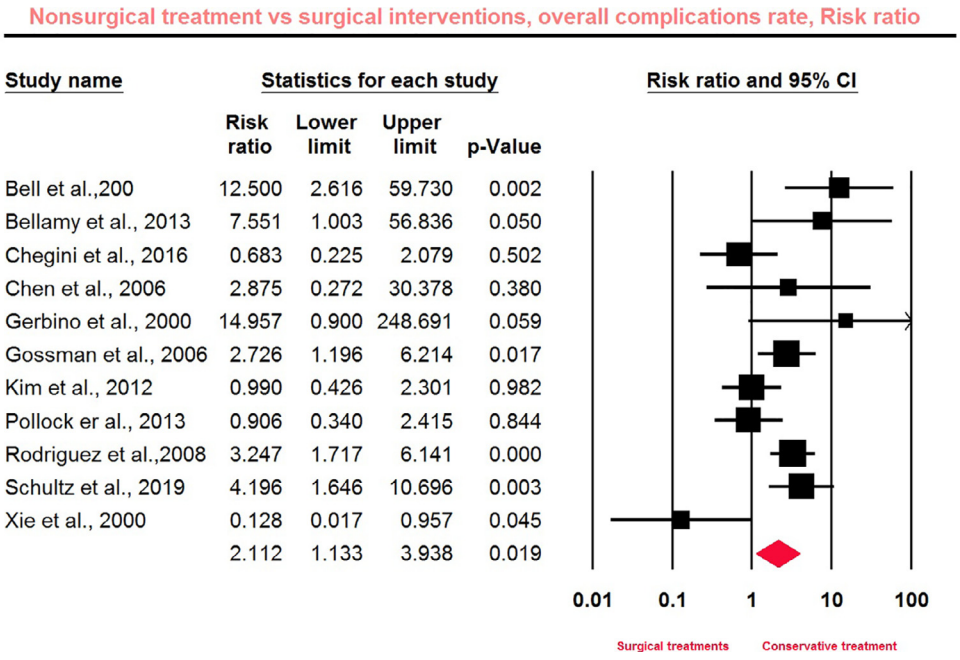

FIGURE 7. Conservative treatment versus surgical interventions, meta-analysis, Risk ratio.

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NFOT injury managed by sinus obliteration. However no statistically significant between them was found (Fig 8).

Cranialization: A total of 224 patients in 2 studies underwent cranialization for displaced and/or comminuted FSFs. Two hundred six had NFOT injury and 18 did not have NFOT injury.[14,21] When there was NFOT injury the complication rate was 8.7% (18/206), while when there was no NFOT injury the complication rate was 5.5% (1/18). The presence of NFOT injury following cranialization increased the complication rate by 1.8 times (very low quality evidence, CI: 0.29 to 11.8)

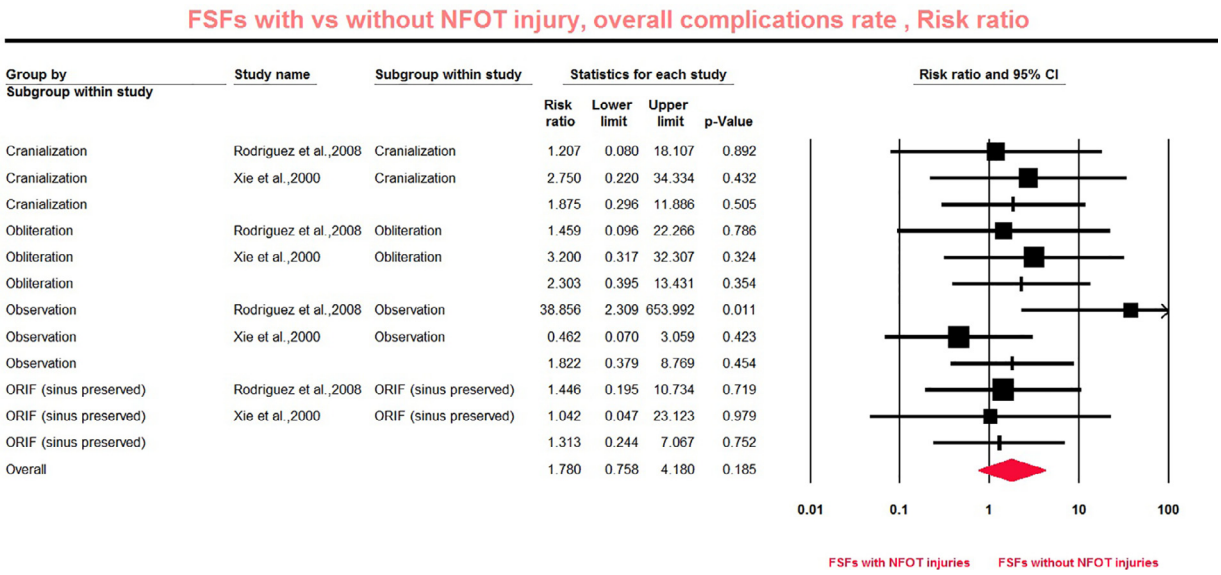

FIGURE 8. FSFs with versus without NFOT injury, proportion of complications, Risk ratio.

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compared to FSFs without NFOT injury that managed by cranialization. However, no statistically significant difference between them was found (Fig 8).

Discussion

Treatment recommendations for FSFs has varied from observation to cranialization. Because, like most fractures with many different variables, algorithms have been created and used to prescribe treatment. It is probable that the many fracture and treatment variables may all be associated with different rates of complications. The main problem with the existing literature is that the case numbers and study methodologies are not usually adequate to sort out the rates of complication for different treatments, and for different types of FSFs. This meta-analysis is the first to compare complication rates for different treatment modalities using a pooled analysis, also it is the first meta-analysis that comparing surgical to nonsurgical treatment and comparing complications for different treatments of FSFs in cases where the NFOT has been injured versus those without involvement of the NFOT.

The findings from our study indicate that most treatments for fractures of the frontal sinus have a complication rate in the 7 to 11% range, with observation having the lowest (7%) and sinus obliteration having the highest (10.6%). What our study did not determine, however, is how these various treatments would perform if used on the same severity of fracture. One would have to assume that if a sinus was obliterated or cranialized, it was a more severe injury than one that was observed, or treated by ORIF of the anterior table. One might therefore expect the rate of complication to increase with the severity of the fracture no matter how it was treated.

To answer the binary question, "what is the rate of complication using observation versus surgical management?", a similar pattern emerges. Observation decreased the complication rate 2.1 times when compared to surgical treatments. This does not mean that all FSFs should be treated by observation because one would again have to assume that the surgically-treated fractures were more severe. These data probably indicate that less severe fractures have fewer complications than more severe fractures.

Most clinicians feel that the involvement of a fracture through the area of the nasofrontal outflow track warrants special consideration and potentially different treatment than those that do not. We indeed found a decrease in prevalence of postoperative complications after various treatments for patients having FSFs without concomitant NFOT injury when compared to FSFs with involvement of NFOT. However, this reduction did not reach a level or significance, even after a subgroup analysis for different treatments provided.

One of the limitations of all studies on frontal sinus injury is that none of them stratified by functionally significant injuries to the NFOT. Instead, studies classified as having fractures through the NFOT without regard to the significance of those fractures. Conceivably, some fractures through the NFOT were functionally insignificant whereas others, may have been. But this information was not available.

In order to provide statistics on complications after fractures of different severity were treated differently,

the best data we can offer is provided in Figure 8. The data indicate that observation for minor fractures provides good outcomes, but when used for more complicated fractures, the complication rate increases greatly. Similarly, ORIF of the outer table is good for most displaced fractures but when used on fractures with displacement of both anterior and posterior walls in association with NFOT disruption, the complication rate is high. Unfortunately, the sample sizes used to calculate the data are small.

Summarizing, frontal sinus fractures vary in their severity and treatments. The more severe fractures, the higher the complication rate, no matter how they were treated.

Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.joms.2021.06.013.

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