ACCSCIENCE PUBLISHING

Advanced Neurology

Review Article

# Outcomes of surgical management and implant consideration for depressed skull fractures: A systematic review

**Andrew Nguyen[1], Akshay Reddy[1], Ramy Sharaf[1], Lauren Ladehoff[2], Michael Joseph Diaz[1], and Brandon Lucke-Wold[3]***

[1]College of Medicine, University of Florida, Gainesville, Florida, USA

[2]College of Medicine, University of South Florida, Tampa, Florida, USA

[3]Department of Neurosurgery, University of Florida, Gainesville, Florida, USA

## ABSTRACT

**Background:** Traumatic brain injuries (TBIs) are associated with high mortality and morbidity. Depressed skull fractures (DSFs) are a subset of fractures characterized by either direct or indirect brain damage, compressing brain tissue. Recent advances in implant use during primary reconstruction surgeries have shown to be effective. In this systematic review, we assess differences in titanium mesh, polyetheretherketone (PEEK) implants, autologous pericranial grafts, and methyl methacrylate (PMMA) implants for DSF treatment.

**Methods:** A literature search was conducted in PubMed, Scopus, and Web of Science from their inception to September 2022 to retrieve articles regarding the use of various implant materials for depressed skull fractures. Inclusion criteria included studies specifically describing implant type/material within treatment of depressed skull fractures, particularly during duraplasty. Exclusion criteria were studies reporting only non-primary data, those insufficiently disaggregated to extract implant type, those describing treatment of pathologies other than depressed skull fractures, and non-English or cadaveric studies. The Newcastle-Ottawa Scale was utilized to assess for presence of bias in included studies.

**Results:** Following final study selection, 18 articles were included for quantitative and qualitative analysis. Of the 177 patients (152 males), mean age was 30.8 years with 82% implanted with autologous graft material, and 18% with non-autologous material. Data were pooled and analyzed with respect to the total patient set, and additionally stratified into those treated through autologous and non-autologous implant material. There were no differences between the two cohorts regarding mean time to encounter, pre-operative Glasgow coma scale (GCS), fracture location, length to cranioplasty, and complication rate. There were statistically significant differences in post-operative GCS ($p < 0.0001$), LOS ($p = 0.0274$), and minimum follow-up time ($p = 0.000796$).

**Conclusion:** Differences in measurable post-operative outcomes between implant groups were largely minimal or none. Future research should aim to probe these basic results deeper with a larger, non-biased sample.

***Keywords:*** Autologous graft; Non-autologous graft; Implant material; Cranioplasty; Depressed skull fracture; Duraplasty

***Corresponding author:**
Brandon Lucke-Wold
(Brandon.Lucke-Wold@neurosurgery.ufl.edu)

**Citation:** Nguyen A, Reddy A, Sharaf R. *et al.*, 2023, Outcomes of surgical management and implant consideration for depressed skull fractures: A systematic review. *Adv Neuro*, 2(1): 247. https://doi.org/10.36922/an.247

**Received:** November 2, 2022

**Accepted:** January 16, 2023

**Published Online:** February 3, 2023

**Copyright:** © 2023 Author(s). This is an Open Access article distributed under the terms of the Creative Commons Attribution License, permitting distribution, and reproduction in any medium, provided the original work is properly cited.

**Publisher's Note:** AccScience Publishing remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

## 1. Introduction

Traumatic brain injuries (TBIs) are a worldwide issue that is associated with high levels of mortality and morbidity[1,2]. Skull fractures vary in etiology as several factors influence the fracture such as bone mineralization and trauma type[3,4]. Depressed skull fractures (DSFs) are a subset of fractures characterized by a portion of the inner table of the skull displacing and lying above the outer table[5,6]. Incidence of depressed skull fractures (DSFs) within TBI patients ranges from 2% to 11%[5]. In DSFs, there is often underlying brain damage of two different varieties: direct damage to tissue and indirect damage via hematomas compressing the brain tissue[4]. Recent advancements of computed tomography (CT) and magnetic resonance imaging (MRI) provide better understanding of diagnosing DSFs and survival interventions.

Treatment for DSFs includes either surgical interventions, such as cranioplasty or conservative treatment. Surgery is pursued based on indications, such as neurologic, infective, and cosmetic issues and open skull fractures are managed in two stages: through primary reconstruction or delayed cranioplasty[5,7]. Previously, delayed cranioplasty was preferred due to reduction of infections such as meningitis and osteomyelitis[8]. However, several limitations are presented in these patients' lives. Furthermore, recent studies have shown no difference in infection rate between delayed cranioplasty and immediate titanium mesh reconstruction[8,9]. Although it is preferable to use patients' own bone material, due to several reasons, rather than artificial mesh during surgery, cases of DSF may be near impossible for bone material reconstruction[9,10]. Furthermore, recent work has demonstrated a higher failure rate with autologous bone due to infection and bone flap necrosis[10,11]. Urgent cranioplasty using artificial material such as titanium mesh, methyl methacrylate (PMMA), and several unique varieties has become more common[9].

Primary reconstruction for DSF was developed to avoid delayed cranioplasty, prevent further CSF complications, and for cosmetic reasons[12]. Variations and effectiveness of the different implants is a field of ongoing research. Differences in tissue tolerance, cost, and resistance to infections and other characteristics are considered when choosing the specific alloplastic material[13]. Titanium mesh bone grafts have been seen to be effective in preventing an inflammatory reaction[13]. PMMA, similarly, has been popular recently due to the ease of confirmation and application[13]. Studies have shown no significant difference between these two alloplastic materials, and both have demonstrated similar results, both functionally and cosmetically[10,13]. However, titanium mesh patients have been seen to develop less inflectional complications going forward[10,13].

With the goal of improving patient outcomes in addressing DSF, an effective route may involve optimization of the implantation approach required in surgical management. Specifically, the decision in implant material utilized can hold considerable weight. In the current review, outcome measures for the surgical management of DSF among various types of implant material are reported in a coherent fashion. We organized a systematic review by organizing the available data regarding outcomes of surgically treated DSF between different implant materials to address the question of how implant material may affect the post-operative outcomes of DSF patients.

## 2. Methods

### 2.1. Eligibility criteria

Retrospective cohort studies, case series, and case reports were included in this systematic review. Our analysis included the study design, country, number of patients, age, sex, preoperative Glasgow coma scale (GCS), fracture location, primary implant material, time to encounter, time to cranioplasty, presence of complications, postoperative GCS, length of stay, and follow-up duration. Inclusion criteria pertained to studies reporting use of specific implant material within treatment for depressed skull fractures. Exclusion criteria included studies not sufficiently disaggregated for extracting data pertaining to depressed skull fractures, those failing to specifically report surgical approach regarding implant material. Non-primary data including presentations, letters to the editor, editorials, and other sources that appeared non-peer-reviewed were strictly excluded. Articles written in languages other than English, or cadaver/non-human studies were excluded from the study. The selection process is shown in Figure 1.

### 2.2. Information sources

A literature search was performed in Web of Science, Scopus, and PubMed from their inception to September 2022 to identify studies reporting the outcome of implant usage in subsequent duraplasty in treatment of depressed skull fractures. The search strategy was developed by one reviewer (A.N.) by consulting the peer review of electronic search strategies (PRESS) criteria[14]. This review was reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)[9]. The search strategy is (depressed skull fracture) AND (implant OR shunt OR inlay OR onlay OR patch OR mesh OR titanium OR cranioplasty). Study selection was performed by one reviewer (A.N.) and data

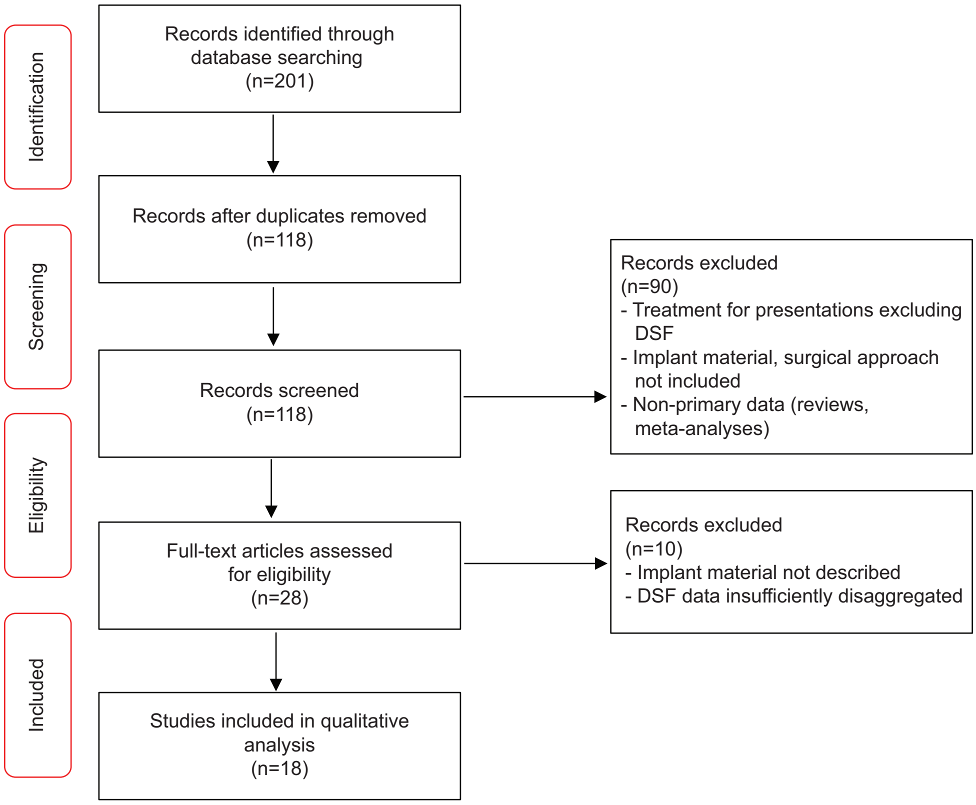


**Figure 1.** PRISMA study selection flow diagram.

extraction was performed by two reviewers (A.N., R.S.). Accuracy of data extraction was ensured through the use of a third reviewer, who monitored all data entries for correctness. When disagreements pertaining to study selection arose, an additional reviewer (M.D.) mediated the final decision. Full articles were retrieved when titles and abstracts potentially relevant to the inclusion criteria were found. The data from each study was then extracted and analyzed. With regard to the data points of interest, the corresponding values were extracted and collected for future analysis in an Excel spreadsheet. If a study did not explicitly mention the presence of a clinical characteristic, it was assumed that the characteristic was not present in that patient set.

### 2.3. Selection of sources of evidence

Titles and abstracts were screened by two reviewers independently (A.N., R.S.). Following individual screening, records identified through the searches were added to a database and duplicates were removed through Rayyan web app for systematic reviews.

### 2.4. Qualitative analysis

To assess the quality and risk of bias of the studies eligible for inclusion, Newcastle-Ottawa Scale (NOS) criteria were used to rate our included cohort studies and case reports/series[15]. The NOS cohort criteria allowed for a maximum of four stars in *selection*, two stars in *comparability*, and three stars in *outcome:* the total range was 0–9. Case reports and series were analyzed with NOS cohort guidelines without application of comparability questions, making their effective range 0–7. Two reviewers (M.D., A.N.) conducted this assessment.

### 2.5. Statistical analysis

Data were analyzed using JMP Statistical Software (SAS). Quantitative variables were analyzed through two-tailed independent samples t-tests. $p < 0.05$ was considered to be significant. Data were quantitatively pooled to present statistics in a coherent manner representative of the total patient set. Following this, analysis was conducted similarly, stratifying the dataset by autologous and nonautologous implant material. The implant material specifically dichotomized as autologous versus nonautologous material, and their respective outcomes were considered to be the primary analysis of the current review. Precluding this analysis, differences in age, sex, time to encounter, pre-operative GCS, and fracture location were assessed to determine the presence of confounding variables.

## 3. Results

### 3.1. Selection of sources of evidence

Figure 1 shows the study selection process. The literature search initially identified 201 studies, of which 118 were non-duplicate. Initially, 28 articles published between 1999 and 2022 were selected based on the inclusion and exclusion criteria for the present review of the literature. Eighteen articles were quantitatively analyzed following full-text analysis of the initial selected articles. These included 1 retrospective cohort study, 8 case series, and 9 case reports (Table 1)[7-9,16-30]. Five studies were conducted in the United States, three in China, and one each in Brazil, Egypt, Germany, India, Indonesia, Japan, Nigeria, South Korea, Switzerland, and Turkey (10).

### 3.2. Qualitative analysis

The eighteen studies were assessed with appropriate guidelines to characterize their quality based on several criteria (Table 2). NOS scores of 7–9 were deemed sufficient for the study as it fell in the region of high-quality study according to the NOS guidelines. The single retrospective cohort study was analyzed with the NOS for cohort studies. For case reports/series which had a maximum of 7, sufficient studies included those dissatisfying only 1 item per domain at maximum, with a total score of 5/7. The single cohort study scored a 7. Six case reports/series scored a 6 and eleven case reports/series scored a 5.

### 3.3. Analysis of confounding variables

From the extracted data, potential confounders were analyzed with respect to the two categories of implant type, that is, autologous and nonautologous. This included the age, gender, duration to hospital encounter, pre-operative GCS, and fracture location. With respect to all variables, barring age, there were no statistically significant differences observed between autologous versus non-autologous implant material. Age within the autologous patient sample set was skewed toward younger patients, particularly in a study by AbdelFatah *et al.*[16] Removal of this study in the same analysis revealed a transition to non-statistical significance of age. With this in mind, the study was included for outcome analysis acknowledging the large sample of younger patients in this study skewed autologous patient age toward the left.

### 3.4. Synthesis of results

The sample size across all studies was 177 patients after application of inclusion and exclusion criteria. The mean age was 30.77 years. There were 152 males (85.9%). Regarding duraplasty implant material, 82% utilized autologous pericranial grafts, 16% titanium mesh, 1% polyetheretherketone (PEEK), and 1% PMMA. After dichotomization, 82% utilized autologous implant material and 18% non-autologous implants. In the autologous group, the mean age of subjects was 25.2 years old, and the proportion of male was 64%. In the non-autologous group, the mean age of subjects was 42.0 years old, and the proportion of males was 16.5%.

### 3.5. Pre-operative characteristics

In total, the mean pre-operative GCS was 13.5, and time to initial encounter was 1.9 days. The proportion of fracture location was 44% frontal, 30% parietal, 15% occipital, and 11% temporal across the total patient sample. With respect to the autologous group, mean preoperative GCS was 12.8. Mean time to encounter was 1.67 days. Location of fracture was 36% frontal, 33% parietal, 17% occipital, and 14% temporal. In the non-autologous group, pre-operative GCS was 14.8. Mean time to encounter was 2.68 days. Location of fracture was 68% frontal, 22% parietal, and 10% occipital. There was no statistically significant difference between the two groups for preoperative GCS ($p = 0.1570$), time to encounter ($p = 0.4785$), or fracture location ($p = 0.09$) (Table 3).

### 3.6. Perioperative characteristics

Decision for cranioplasty was reported in 97% of the surgically treated patients. Mean length to cranioplasty 11.4 days. In the autologous group, mean length to cranioplasty was 10.3 days. The non-autologous group had a mean length to cranioplasty of 16.1 days. There was no difference between the two groups for days to cranioplasty ($p = 0.4780$) (Table 3).

### 3.7. Post-operative outcomes

The overall complication rate was 4.0%% including two cases of intraoperative epidural hematoma and postoperative wound infection. The mean post-operative GCS was 14.95. The mean length of stay was 18.6 days for the total sample size. Finally, the overall minimum follow-up time was 1.2 years. In the autologous group, the mean post-operative GCS was 15, while the non-autologous group had a mean of 14.74. In the autologous group, complication rate was 4.14%, and in the non-autologous group, the rate was 3.13%. There was no difference in complication rate ($p = 0.8584$). The autologous group had an average LOS of 36.3 days, and the non-autologous group had a LOS of 16.7 days. In the autologous group, minimum follow-up time was 1.21 years, and in the non-autologous group, the rate was 0.93 years (Table 4). There was a significant difference for GCS ($p < 0.0001$), LOS ($p = 0.0274$), and minimum follow-up time ($p = 0.000796$).

**Table 1. Newcastle-Ottawa Scale qualitative analysis**

| Case series/report | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Selection | | | | Comparability | Outcome | | Adequacy of follow up of cohorts | Total |
| Author and year | Study type | Representativeness of the exposed cohort | Selection of the non-exposed cohort | Ascertainment of exposure | Demonstration that outcome of interest was not present at start of study | Comparability of cohorts on the basis of the design or analysis | Assessment of outcome | Was follow-up long enough for outcomes to occur | | |
| Wylen *et al*., 1999 [29] | Case series | 1 | n/a | 1 | 1 | n/a | 1 | 1 | 1 | 6 |
| Ebel *et al*., 2000[20] | Case series | 1 | n/a | 1 | 1 | n/a | 1 | 1 | 1 | 6 |
| Marbacher *et al*., 2008[7] | Case series | 1 | n/a | 1 | 1 | n/a | 1 | 1 | 1 | 6 |
| McCall *et al*., 2008[25] | Case series | 1 | n/a | 1 | 1 | n/a | 1 | 0 | 1 | 5 |
| Hewitt *et al*., 2009[24] | Case report | 1 | n/a | 1 | 1 | n/a | 1 | 1 | n/a | 5 |
| Forbes *et al*., 2010[22] | Case report | 1 | n/a | 1 | 1 | n/a | 1 | 1 | n/a | 5 |
| Bot *et al*., 2013[19] | Case report | 1 | n/a | 1 | 1 | n/a | 1 | 1 | n/a | 5 |
| Muderris *et al*., 2013[26] | Case report | 1 | n/a | 1 | 1 | n/a | 1 | 1 | n/a | 5 |
| Wan *et al*., 2013[28] | Case series | 1 | n/a | 1 | 1 | n/a | 1 | 1 | 1 | 6 |
| Sheng *et al*., 2017[27] | Case report | 1 | n/a | 1 | 1 | n/a | 1 | 1 | n/a | 5 |
| Ballestero *et al*., 2019[18] | Case report | 1 | n/a | 1 | 1 | n/a | 1 | 1 | n/a | 5 |
| Faried *et al*., 2019[21] | Case report | 1 | n/a | 1 | 1 | n/a | 1 | 1 | n/a | 5 |
| Hitoshi *et al*., 2019[9] | Case series | 1 | n/a | 1 | 1 | n/a | 1 | 1 | 1 | 6 |
| Eom *et al*., 2020[8] | Case series | 1 | n/a | 1 | 1 | n/a | 1 | 1 | 1 | 6 |
| Haider *et al*., 2020[23] | Case report | 1 | n/a | 1 | 1 | n/a | 1 | 1 | n/a | 5 |
| Yang *et al*., 2021[30] | Case series | 1 | n/a | 1 | 1 | n/a | 1 | 1 | 0 | 5 |

*(Cont'd...)*

**Table 1. (Continued)**

| Author and year | Study type | Selection | | | | Comparability | Outcome | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Representativeness of the exposed cohort | Selection of the non-exposed cohort | Ascertainment of exposure | Demonstration that outcome of interest was not present at start of study | Comparability of cohorts on the basis of the design or analysis | Assessment of outcome | Was follow-up long enough for outcomes to occur | Adequacy of follow up of cohorts | |
| Case series/report | | | | | | | | | | |
| Anehosur *et al*., 2022[17] | Case report | 1 | n/a | 1 | 1 | n/a | 1 | 1 | n/a | 5 |
| Cohort | | | | | | | | | | |
| AbdelFatah *et al*., 2016[16] | Retrospective cohort | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 7 |

n/a: Not available

## 4. Discussion

Surgical reconstruction of DSFs has been achieved using various implant materials; however, comparative analysis of post-operative outcomes associated with the type of implant material has yet to be conducted[31-33]. With the goal of improving outcomes in patients presenting to the emergency department with DSFs, the authors conducted a systematic review to explore the outcomes and operative considerations associated with DSF reconstruction achieved through use of either autologous or non-autologous implant material (Tables 1 and 2).

Comparative analysis of pre-operative factors, such as GCS, was conducted between patients in whom DSF reconstruction was achieved using either autologous or non-autologous implant material to identify the implications of pre-operative GCS assessment on surgical approach (Table 3). Despite the lack of a statistically significant difference in pre-operative GCS between the two groups, there was an advantageous trend toward the use of an autologous implant among patients with a lower pre-operative GCS (GCS: 12.8 vs. 14.8) (Table 3). Although there is limited evidence in the literature citing a preference towards the use of either an autologous or allogenic graft in patients with lower GCS, it is hypothesized that autologous grafts are preferred in patients with lower GCS scores to prevent further complications related to graft rejection[34]. It is also possible that patients with the lower GCS scores were deemed to require more urgent intervention that did not allow ample opportunity for sourcing an appropriate HLA-matched allogenic graft; however, further investigation is needed to ascertain whether autologous grafts may enable reduced post-operative complication in patients with lower GCS scores[34]. Further evaluation of the association between the time to encounter – defined as the duration between injury and arrival at the ER – and its implications on the use of either an autologous or non-autologous implant also did not reveal any statistically significant differences. However, comparative analysis suggests a trend towards the use of an autologous implant for DSF reconstruction in patients with a shorter time to encounter (1.67 days vs. 2.68 days), which may support the hypothesis that autologous implants are preferred in cases of greater interventional urgency (Table 3). In addition, the association between fracture location and the type of implant material utilized for reconstruction was evaluated to identify whether differences in selection of implant material are preferentially attributable to fracture location (Table 3). The frontal region of the skull was the most common location of reconstruction within both cohorts of patients; however, reconstruction of the frontal region of the skull occurred in 68% of patients in

**Table 2. Characteristics of included studies and patient demographics**

| Study | Study type | Country | Number of total subjects | Mean age (year) | Sex (M/F) | Implant material |
|---|---|---|---|---|---|---|
| Wylen *et al.*,1999[29] | Case series | United States | 32 | n/a | 27/5 | Pericranial graft |
| Ebel *et al.*, 2000[20] | Case series | Germany | 2 | 49 | 2/0 | Pericranial graft |
| Marbacher *et al.*, 2008[7] | Case series | Switzerland | 5 | 32.2 | 5/0 | Titanium mesh |
| McCall *et al.*, 2008[25] | Case series | United States | 1 | 49 | 1/0 | Pericranial graft |
| Hewitt *et al.*, 2009[24] | Case report | United States | 1 | 14 | 1/0 | n/a |
| Forbes *et al.*, 2010[22] | Case report | United States | 1 | 6 | 1/0 | n/a |
| Bot *et al.*, 2013[19] | Case report | Nigeria | 1 | 40 | 1/0 | Methylmethacryalte (PMMA) |
| Muderris *et al.*, 2013[26] | Case report | Turkey | 1 | 45 | 1/0 | Pericranial graft |
| Wan *et al.*, 2013[28] | Case series | China | 18 | 41 | 11/7 | Pericranial graft |
| AbdelFatah *et al.*, 2016[16] | Retrospective cohort | Egypt | 87 | 21 | 76/11 | Pericranial graft |
| Sheng *et al.*, 2017[27] | Case report | China | 1 | 22 | 1/0 | Pericranial graft |
| Ballestero *et al.*, 2019[18] | Case report | Brazil | 1 | 0 | 1/0 | n/a |
| Faried *et al.*, 2019[21] | Case report | Indonesia | 1 | 19 | 1/0 | Pericranial graft |
| Hitoshi *et al.*, 2019[9] | Case series | Japan | 2 | 8 | 2/0 | Titanium mesh |
| Eom *et al.*, 2020[8] | Case series | South Korea | 19 | 50.4 | 18/1 | Titanium mesh |
| Haider *et al.*, 2020[23] | Case report | United States | 1 | 27 | 1/0 | Titanium mesh |
| Yang *et al.*, 2021[30] | Case series | China | 2 | 47 | 1/1 | PEEK |
| Anehosur *et al.*, 2022[17] | Case report | India | 1 | 6 | 1/0 | Titanium mesh |
| Total (mean) | | | 177 | 30.77 | 152/25 | |

n/a: Not available

**Table 3. Pre- and peri-operative characteristics**

| Pre-operative GCS | Time to encounter (days) | Fracture location | Length to cranioplasty (days) |
|---|---|---|---|
| Autologous | | | |
| 12.8 (10–15) | 1.67 (0–21) | 36% frontal<br>33% parietal<br>17% occipital<br>14% temporal | 10.27 (0–210) |
| Non-autologous | | | |
| 14.8 (8–15) | 2.68 (0–45) | 68% frontal<br>22% parietal<br>10% occipital | 16.10 (0–210) |
| p-value | | | |
| p=0.1570 | p=0.4785 | p=0.09 | p=0.4780 |
| Overall | | | |
| 13.5 (10–15) | 1.9 (0–45) | 44% frontal<br>30% parietal<br>15% occipital<br>11% temporal | 11.43 (0–180) |

All values reported as either means with standard deviations or sole proportions

**Table 4. Post-operative outcomes**

| Post-operative GCS | Length of stay (days) | Complication rate | Minimum follow-up time (years) |
|---|---|---|---|
| Autologous | | | |
| 15 | 36.3 (7–42) | 4.14 | 1.21 (0.25–2) |
| Non-autologous | | | |
| 14.74 (10–15) | 16.7 (3–75) | 3.13% | 0.93 (0.20–2.67) |
| p-value | | | |
| p<0.0001 | p=0.0274 | p=0.8484 | p=0.000796 |
| Overall | | | |
| 14.95 (10–15) | 18.6 (3–75) | 4 0.0% | 1.15 (0.20–2.67) |

All values reported as either means with ranges or sole proportions

the non-autologous cohort, versus 36% in the autologous cohort (Table 3). Assessment of variation in reconstruction location revealed a coinciding trend among both cohorts of patients, with DSF reconstructions of the parietal and occipital regions being the second and third most common, respectively. Interestingly, however, while reconstruction of the temporal region was conducted in 14% of patients within the autologous implant cohort, reconstruction of the temporal region among the non-autologous implant cohort was not reported in the analyzed patient sample. As some studies have reported greater occurrences of post-operative complications associated with autologous implants, it is possible that there may be a preferential bias towards the use of allogenic grafts for reconstruction of the frontal skull bone; however, it is also possible that these observations could be due to the relatively small sample size of the studied patient population[35]. Thus, further investigation of the association between the location of fracture reconstruction and post-operative outcomes associated with the type of implant material is warranted.

Perioperative characteristics were also comparatively assessed to identify differences associated with operative considerations and selection of implant material. Although studies have reported reduced incidence of post-operative infection attributable to delayed surgical intervention, clinical equipoise remains as to the optimal timing of operation post-injury given conflicting evidence in the literature[36-38]. There is more consensus in the literature, however, that immediate cranioplasty following injury should be restricted to the removal of damaged bone, and later followed by cranioplasty in a staged surgical approach[8,33,38]. As such, we investigated whether this equipoise persists in consideration of DSF reconstructions utilizing autologous or non-autologous implant material (Table 3). In comparing the duration of time between injury and cranioplasty between both cohorts, we identified a mean duration of 11.43 days among the autologous implant cohort as compared to a mean duration of 10.27 days in the non-autologous implant cohort (Table 3). This slight delay in intervention time among the autologous cohort may be indicative of a deliberate attempt to reduce postoperative infection, which is supported as a precautionary measure given the lower preoperative GCS observed in this cohort (Table 2). We additionally compared the average length of stay between both cohorts to determine whether DSF reconstruction utilizing either autologous or non-autologous implant material was associated with improved post-operative outcomes. This revealed a significant statistical difference between the autologous and non-autologous cohorts (36.3 days vs. 16.7 days, $p = 0.0274$), which supports the possibility that enhanced postoperative outcomes can be achieved through use of non-autologous implant material (Table 4).

In addition, post-operative outcomes were analyzed between patients with autologous or nonautologous implant material. The previous literature has shown no significant difference in post-operative outcomes between different implant materials[39,40], but male patients, patients with complex injuries, and cases with involvement of the frontal sinus experienced a higher risk of postoperative complications[39]. Zanotti et al. additionally reported that complications after cranioplasty are influenced by implant design (Y). Although autologous implants show desirable biomimetic properties, they display a variable reabsorption rate between 3% and 50%, leading to failure of the implant (Y). Nonautologous implants may overcome these disadvantages of autologous material; however they may be associated with their own shortcomings such as higher infection rate or higher costs. Due to these proposed differences, we analyzed post-operative complication rates between patients utilizing autologous or nonautologous graft material (Table 4). Of 145 patients with an autologous graft, 4.14% (6/145) had experienced at least one post-operative complication. This was compared against the nonautologous patient sample in which 3.13% (1/32) of patients reported at least one post-operative complication, resulting in a mean complication rate of 4% across groups. Thus, there was no significant difference in complication rate between both groups. The previous literature reports minor complications usually occur within the first 2 – 3 months after cranioplasty, and major complications occur around 6 months after surgery (Y). Both patients in the autologous and nonautologous groups had a mean follow-up time of 13.2 months, 14.5 months in the autologous group and 11.2 months in the nonautologous group, thus allowing adequate time for the occurrence of complications. The outcome of depressed skull fractures has been significantly associated with GCS, with patients scoring between 13 and 15 having fewer complications (Z)[41], which allows for accurate comparison between both autologous and nonautologous groups with a similar GCS of 15 and 14.75 for the autologous and nonautologous groups, respectively. The length of stay was significantly different between the two groups, with 36.3 days for patients receiving an autologous implant and 16.7 days for patients receiving a nonautologous implant ($p = 0.0274$). Although hospital length of stay is commonly used as a measure of quality of care, there were no significant differences in post-operative complication rates with longer hospital stay following cranioplasty with an autologous implant when compared with shorter hospital stay in the nonautologous implant group.

We confer there were few limitations to the present systematic review. Due to the stringency of the chosen inclusion criteria, a minority of studies that met the requirements were included in the present analysis. The relationship between perioperative characteristics and outcomes were also difficult to establish across groups due to the variable length of follow-up across studies. Moreover, a larger, non-homogeneous sample is desired to resolve a generalizable relationship between patient outcomes related to receiving autologous or nonautologous implants. The autologous patient population was predominantly young adult males, whereas the non-autologous patient population was predominantly middle-aged females (Table 2). In addition, significant differences were reported between post-operative GCS and minimum follow-up times between both groups. This was likely due to small sample size leading to differences that may not be representative of patients receiving autologous and nonautologous implants. In addition, the country of origin for included studies should be further analyzed with a report of justification regarding chosen implant material. Finally, pooled effect sizes described here could not be rigorously adjusted for covariates.

With the goal of improving patient outcomes in addressing DSF, we hope to address how implant material may affect post-operative outcomes. Future research should be conducted, adjusting for standard of care across national health systems, patient socio-demographic factors, and patient comorbidities. We also require a clearer focus on primary outcomes evaluated to better compare across groups.

## 5. Conclusions

The current study represents a scoping systematic review of the Web of Science, Scopus, and PubMed databases. Here, we provide novel efforts to elucidate depressed skull fracture outcomes in patients receiving autologous-based interventions compared to non-autologous-based interventions. We identified trends toward autologous implant usage among low preoperative-GCS patients, though DSF patients receiving autologous grafts reported greater likelihood of postoperative complication. Still, however, these data largely corroborate previous research indicating little-to-no statistically significant contributions of selected implant material towards post-operative complication rates among neurosurgical patients. Limitations of the present review include uncontrolled cofounders in patient and hospital factors, distinctly heterogenous patient cohorts, and inconsistent follow-up times. Future investigation of implant considerations for depressed skull fractures should focus its efforts on studying large, non-biased treatment cohorts with adequate control measures in place for differences attributable to interacting factors.

## Acknowledgments

None.

## Funding

None.

## Conflict of interest

The authors declare that they have no conflict of interest.

## Author contributions

*Conceptualization:* Brandon Lucke-Wold, Andrew Nguyen
*Formal analysis:* Andrew Nguyen
*Investigation:* Andrew Nguyen, Michael Joseph Diaz
*Methodology:* Andrew Nguyen
*Writing – original draft:* Andrew Nguyen, Akshay Reddy, Ramy Sharaf, Lauren Ladehoff, Michael Joseph Diaz
*Writing – review & editing:* Andrew Nguyen, Akshay Reddy, Ramy Sharaf, Lauren Ladehoff, Michael Joseph Diaz, Brandon Lucke-Wold

## Ethics approval and consent to participate

Not applicable.

## Consent for publication

Not applicable.

## Availability of data

All data generated or analyzed during this study are included in this published article.

## References

1. Abdelmalik PA, Draghic N, Ling GS, 2019, Management of moderate and severe traumatic brain injury. *Transfusion,* 59(S2): 1529–1538.

   https://doi.org/10.1111/trf.15171

2. Ahmad S, Afzal A, Rehman L, *et al.*, 2018, Impact of depressed skull fracture surgery on outcome of head injury patients. *Pak J Med Sci,* 34: 130–134.

   https://doi.org/10.12669/pjms.341.13184

3. Ali L, Badar A, 2021, Management of depressed skull fracture. *JSMC,* 11: 30–33.

   https://doi.org/10.52206/jsmc.2021.11.1.30-33

4. Prakash A, Harsh V, Gupta U, *et al.*, 2018, Depressed fractures of skull: An institutional series of 453 patients and brief review of literature. *Asian J Neurosurg,* 13: 222–226.

   https://doi.org/10.4103/ajns.AJNS_168_16

5. Kumar S, Nahar S, Sahana D, *et al.*, 2022, A prospective comparative evaluation of surgery and conservative treatment for compound depressed skull fractures. *World Neurosurg,* 164: e1281–e1289.

   https://doi.org/10.1016/j.wneu.2022.06.019

6. Márquez-García JC, Granados-Sáncheza AM, Moreno-Arango I, 2022, Isolated depressed fracture of the inner table of the skull. *Interdiscip Neurosurg*, 30: 101604.

   https://doi.org/10.1016/j.inat.2022.101604

7. Marbacher S, Andres RH, Fathi AR, *et al.*, 2008, Primary reconstruction of open depressed skull fractures with

titanium mesh. *J Craniofac Surg*, 19: 490–495.

https://doi.org/10.1097/SCS.0b013e3181534ae8

8. Eom KS, 2020, Single-stage reconstruction with titanium mesh for compound comminuted depressed skull fracture. *J Korean Neurosurg Soc,* 63: 631–639.

   https://doi.org/10.3340/jkns.2019.0181

9. Hitoshi Y, Yamashiro S, Yoshida A, *et al.*, 2020, Cranial reconstruction with titanium mesh for open depressed skull fracture in children: Reports of two cases with long-term observation. *Kurume Med J*, 66: 77–80.

   https://doi.org/10.2739/kurumemedj.MS661011

10. Honeybul S, Morrison DA, Ho KM, *et al.*, 2017, A randomized controlled trial comparing autologous cranioplasty with custom-made titanium cranioplasty. *J Neurosurg,* 126: 81–90.

    https://doi.org/10.3171/2015.12.JNS152004

11. Dunisch P, Walter J, Sakr Y, *et al.*, 2013, Risk factors of aseptic bone resorption: A study after autologous bone flap reinsertion due to decompressive craniotomy. *J Neurosurg,* 118: 1141–1147.

    https://doi.org/10.3171/2013.1.JNS12860

12. Khan A, Shrivastava N, Pal SS, 2018, Primary reconstruction of depressed skull fracture. *Int Surg J*, 5: 1802–1806.

    https://doi.org/10.18203/2349-2902.isj20181586

13. Darwish M, Nanous WZ, 2021, Cranioplasty using titanium mesh versus acrylic bone cement: Short-term outcomes and complications. *Benha Med J (BMFJ),* 38: 146–154.

    https://doi.org/10.21608/BMFJ.2021.144804

14. McGowan J, Sampson M, Salzwedel DM, *et al.*, 2016, PRESS peer review of electronic search strategies: 2015 guideline statement. *J Clin Epidemiol,* 75: 40–46.

    https://doi.org/10.1016/j.jclinepi.2016.01.021

15. Wells GA, Sheda B, O'Connell D, *et al.*, 2021, The Newcastle-Ottawa Scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses. Available from: https://www.ohri.ca/programs/clinical_epidemiology/oxford.asp.

16. AbdelFatah MA, 2016, Management of bone fragments in nonmissile compound depressed skull fractures. *Acta Neurochir (Wien)*, 158: 2341–2345.

    https://doi.org/10.1007/s00701-016-2976-0

17. Anehosur V, Sahana MS, Kumar N, 2022, Grossly depressed frontal bone fracture in a paediatric patient: A case report. *J Maxillofac Oral Surg*, 21: 442–446.

    https://doi.org/10.1007/s12663-020-01456-2

18. Ballestero MF, De Oliveira RS, 2019, Closed depressed skull fracture in childhood reduced with suction cup vacuum method: Case report and a systematic literature review. *Cureus*, 11: e5205.

    https://doi.org/10.7759/cureus.5205

19. Bot GM, Ismail NJ, Usman B, *et al.*, 2013, Using the head as a mould for cranioplasty with methylmethacrylate. *J Neurosci Rural Pract*, 4: 471–474.

    https://doi.org/10.4103/0976-3147.120207

20. Ebel H, Schillinger G, Walter C, *et al.*, 2000, Titanium clamps for refixation of bone fragments in the repair of depressed skull fractures: Technical note. *Minim Invasive Neurosurg*, 43: 212–214.

    https://doi.org/10.1055/s-2000-11380

21. Faried CK, Halim D, Arifin M, 2019, A rare care of depressed skull fractures at the anterior cranial fossa associated with communicating hydrocephalus resulting a progressive vision loss. *Interdiscip Neurosurg,* 17: 119–123.

22. Forbes JA, Reig AS, Tomycz LD, *et al.*, 2010, Intracranial hypertension caused by a depressed skull fracture resulting in superior sagittal sinus thrombosis in a pediatric patient: Treatment with ventriculoperitoneal shunt insertion. *J Neurosurg Pediatr*, 6: 23–28.

    https://doi.org/10.3171/2010.3.PEDS09441

23. Haider G, Omofoye OA, Holsapple JW, 2020, Intracranial hypertension following gunshot wound to the torcula: Case report and literature review. *World Neurosurg*, 137: 94–97.

    https://doi.org/10.1016/j.wneu.2020.01.170

24. Hewitt DK, Scheidt TD, Calhoun KH, 2009, Depressed anterior table fracture: A minimally invasive method of reduction. *Ear Nose Throat J*, 88: 734–735.

25. McCall TD, Fults DW, Schmidt RH, 2008, Use of resorbable collagen dural substitutes in the presence of cranial and spinal infections-report of 3 cases. *Surg Neurol*, 70: 92–96; discussion 96–97.

    https://doi.org/10.1016/j.surneu.2007.04.007

26. Muderris SB, Ergun Sevil, Kiris M, 2013, Management of frontal sinus fracture: Reconstruction of the sinus with iliac bone graft. *J Craniofac Surg*, 24: e194–e195.

    https://doi.org/10.1097/SCS.0b013e318280223a

27. Sheng HS, Shen F, Lin J, *et al.*, 2017, Traumatic open depressed cranial fracture causing occlusion of posterior superior sagittal sinus: Case report. *Medicine (Baltimore)*, 96: e7055.

    https://doi.org/10.1097/MD.0000000000007055

28. Wan Y, Li X, Qian C, *et al.*, 2013, The comparison between dissociate bone flap cranioplasty and traditional cranioplasty in the treatment of depressed skull fractures. *J Craniofac Surg,* 24: 589–591.

    https://doi.org/10.1097/SCS.0b013e3182801bae

29. Wylen EL, Willis BK, Nanda A, 1999, Infection rate with

replacement of bone fragment in compound depressed skull fractures. *Surg Neurol*, 51: 452–457.

https://doi.org/10.1016/s0090-3019(98)00040-8

30. Yang M, Wu Z, Yu H, *et al.*, 2021, Reconstruction for diverse fronto-orbital defects with computer-assisted designed and computer-assisted manufactured PEEK implants in one-stage operation: Case reports. *Medicine (Baltimore*), 100: e27452.

    https://doi.org/10.1097/MD.0000000000027452

31. Shah AM, Jung H, Skirboll S, 2014, Materials used in cranioplasty: A history and analysis. *Neurosurg Focus*, 36: E19.

    https://doi.org/10.3171/2014.2.FOCUS13561

32. Yu Q, Chen L, Qiu Z, *et al.*, 2017, Skull repair materials applied in cranioplasty: History and progress *Transl Neurosci Clin*, 3: 48–57.

    https://doi.org/10.18679/CN11-6030_R.2017.007

33. Wolff A, Santiago GF, Belzberg M, *et al.*, 2018, Adult cranioplasty reconstruction with customized cranial implants: Preferred technique, timing, and biomaterials. *J Craniofac Surg*, 29: 887–894.

    https://doi.org/10.1097/SCS.0000000000004385

34. Champlin R. Selection of autologous or allogeneic transplantation. In: Kufe DW, Pollock RE, Weichselbaum RR, *et al.*, editors. Holland-Frei Cancer Medicine. 6th ed. Hamilton, ON: BC Decker; 2003. Available from: https://www.ncbi.nlm.nih.gov/books/NBK12844

35. van de Vijfeijken S, Munker T, Spijker R, *et al.*, 2018, Autologous bone is inferior to alloplastic cranioplasties: Safety of autograft and allograft materials for cranioplasties, a systematic review. *World Neurosurg,* 117: 443–452.e448.

    https://doi.org/10.1016/j.wneu.2018.05.193

36. Beauchamp KM, Kashuk J, Moore EE, *et al.*, 2010, Cranioplasty after postinjury decompressive craniectomy: Is timing of the essence? *J Trauma*, 69: 270–274.

    https://doi.org/10.1097/TA.0b013e3181e491c2

37. Neville IS, Amorim RL, Paiva WS, *et al.*, 2014, Early surgery does not seem to be a pivotal criterion to improve prognosis in patients with frontal depressed skull fractures. *Biomed Res Int*, 2014: 879286.

    https://doi.org/10.1155/2014/879286

38. De Cola MC, Corallo F, Pria D, *et al.*, 2018, Timing for cranioplasty to improve neurological outcome: A systematic review. *Brain Behav*, 8: e01106.

    https://doi.org/10.1002/brb3.1106

39. Klinger DR, Madden C, Beshay J, *et al.*, 2014, Autologous and acrylic cranioplasty: A review of 10 years and 258 cases. *World Neurosurg*, 82: e525–e530.

    https://doi.org/10.1016/j.wneu.2013.08.005

40. Zanotti B, Zingaretti N, Verlicchi A, *et al.*, 2016, Cranioplasty: Review of materials. *J Craniofac Surg*, 27: 2061–2072.

    https://doi.org/10.1097/SCS.0000000000003025

41. Satardey RS, Balasubramaniam S, Pandya JS, *et al.*, 2018, Analysis of factors influencing outcome of depressed fracture of skull. *Asian J Neurosurg*, 13: 341–347.

    https://doi.org/10.4103/ajns.AJNS_117_16