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Cranioplasty optimal timing in cases of decompressive craniectomy after severe head injury: a systematic literature review

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ABSTRACT

Object: Cranioplasty has been considered for several decades as a protective and cosmetic procedure. It has recently been postulated that cranioplasty may have a therapeutic role, and improve the patient's functional outcome after decompressive craniectomy (DC). The appropriate timing for cranioplasty remains unknown. In our current study, we review the literature for evaluating the relationship of cranioplasty timing and its complication rate and outcome.
Methods: The PubMed database was searched to identify any relevant articles. The following terms were used as keywords: "cranioplasty", "timing cranioplasty", "early cranioplasty", "late cranioplasty", "delayed cranioplasty", "early versus late cranioplasty". Clinical studies with more than 10 participants, and closed head injury as the underlying cause for DC were included in our study. The study design, the timing performing cranioplasty, the complication rate, and the patients' outcome were evaluated.
Results: Ten clinical series met our inclusion criteria. The observed complication rate associated to cranioplasty after DC is not negligible. Several reports have demonstrated that late cranioplasty may minimize procedure-associated complications. Early cranioplasty has been associated with complications, but improves CSF dynamics, and regional cerebral perfusion and metabolism, minimizes the complications from a sunken scalp, reduces the overall length of hospitalization, and thus the overall cost of care.
Conclusions: Cranioplasty is a relatively simple procedure that is nevertheless burdened by considerable morbidity. However, an early cranioplasty procedure may improve the outcome in selected cases. Prospective, large-scale studies are necessary to outline the actual complication rate, the neurological outcome, and define the optimal timing for a cranioplasty.

Introduction

Decompressive craniectomy (DC) may be a potentially life-saving procedure in managing patients with medically intractable intracranial hypertension secondary to severe closed head injuries or massive strokes [1–4]. Though DC is increasingly performed, its efficacy is still highly controversial [5,6]. Contrariwise, there is a general consensus regarding the necessity of cranial reconstruction after a DC.

Cranioplasty is required for protecting the brain exposed through the skull defect brain, and also for cosmetic purposes. Moreover, there is an increasing body of evidence in the recent literature, which demonstrates that cranioplasty may also accelerate and improve neurological recovery. Although the exact pathophysiological mechanisms for this improvement remain essentially unknown, there are a rapidly growing number of neurosurgeons adopting this concept [5,7–27]. Despite the fact that cranioplasty is a time-honored, straight-forwarded procedure, it is still associated with a relatively high complication rate, ranging between series from 12% to 50% [28–36].

Several parameters, such as the initial underlying pathology, the biotechnological characteristics of the bone graft, the technical aspects of the cranioplasty technique, etc., have been associated with the occurrence of complications in cranioplasty cases [5,7,8,10,12–15,17–23,25–27]. The optimal timing for performing a cranioplasty seems to play an important role not only in avoiding procedure-associated complications, but also in the neurological outcome of these patients. According to the traditional neurosurgical dictum, a short interval between DC and cranioplasty, was associated with poor outcome [37–39]. In the last decade however, there have been a rapidly increasing number of clinical series suggesting that cranioplasty can safely be performed sooner than previously suggested [17,18,21,23,25,34,40,41]. When considering ideal timing for cranioplasty, predominant issues include residual brain edema, brain retraction into the cranial vault, risk of infection, and

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development of delayed post-traumatic hydrocephalus. Recent studies suggest, however, that bone reconstruction should not be intentionally delayed [28,32,34,40,41].

In our current study, we attempted to systematically review the pertinent literature for identifying the optimal timing for performing cranioplasty after DC in patients with severe closed head injury. We also attempted to address why cranioplasty, although a selective procedure, still carries a relatively high complication rate, and what is the current evidence supporting the recent trend that early cranioplasty may improve the patient's neurological outcome.

Methods

An extensive search through the PubMed medical database was performed using the terms "cranioplasty", "timing cranioplasty", "early cranioplasty", "late cranioplasty", "delayed cranioplasty", and "early versus late cranioplasty", and all their possible combinations. Search was limited to articles in English, and only in series of human subjects. Additionally, the references of the retrieved articles were meticulously reviewed for any additional articles of interest.

Our inclusion criteria included adult clinical series, with a minimum number of 10 participants, and series of cranioplasty performed secondary to DC solely for severe head injuries. Special attention was paid in avoiding repetition of clinical data from overlapping series, published in different journals or at different time. However, such redundancies cannot be ruled out.

The retrieved articles were thoroughly analyzed for the study characteristics (retrospective vs. prospective), the exact time of cranioplasty after DC, the cranioplasty associated complications, and the neurological and overall outcome.

Results

Ten clinical studies met our inclusion criteria. The study characteristics, population, timing of cranioplasty, associated complications, and outcome rates are summarized in Table 1. There were only three prospective studies, while the total number of the reported cranioplasties was 1130.

The overall complication rate ranged from 7% to 39% in the reported series (Table 1). Schuss et al., reported that their overall complication rate was 16.4% in their study [42]. They concluded that patients who underwent early cranioplasty suffered significantly more often from complications compared to those undergoing late procedures (25.9% versus 14.2%). Likewise, Thavarajah et al., reported only 11% infection rate [43]. They claimed that their low infection rate was achieved by performing all their cranioplasties at least six months after DC.

Contrariwise, three recent series reported their results regarding early cranioplasty associated complications [30,34,44]. They found that, none of their patients presented with major complications, thus concluding that early cranioplasty predisposes to no increased risk of infection or any other complication.

Several of the analyzed series revealed no association of the observed complication rates to the timing of cranioplasty. Beauchamp et al., were unable to recognize any specific pattern regarding the incidence of complications and cranioplasty timing [28]. Similarly, Bender et al., and Song et al., in their studies found that the observed complication rates were comparable between early and late cranioplasty groups [45,46]. Likewise, De Bonis et al., found no association between complication incidence and timing of cranioplasty [31]. Interestingly, their data showed that the only factor independently associated with complication incidence was the anatomical site of the cranioplasty (bifrontal cranioplasty had a 2-fold increased risk of complication, and a 2.5-fold increased risk of infection) [31].

In regard to the association of timing of cranioplasty to the patients' functional outcome, only 3/10 studied series concluded that early cranioplasty would improve the prognosis [34,44,45]. Bender et al., demonstrated that patients with early cranioplasty had better outcome than patients with late cranioplasty [45]. They also showed that the patient's age, pre-operative Barthel Index, and Coma Remission Scale scores were additional independent outcome factors. Furthermore, Chibbaro et al., found that the vast majority of patients undergoing early cranioplasty had a favorable outcome (67% GOS score 4 or 5) [44]. Analysis of their data in regard to the previously performed DC outcome demonstrated that a younger age (<50 years), and earlier operation (within 9 h from trauma) had a significant effect on positive outcome. Liang et al., showed improvement of neurological function in the majority of their patients after an early cranioplasty [34]. Their long-term prognosis (18 months postoperatively) revealed 74% independency, 17% severe disability, 9% vegetative state, and no deaths. Moreover, Song et al., found better cerebral blood flow measurements in the early cranioplasty group [46]. On the other hand, two clinical series found no association between cranioplasty timing and patients' global outcome, [46,47].

Discussion

It has been documented that cranioplasties were performed by the Incas many centuries ago [48,49]. Thus, cranioplasty may well be considered as one of the earliest neurosurgical procedures, along with cranial trephinations. However, it was several centuries later, when the first report of cranioplasty by Job Janszoon van Meekeren in 1668, appeared [49]. In this report, which may be considered as the first description of cranioplasty, an unknown surgeon performed a skull restoration, by using a bone allograft taken from a dog.

The main reason for performing a cranioplasty nowadays is the previous performance of a DC. Although, the indications and the clinical value of DC remain ill defined and under investigation, there are a large number of DC cases performed around the world [5,6]. Initially, it was considered that cranioplasty played only cosmetic and protective roles. In the recent literature there are studies acknowledging that this procedure may also provide neurological function improvement [34,44,45]. It is well known that DC has been associated with disturbances of CSF circulation [6,27]. Furthermore, DC causes significant changes in the dynamics of local cerebral blood flow, as well as, cerebral metabolic rate of oxygen and glucose changes, which effect normal brain function and metabolism [13,27,50]. Thus, the performance of cranioplasty may theoretically restore all these altered conditions, and improve the patient's overall neurological condition [40,51,52]. It has also been demonstrated that cranioplasty can increase the cerebral blood flow by increasing blood flow velocities of the ipsilateral middle cerebral and internal carotid arteries, as well as, improve the cardiovascular functions [13,27,53]. Moreover, there is a syndrome characterized by headaches, dizziness, irritability, epilepsy, discomfort, and psychiatric symptoms observed in patients with cranial defects, known as "syndrome of the trephine" [12]. There is an increasing body of evidence in the literature showing that cranioplasty helps in prevention or recovery of the trephine syndrome [7,12,52].

The optimal timing for performing a cranioplasty after DC remains an unsolved dilemma. For several decades, the performance of an early (in less than three months after DC) cranioplasty was associated with a poor outcome [37–39]. Rish et al., reported that cranioplasties taking place 1–6 months after DC, had the highest complication rate, while procedures performed 12–18 months after DC, showed significantly lower complication rate [54]. The main reason for delaying the performance of a cranioplasty, was to minimize the possibility of intervening in a still contaminated wound. This is more

Table 1
Data of previously published clinical series regarding complication, and outcome rates in association with timing of posttraumatic cranioplasty.

Authors & Year	Study design	No of pts or No of CPs	Timing	Complication rate (%)	Outcome
Beauchamp et al., 2010	Prospective	69 pts	Median time: 87 d	39% (19% infection rate, 20% hydrocephalus)	very early CP in <2 w lowers the overall cost of care
Bender et al., 2013	Retrospective	147 pts	Early < 86 d Late > 85 d	NA, equal in both groups	better in pts with early CP
Chibbaro et al., 2010	Prospective	133 pts	Early (12 w)	NA	67% GOS 5–4 19% GOS 3–2 14% GOS 1
Chun et al., 2011	Retrospective	30 pts	Early (1 m) Late > 3 m	7% subdural fluid collection, no infections	NA
De Bonis et al., 2012	Retrospective	218 CPs	Early < 3 m Late > 3 m	19.7%	NA
Huang, 2013	Retrospective	105 pts	13–245 d	NA	NA. Timing is not related to the neurological outcome
Liang et al., 2007	Retrospective	23 pts	Early (5–8 w)	26% hydrocephalus, no infections	Early outcome: improved neurologic function in 78.3% Long-term outcome: 74% GOS 5–4 17% GOS 3 9% GOS 2
Schuss et al., 2012	Prospective	280 CPs	Early < 2 m Late > 2 m	16.4%	NA. Lower complication rate in pts undergo late CP
Song et al., 2013	Retrospective	43 pts	Early < 12w Late > 12w	NA, equal in both groups	NA. No effect on global outcome by GOS
Thavarajah et al., 2012	Retrospective	82 pts	Early < 6 m Late >6 m	11% infection rate	NA. Delayed CP limits the risk of infection

No, number; pts, patients; CPs, cranioplasties; d, days; w, weeks; NA, not applicable; m, months.

common in cases of heavily contaminated open skull fractures, burst skull fractures, or in cases of penetrating head injuries [37]. Similarly, the results of two other clinical series, reported by Schuss et al., and Travarajah et al., agreed that patients who underwent late cranioplasty had a lower complication rate [42,43]. They claimed that the lower complication rate in their series could be explained by the smaller possibility of surgical wound contamination due to the delayed cranioplasty. However, their complication rates are consistent with the average reported complication rate in the literature [35,55–58]. It has to be emphasized, that many of the cranioplasty-reported complications could be attributed to the previously performed DC and the initial head injury, and not to the cranioplasty per se. De Bonis et al., found that early cranioplasty was significantly associated with bone graft dislocation in their series [31]. They found that the anatomic location was more important factor than the timing of cranioplasty in the development of any procedure associated infections [31].

Contrariwise, there is recently a rapidly growing body of clinical series reporting very promising results from performing early (in less than three months) cranioplasty [34,40]. The main argument for early restoration of a skull defect is the avoidance of post-decompression hydrocephalus, and/or the development of the trephination syndrome [17,18,21,23,25,41]. It has been postulated that prolonged persistence of large skull defects exposes the patient's brain to increased atmospheric and mechanical external pressures, which consequently causes regional hemodynamic and metabolic impairments [11]. Indeed, Magnaes et al., have demonstrated that the altered zero CSF pressure level, and the hydrostatic indifferent point in patients with large skull defects, became normal after cranioplasty [59,60]. Moreover, the reported neurological improvement after early cranioplasty could be attributed to normalization of the impaired from the DC cerebral hemodynamics [61]. Likewise, Chang et al., reported their results from a comparative study examining the cranioplasty associated complication rates between early (less than 3 months), and late (more than 6 months) cranioplasty [29]. They found that the complication rate was significantly higher among patients undergoing late cranioplasty. Chibbaro et al., found that early cranioplasty was associated with minor only complications, which were conservatively managed with no further sequelae [44]. Chun et al., concluded that early cranioplasty was a safe procedure in their hands, associated with no major complications [30]. They stated that early cranioplasty allows safer surgical dissection of the DC site tissues, resulting into reduced blood loss, and minimalization of any operative adverse events. Additionally, Beauchamp et al., suggested early cranioplasty, since early intervention lowers the overall cost of care [28]. Furthermore, Liang et al., recommended early cranioplasty, based on the postulation that postcraniectomy-related complications, such as hydrocephalus and subdural fluid collection development, might cause neurological impairment [34].

There are also several reports in the literature indicating no difference in the observed complication rates between early versus late cranioplasty. Bender et al., found no difference in the overall complication rates between early and late cranioplasty [45]. Similarly, Song et al., observed no difference in complication rates between early and late cranioplasty groups [52]. Yadla et al., in their meta-analysis found that early cranioplasty showed no lower infection or overall complication rates than late cranioplasty [62].

The optimal timing for performing a cranioplasty may affect not only the observed complication rate but also the overall functional outcome. Several recent clinical reports have established a relationship between cranioplasty timing and functional outcome. In our current literature review, there are three series showing that early cranioplasty provides a better functional outcome. Bender et al., found that patients with shorter delays to cranioplasty (<86 days) had a better functional outcome than patients with longer delays [45]. Chibbaro et al., concluded in their cohort that early cranioplasty could improve the neurological outcome [44]. Similarly, Liang et al., suggested that early cranioplasty could be safe, and may improve the patients' neurological function, and their overall prognosis [34]. They found that most of their patients regained consciousness, and improved their neurological performance after cranioplasty. On the other hand, two of the reviewed series found no association between cranioplasty timing and functional outcome [46,47]. Huang et al., showed that there is no statistically significant correlation between cranioplasty timing and outcome [47]. Song et al., demonstrated, that although early cranioplasty improves regional cerebral blood flow, no association could be established between early cranioplasty and functional outcome [46].

Conclusions

In general, cranioplasty is a relatively simple procedure, which however is burdened by considerable morbidity. There is a highly variable definition of cranioplasty-associated complications in the literature, which could lead to an inaccurate estimation of the actual complication rate. In addition, the vast majority of the existent studies are retrospective, while their size and therefore their statistical strength are limited.

Moreover, the definition of early cranioplasty remains highly variable in the literature. There is a lack of well-designed clinical studies reporting on optimal timing of cranioplasty. It has been demonstrated that early cranioplasty, in patients undergoing DC after suffering severe brain trauma, has been associated with several complications. However, it has been demonstrated that early cranioplasty normalizes altered CSF dynamics, increases regional cerebral blood flow, optimizes cerebral metabolic rate of oxygen and glucose, and minimizes the chance of developing trephination syndrome. It has recently been demonstrated that early cranioplasty may also reduce the overall length of stay, and thus the overall cost of care. For all these reasons, an early procedure may contribute to a better neurological outcome, and improve the overall prognosis in selected cases.

However, the existent data in the literature are not solid enough for drawing any safe conclusions regarding the ideal timing for performing a cranioplasty. Prospective, large-scale, randomized trials, using standardized methods for data collection and accurately defined timing, complication, and outcome evaluation after cranioplasty, are necessary for estimating the actual incidence of cranioplasty-associated complications, and also for resolving the dilemma of optimal timing for cranioplasty.

Disclosure

The authors report no conflict of interest concerning the materials and methods used in this study or the findings specified in this paper.

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