Journal of Clinical Neuroscience 33 (2016) 39–51

Contents lists available at ScienceDirect

Journal of Clinical Neuroscience

journal homepage: www.elsevier.com/locate/jocn

Review

Complications following cranioplasty and relationship to timing: A systematic review and meta-analysis

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ARTICLE INFO

Article history:
Received 1 March 2016
Accepted 2 April 2016

Keywords:
Craniectomy
Cranioplasty
Complications
Early
Timing

ABSTRACT

The optimal timing of cranioplasty after decompressive craniectomy has not been well established. The purpose of this study was to evaluate the relationship between timing of cranioplasty and related complications. A systematic search of MEDLINE, Scopus, and the Cochrane databases was performed using PRISMA guidelines for English-language articles published between 1990 and 2015. Case series, case–control and cohort studies, and clinical trials reporting timing and complication data for cranioplasty after decompressive craniectomy in adults were included. Extracted data included overall complications, infections, reoperations, intracranial hemorrhage, extra-axial fluid collections, hydrocephalus, seizures, and bone resorption for cranioplasty performed within (early) and beyond (late) 90 days. Twenty-five of 321 articles met inclusion criteria for a total of 3126 patients (1421 early vs. 1705 late). All were retrospective observational studies. Early cranioplasty had significantly higher odds of hydrocephalus than late cranioplasty (Odds Ratio [OR] 2.38, 95% Confidence Interval [CI] 1.25–4.52, $p = 0.008$). There was no difference in odds of overall complications, infections, reoperations, intracranial hemorrhage, extra-axial fluid collections, seizures, or bone resorption. Subgroup analysis of trauma patients revealed a decreased odds of extra-axial fluid collection (OR 0.30, $p = 0.02$) and an increased odds of hydrocephalus (OR 4.99, $p = 0.05$). Early cranioplasty within 90 days after decompressive craniectomy is associated with an increased odds of hydrocephalus than with later cranioplasty, but no difference in odds of developing other complications. Earlier cranioplasty in the trauma population is associated with fewer extra-axial fluid collections.

1. Introduction

Cranioplasty after decompressive craniectomy is a common neurosurgical procedure that carries known perioperative risks and complications [1]. The initial decompressive procedure is often performed to relieve elevated intracranial pressure in the setting of traumatic brain injury [2], ischemic [3,4] or hemorrhagic stroke [5,6], or aneurysmal subarachnoid hemorrhage [7–9]. Subsequent cranioplasty to repair the skull defect is typically delayed several months to years after craniectomy to allow the patient to convalesce from the acute phase of illness and ensure resolution of elevated intracranial pressure. The goals of cranioplasty are to restore cerebral protection and craniofacial cosmesis [10]. Cranioplasty may also address post-craniectomy complications such early pseudomeningocele collection [1,11] and delayed paradoxical herniation (sinking skin flap syndrome) [12], and has been shown to improve patients' neurological status [13–17]. Furthermore, a recent systematic review showed no significant difference in infectious and overall complications between early and late cranioplasty [18]. For these reasons, earlier cranioplasty has been advocated in some patients, though optimal timing has yet to be determined.

The purpose of this study was to evaluate the relationship between cranioplasty timing (early versus late) after decompressive craniectomy, and the rate and type of related complications via a systematic review and meta-analysis of the literature. By identifying complications related to timing of cranioplasty, it may be possible to improve neurologic outcome and minimize complication risk by varying the delay between craniectomy and cranioplasty for select patients.

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http://dx.doi.org/10.1016/j.jocn.2016.04.017
0967-5868/

2. Methods

2.1. Search strategy

A systematic review of the literature adherent to Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines was performed for published articles reporting on timing of cranioplasty after craniectomy [19]. PubMed/MEDLINE, Scopus, and the Cochrane Database of Systematic Reviews were searched using the keywords "cranioplasty, early" or "cranioplasty, timing" included in the title, abstract, or keyword list. The search was restricted to original clinical studies published between January 1990 and December 2015. Thorough bibliographic searches of qualifying articles and relevant medical journals were also performed to identify additional articles for inclusion.

2.2. Study selection

Articles reporting on the relationship between timing of cranioplasty (early versus late) after decompressive craniectomy, and type and rate of related complications in human adults were included in the analyses.

Case–control studies, cohort studies, or clinical trials that directly compared complication rates between early and late cranioplasty time-points were included. Case series that reported enough raw timing and outcome data to allow authors to make the necessary computations for at least 10 patients were also included. Case reports, technical notes, letters, and editorials were excluded. Meta-analyses and reviews were also excluded; however, referenced articles were thoroughly screened for possible inclusion [1,18,20–24]. Non-English articles were excluded, unless the article had been previously included in a related systematic review [25,26]. Studies that involved animals, included non-calvarial or maxillofacial procedures, or focused exclusively on the pediatric population were excluded [21]. Studies were excluded if a significant proportion of patients underwent non-decompressive craniectomy (for example, for resection of skull tumor). For articles that mentioned collection but no report of timing or complication data, attempts were made to contact authors for further details and potential inclusion.

The search results were independently screened by two authors (JGM and RSR); disagreements were resolved by consensus.

2.3. Data extraction

The following data were extracted from each article, if reported: number of patients, indication for initial craniectomy, anatomic location of procedure, time interval between craniectomy and cranioplasty, incidence and types of cranioplasty-associated complications. Complications were grouped into the following categories: total overall complications; infection requiring treatment (antibiotics, drainage, or reoperation); reoperations (e.g. for infection, resorption, or drainage of fluid collection); intracranial hemorrhage (intracerebral hemorrhage, subdural hematoma, epidural hematoma); extra-axial fluid collection (non-hemorrhagic collections, subdural effusions, cerebrospinal fluid leaks, or hygroma); hydrocephalus (treated with or without a ventriculoperitoneal shunt); new-onset seizures; and bone resorption (by clinical exam or imaging).

Seventeen authors were contacted for further information regarding missing data [15,25,27–41]. Five authors responded and provided data that had not been included in the original publication [15,28,29,34,36]. These data were included in pooled analyses.

Study quality of individual articles was determined according to the Oxford Center for Evidence-Based Medicine (OCEBM) guidelines [42]. Risk of bias was assessed by the Newcastle-Ottawa Scale, which is a three-category, 9-point scale assessing cohort selection, comparability, and outcome [43]. A higher score indicates higher quality.

2.4. Data analysis

Data were analyzed using Review Manager 5.3.5 (The Cochrane Collaboration). Complications were first grouped by specific type (e.g. overall complications, infection, seizure, etc.). If overall complications were not reported in a study, individual complications were summed. Complications were then grouped by "early" and "late" cranioplasty time-points. "Early" cranioplasty was defined as less than or equal to 90 days after craniectomy. The 90-day timepoint was chosen for several reasons: (1) in the authors' experience, cranioplasty procedures often occur around 90 days after initial craniectomy; (2) several studies utilized the median time to cranioplasty in their data as a cutoff for defining early/late time-points, which was around 90 days; (3) grouping around 90 days allowed for inclusion of more studies in the pooled analysis. Studies that provided raw timing data were dichotomized at this time-point for analysis. For studies that did not provide raw data or used a different time-point than 90 days, the study's reported definition was accepted, and the results were pooled in the overall analyses.

Odds ratios (OR) and 95% confidence intervals (CI) for each outcome were then calculated by "early" and "late" time-points. Odds ratios were pooled by using the Mantel–Haenszel method with fixed-effects model, except where the chi-squared test indicated significant heterogeneity among studies, in which case a random-effects model was used. The I^2 metric was reported to further quantify heterogeneity (0% = no heterogeneity, 100% = maximal heterogeneity) [44]. P values of less than 0.05 were considered statistically significant.

For each complication, a subgroup analysis comparing trauma and mixed populations was performed in addition to the overall analysis. The chi-squared test was used to evaluate significant differences between subgroups.

3. Results

Literature review results are depicted in the PRISMA flow diagram (Fig. 1). Three hundred twenty-one non-duplicate studies were screened. This included 309 articles from the database search, three articles identified from review of relevant journals [28,37,45], and nine articles identified from bibliographic review [25,26,36,46–51]. Two of these were non-English articles, but were included because they appeared in a previous meta-analysis on cranioplasty [18,25,26]. Thirty three articles were excluded after full-text review. Reasons for exclusion were as follows: review article [18,20–24], lack of craniectomy to cranioplasty timing data [12,41,52–58], all procedures within 90 days [59,60], significant proportion of non-decompressive craniectomies [31], insufficient data (i.e. authors unreachable or unable to provide) [11,27,35,38,39,61–66], or cranioplasty complications not reported [67–69].

The final twenty-five studies that met inclusion criteria for analysis represented 3126 cranioplasty procedures (1421 early, 1705 late) (Table 1). All were retrospective cohort studies with non-matched cohorts, with an OCEBM Level 4 evidence [14,27,33,70]. Indications for initial craniectomy included arteriovenous malformations, ischemic or hemorrhagic stroke, infection, ruptured aneurysm, trauma, or tumors. Cranial procedure locations, when specified, included unilateral, bilateral, and bifrontal. Six of twenty-five studies dichotomized early and late cranioplasty