A multicenter cohort study of early complications after cranioplasty: results of the German Cranial Reconstruction Registry

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OBJECTIVE Cranioplasty (CP) is a crucial procedure after decompressive craniectomy and has a significant impact on neurological improvement. Although CP is considered a standard neurosurgical procedure, inconsistent data on surgery-related complications after CP are available. To address this topic, the authors analyzed 502 patients in a prospective multicenter database (German Cranial Reconstruction Registry) with regard to early surgery-related complications.

METHODS Early complications within 30 days, medical history, mortality rates, and neurological outcome at discharge according to the modified Rankin Scale (mRS) were evaluated. The primary endpoint was death or surgical revision within the first 30 days after CP. Independent factors for the occurrence of complications with or without surgical revision were identified using a logistic regression model.

RESULTS Traumatic brain injury (TBI) and ischemic stroke were the most common underlying diagnoses that required CP. In 230 patients (45.8%), an autologous bone flap was utilized for CP; the most common engineered materials were titanium (80 patients [15.9%]), polyetheretherketone (57 [11.4%]), and polymethylmethacrylate (57 [11.4%]). Surgical revision was necessary in 45 patients (9.0%), and the overall mortality rate was 0.8% (4 patients). The cause of death was related to ischemia in 2 patients, diffuse intraparenchymal hemorrhage in 1 patient, and cardiac complications in 1 patient. The most frequent causes of surgical revision were epidural hematoma (40.0% of all revisions), new hydrocephalus (22.0%), and subdural hematoma (13.3%). Preoperatively increased mRS score (OR 1.46, 95% CI 1.08–1.97, p = 0.014) and American Society of Anesthesiologists Physical Status Classification System score (OR 1.14, 95% CI 1.49–1.86, p = 0.003) were independent predictors of surgical revision. Ischemic stroke, as the underlying diagnosis, was associated with a minor rate of revisions compared with TBI (OR 0.18, 95% CI 0.06–0.57, p = 0.004).
CONCLUSIONS The authors have presented class II evidence–based data on surgery-related complications after CP and have identified specific preexisting risk factors. These results may provide additional guidance for optimized treatment of these patients.

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KEYWORDS cranioplasty; functional outcome; ischemic stroke; surgical complications; traumatic brain injury; surgical technique; vascular disorders

Cranioplasty (CP) is a neurosurgical procedure of increasing importance because it is performed as a subsequent operation after decompressive craniectomy (DC) for traumatic brain injury (TBI) or space-occupying ischemic stroke, which have become more frequent in the last decade.1,2 CP is an important step that facilitates neurological rehabilitation and improved outcome.3,4 Although CP is considered a technically simple neurosurgical procedure, it is reportedly associated with high mortality and complication rates.5–8 Previous studies have suggested that reoperation,9 sinking skin flap syndrome,10,11 hypertension, diabetes,6 prolonged duration of CP,12 and patient age13 are key factors associated with surgical complications. Other studies of perioperative morbidity pinpointed the timing of CP,13–15 and timing of shunt implantation16,17 as critical factors.

Mainly retrospective single-center analyses exist despite the importance of this topic, and these naturally exhibit considerable variance. Recently, data from a similar registry in the United Kingdom and Ireland provided a descriptive overview of complication rates in a cohort of 226 patients who underwent new CP.17 Here, we report a well-standardized analysis of the German Cranial Reconstruction Registry (GCRR) that investigated rates of surgical complications, morbidity, and mortality within the first 30 days after CP.18 Our data reveal valuable insights into surgical implementation of CP at a national level and hence provide essential suggestions for the improvement of therapeutic strategies.

Methods

The GCRR is a prospectively conducted, multicenter open registry. The primary endpoints of this study were death and surgical revision during the first month.18 In addition to these two endpoints, this study also reported the occurrence of any other type of complication, even if these did not lead to surgical revision. For this purpose, a distinction was made between any type of complication including surgical revision (any complication endpoint) and exclusively surgical revision (surgical revision endpoint) in the Results section. We included patients with all clinical conditions that required temporary removal of a bone flap, e.g., TBIs, space-occupying cerebral infarction, and subarachnoid hemorrhage, as well as those with destructive or osteolytic bone tumors (Supplemental Table 1).

Study Design

The GCRR is a procedure-specific registry that was initiated by a consortium of members of the Section for Neurotrauma and Intensive Care in Neurosurgery of the German Society for Neurosurgery. Patient data from 16 participating centers in Germany and Austria were evaluated in this study. A standardized questionnaire about CP was used to record patient-specific data, including risk factors, surgical details, materials used for CP, and intraoperative and postoperative complications, as well as clinical follow-up at discharge. The Case Report Forms for cranioplasty and postoperative monitoring were specifically designed to evaluate and address the questions of this study; these forms were used to record all complications through the day of discharge and readmissions within 30 days after surgery (Supplemental Data). Neurological status and medical morbidities were assessed using the modified Rankin Scale (mRS) score19 and the American Society of Anesthesiologists Physical Status Classification System (ASA) score.20

The study data were reported by all participating centers to their local ethics committees and were obtained in accordance with the ethical standards of the Declaration of Helsinki. Written informed consent was obtained from the patient or the patient’s authorized representative prior to inclusion. Pseudonymized data were collected centrally at the Department of Medical Biometry Heidelberg and transmitted into an electronic database. This trial is indexed in the German Clinical Trials Register (DRKS-ID no. DRKS00007931). The Universal Trial Number is U1111–1168–7425.

Statistical Analysis

Statistical correlation of clinical data was performed using univariate analysis with the chi-square test, Mann-Whitney U-test, or 2-sample t-test, depending on the distributions of the measurements, and using IBM SPSS Statistics version 25 (IBM Corp.). The Kolmogorov-Smirnov test was used to check for differences in the time interval between procedures. Cases of deviating statistical test results are indicated at the respective passages. Odds ratios and 95% confidence intervals were calculated with logistic regression models. We used receiver operating characteristic (ROC) analysis to assess the capability of this model to classify the respective complication category. Correlations between two variables were calculated using Spearman’s rank correlation coefficients. Extent of the osseous defect (A) for CP was calculated using the following formula: A (in cm²) = (horizontal diameter [in mm]/2) × (vertical diameter [in mm]/2) × π/100.

Classification of Evidence and Data Availability

This study provides class II evidence, according to corresponding guidelines, for early complications related to CP procedures.21 We support efforts to promote data sharing for the advancement of science. Trial design, eligibility criteria, anonymized patient characteristics, and outcomes measures are available on request to the steering committee of GCRR.
Results

In total, 529 patients were enrolled in the GCRR for a CP procedure between September 2015 and December 2019. After quality check, 502 patients (94.9%) were eligible for further analysis, whereas 27 patients were excluded owing to the absence of surgical and/or follow-up data. For 394 (78.5%) patients, the CP was the first one performed at time of inclusion in GCRR, whereas at least 1 CP was documented to have preceded enrollment in the register for the remaining group of 108 patients. A flowchart (Supplemental Fig. 1) demonstrates the distribution of patients in terms of number of CPs and their inclusion in GCRR. Additionally, we have provided the clinical characteristics of each patient population (first, second, or third CP) in Supplemental Table 3. Here, it was apparent that the cohorts differed mainly with regard to the use of autologous bone for CP, which was almost exclusively used for the first attempt.

TBI and ischemic stroke were the most common diagnoses (303 patients [60.4%]) for CP procedures (Table 1). The majority of patients with a miscellaneous diagnosis (n = 49) had autologous bone flap infection after previous elective surgery and underwent CP to cover the bone defect. Twenty patients within this group were diagnosed with an osseous tumor that was resected during the same operation in which CP was performed (single-stage procedure) (Supplemental Tables 2 and 3).

Mortality and Morbidity

The overall in-hospital mortality rate was 0.8% (4 patients). Any type of complication was reported for 130 patients (25.9%) during the in-patient stay. Surgical revision was necessary for 45 patients (9.0%) (Table 2). Immediate bone flap explantation (during the same hospital stay) was necessary for 13 patients (2.6%). We have indicated whether a variable refers to any type of complication or a surgically treated complication. Indications of medical risk factors, such as use of anticoagulant or immunosuppressive medications or diabetes, were not correlated with the occurrence of any complication.

Figure 1A shows neurological status at time of admission and discharge according to mRS score. Patients with any complication in the early course after CP had an average increase in mRS score of 0.7 points, whereas the group without complications showed an average decrease of 0.3 points (p = 0.242, Kruskal-Wallis ANOVA). The same result was also seen for surgical revision. Increase and decrease in mRS score, as a function of the occurrence of any complication, are shown in Fig. 1B. Furthermore, mRS score at the time of admission for CP differed depending on the diagnosis (e.g., median mRS score of 4 for stroke patients vs 3 for TBI patients, p < 0.001). There was no significant difference between diagnoses in terms of change in mRS score between admission and discharge (p = 0.263).

Surgical Details

Time at which surgery was performed had no impact on the occurrence of any complication or surgical revision. In total, 252 patients (50.2%) were monitored in the ICU, and 85.6% of patients underwent postoperative CT. CT was performed significantly more often on patients with any complication (93.9% vs 82.9%, p = 0.003, Fisher’s exact test). The average postoperative hospital stay was 8.48 days, with a median (range) of 6 (1–119) days. Regression analysis confirmed surgical revision as a predictor of prolonged stay (predicted increase of 13.5 days,
95% CI 3.0–23.9 days, \( p = 0.012 \)). Age, sex, medical risk factors, and underlying diagnosis did not correlate with length of stay. The mean ± SD interval between DC and CP was 136.6 ± 129.3 days. Among patients who required surgical revision after CP, the interval between DC and CP was significantly shorter than that of the patients who did not require revision surgery (98.6 days vs 141.0 days, \( p = 0.014 \), Kolmogorov-Smirnov test). We observed the same tendency in our comparison of patients with and without any type of complication, but this difference was not statistically significant (121.2 days vs 141.7 days, \( p = 0.066 \)). In addition, the time interval was significantly different between patients with TBI (98.5 days) and those with stroke (161.7 days) (\( p < 0.001 \)).

In 43 patients (8.6%), a ventriculoperitoneal (VP) shunt had already been implanted by the time of CP. In 134 patients (26.7%), CSF reduction was necessary during or prior to CP. This was performed in 79 patients (59.0%) with puncture of the lateral ventricle and in 41 patients (30.6%) with preoperative placement of a lumbar drain. The implanted VP shunt was punctured for additional CSF reduction in 2 patients (1.5%), and no further details on the technique for CSF reduction were reported for 12 patients (9.0%). In 10 patients (2.0% of the entire cohort), implantation of a VP shunt was necessary after CP owing to newly diagnosed hydrocephalus, which was considered a complication (Table 2).

During preparation, accidental injury of the dura mater occurred in 184 patients (36.7%). Dural tenting sutures were applied to the bone flap or implant in 397 patients (79.1%). However, none of these parameters showed an impact on the occurrence of any complication or surgical revision. The suture material used, suture technique, and choice of implanted material showed no effects on the perioperative complication rate. The mean ± SD size of the osseous defect was 95.7 ± 39.9 cm\(^2\), and the mean duration of CP was 119.3 ± 45.5 minutes. Sinking skin flap syndrome was reported for 55 patients (11.2%) and was more frequent in patients with any complication (18.4 vs 9.0%, \( p < 0.001 \)). Yet, no difference was found with regard to surgical revision, and sinking skin flap syndrome did not lead to earlier CP in our cohort. Remarkably, the brain parenchyma was more often still above the calvarial level in stroke patients compared with TBI patients (35.2% vs 14.1%), whereas the parenchyma was more frequently below the calvarial level at the time of CP in the latter (41.7% vs 28.9%, \( p < 0.001 \)). Repeated CP could not be proven as a risk factor for any complication, although a tendency was observed (31.1% of patients who underwent repeated CP had complications vs 22.0% of those who underwent a single CP, \( p = 0.056 \)). Likewise, operative experience of the surgeon did not affect the frequency of any complication or surgical revision.

### Predictors of Any Complication and Surgical Revision

To assess which parameters are crucial risk factors for complications during the first month after CP, we performed regression analysis of both endpoints by using

<table>
<thead>
<tr>
<th>Comp</th>
<th>No. of Patients (n = 130)</th>
<th>% of All Comp</th>
<th>Surgical Revision</th>
</tr>
</thead>
<tbody>
<tr>
<td>----------------------------</td>
<td>----------------------------</td>
<td>---------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>Epidural hematoma</td>
<td>41</td>
<td>19.9</td>
<td>18 (40.0)</td>
</tr>
<tr>
<td>Subgaleal hematoma</td>
<td>36</td>
<td>17.5</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Subdural hematoma</td>
<td>19</td>
<td>9.2</td>
<td>6 (13.3)</td>
</tr>
<tr>
<td>New-onset seizure</td>
<td>18</td>
<td>8.7</td>
<td>0</td>
</tr>
<tr>
<td>CSF fistula</td>
<td>16</td>
<td>7.8</td>
<td>3 (6.7)</td>
</tr>
<tr>
<td>New hydrocephalus</td>
<td>12</td>
<td>5.8</td>
<td>10 (22.0)</td>
</tr>
<tr>
<td>Wound dehiscence</td>
<td>8</td>
<td>3.9</td>
<td>3 (6.7)</td>
</tr>
<tr>
<td>Anesthesiological or medical</td>
<td>8</td>
<td>3.9</td>
<td>0</td>
</tr>
<tr>
<td>ICH/SAH</td>
<td>7</td>
<td>3.4</td>
<td>0</td>
</tr>
<tr>
<td>CSF leak</td>
<td>6</td>
<td>2.9</td>
<td>2 (4.4)</td>
</tr>
<tr>
<td>Ischemia</td>
<td>6</td>
<td>2.9</td>
<td>1 (2.2)</td>
</tr>
<tr>
<td>Subdural/epidural hygroma</td>
<td>6</td>
<td>2.9</td>
<td>0</td>
</tr>
<tr>
<td>Wound infection</td>
<td>5</td>
<td>2.4</td>
<td>0</td>
</tr>
<tr>
<td>Other wound healing disorder</td>
<td>3</td>
<td>1.5</td>
<td>0</td>
</tr>
<tr>
<td>Meningitis/ventriculitis</td>
<td>3</td>
<td>1.5</td>
<td>0</td>
</tr>
<tr>
<td>Pneumocephalus</td>
<td>3</td>
<td>1.5</td>
<td>1 (2.2)</td>
</tr>
<tr>
<td>Neurological deficit</td>
<td>3</td>
<td>1.5</td>
<td>0</td>
</tr>
<tr>
<td>Comp w/ existing VP shunt</td>
<td>3</td>
<td>1.5</td>
<td>2 (4.4)</td>
</tr>
<tr>
<td>Misc comp</td>
<td>3</td>
<td>1.5</td>
<td>0</td>
</tr>
<tr>
<td>All comp</td>
<td>206</td>
<td>45 (100)</td>
<td></td>
</tr>
</tbody>
</table>

Comp = complications; SAH = subarachnoid hemorrhage. Patients may have had more than 1 complication.
the parameters with a significant correlation in univariate tests (data not shown).

We found that sinking skin flap syndrome and an existing VP shunt were more frequent in patients who developed any complication. Furthermore, more complications occurred in patients with lower mRS score at time of admission, larger bone defects, prolonged operative time for CP, and increased blood loss. On logistic regression, sinking skin flap syndrome and amount of intraoperative blood loss were identified as independent parameters (Table 3). To evaluate this result, it should be noted that intraoperative blood loss was strongly correlated with duration of surgery (\( \rho = 0.34, p < 0.001 \)) and size of the bone defect (\( \rho = 0.27, p < 0.001 \)).

Next, we analyzed risk factors for surgical revision. Univariate analysis revealed that large bone defect and poor mRS score, as well as poor ASA score, were risk factors for surgical revision in our study population. Counterintuitively, the mean patient age was younger in the group that required surgical revision (47.1 years vs 52.4 years, \( p = 0.036 \)). Furthermore, underlying diagnosis and simultaneous shunt implantation had different distributions in the two groups. However, simultaneous shunt implantation was performed on only 13 patients (2.6%), which makes further analysis of this subgroup not worthwhile.

In the regression analysis, increased mRS and ASA scores were independent predictors of surgical revision (Table 4). In comparison with the other diagnoses, diagnosis of stroke was a protective factor associated with a minor rate of surgical revisions compared with TBI (OR 0.18, with TBI as the reference). Older age had a protective though minor influence on surgical revision (OR 0.98, \( p = 0.046 \)). The favorable influence of older age is most likely due to bias because the age distributions of the stroke and TBI groups were notably different (\( p = 0.001 \), Kruskal-Wallis ANOVA), with a mean age of 56.0 years for the stroke group versus 47.2 years for the TBI group.

Based on the results of the regression analysis model,
we used ROC curve analysis to predict the probability of each variable and compare sensitivities. Figure 2 shows the ROC curves for the occurrence of any complication and surgical revision, with satisfactory sensitivity calculated for the probabilities of both complication categories.

Discussion

Our work confirmed an overall high rate of complications (9.0%) that required surgical revision within the first 30 postoperative days. In previous publications, the reported revision rates ranged between 25% and 30%. However, these results also included complications that occurred more than 30 days after CP, such as aseptic bone necrosis, and therefore our reported rate of 9.0% seems realistic. Previous retrospective studies did not examine a uniform, predefined point of time through which complications were recorded. Naturally, the cumulative rate is expected to increase with the length of the observation period. Therefore, it is important to emphasize that our work recorded complications through a 30-day period after the intervention.

We were able to identify the patient’s preexisting state of health and underlying diagnosis as the most important predictors of revision surgery during the early follow-up. This may be discouraging because these factors are predefined and beyond the influence of the treating surgeon. However, this result is all the more important because it clearly shows that predefined risk factors need to be taken into account prior to any treatment. Fountain et al. reported a 30-day readmission rate of 6.7% (14/209 patients), which is somewhat lower than ours but within a similar range. The comparability of the results is diminished by the predominant use of titanium implants and differing inclusion criteria within the UK registry. However, this also provides an opportunity to investigate differences in surgical techniques and their impacts on complication rates by comparing these two prospective databases. In contrast to our data, the UK registry found that neither mRS score, diagnosis, nor any other clinical characteristic was a predictive marker of readmission, which is probably due to the

<table>
<thead>
<tr>
<th>Variable</th>
<th>p Value</th>
<th>OR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>mRS score at admission</td>
<td>0.014</td>
<td>1.46 (1.08–1.97)</td>
</tr>
<tr>
<td>ASA score</td>
<td>0.003</td>
<td>2.89 (1.42–5.89)</td>
</tr>
<tr>
<td>Age</td>
<td>0.046</td>
<td>0.98 (0.95–1.00)</td>
</tr>
<tr>
<td>Diagnosis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TBI</td>
<td>1.00</td>
<td>(ref)</td>
</tr>
<tr>
<td>Stroke</td>
<td>0.004</td>
<td>0.18 (0.06–0.57)</td>
</tr>
<tr>
<td>ICH</td>
<td>0.991</td>
<td>1.01 (0.35–2.93)</td>
</tr>
<tr>
<td>SAH</td>
<td>0.747</td>
<td>1.17 (0.45–3.05)</td>
</tr>
<tr>
<td>Misc</td>
<td>0.181</td>
<td>0.23 (0.03–1.97)</td>
</tr>
<tr>
<td>Defect size</td>
<td>0.307</td>
<td>1.007 (0.994–1.021)</td>
</tr>
<tr>
<td>Simultaneous shunt placement</td>
<td>0.192</td>
<td>2.634 (0.615–11.287)</td>
</tr>
</tbody>
</table>

Boldface type indicates statistical significance (p < 0.05).

FIG. 2. ROC curves of the variables included in the regression models. A: ROC curves showing the ability to predict any complication on the basis of blood loss (area under the curve [AUC] 0.592, 95% CI 0.526–0.659, p = 0.005) and sinking skin flap syndrome (AUC 0.557, 95% CI 0.490–0.623, p = 0.084), as well as the predicted probability based on the regression model (AUC 0.613, 95% CI 0.547–0.679, p = 0.001). B: ROC curves showing the ability to predict surgical revision on the basis of mRS score at admission (AUC 0.736, 95% CI 0.655–0.817, p < 0.001), ASA score (AUC 0.664, 95% CI 0.577–0.751, p = 0.001), diagnosis (AUC 0.371, 95% CI 0.285–0.458, p = 0.008), and age (AUC 0.414, 95% CI 0.324–0.503, p = 0.075), as well as the predicted probability based on the regression model (AUC 0.821, 95% CI 0.747–0.894, p < 0.001). prob. = probability; synd. = syndrome. **p < 0.01; ***p < 0.001. Figure is available in color online only.
limited number of patients. However, higher ASA score was associated with increased rate of infection, which is in line with the findings of our study (i.e., ASA score was a predictive marker of surgical revision).

In one retrospective study, the complication rate was higher in stroke patients than in trauma patients, in contrast to the results shown by us.9 This raises the question of why is the underlying diagnosis of stroke associated with a lower complication rate than TBI? Interestingly, we found no differences in our data sets between the two diagnoses in terms of intraoperative blood loss, duration of DC, or size of DC, which might have served as a surgical explanation. One explanation of this finding may be that TBI is frequently associated with concomitant injuries and complications during intensive care, with possible subsequent worsening of overall severity of injury.22 Pathophysiologically, stroke is a much more definable entity than TBI, where multiple primary effects on the brain are often followed by multiple secondary parenchymal injuries. There is comparative work in the literature on neurological outcomes after DC in relation to the underlying diagnosis.23–25 However, in the current recommendations for CP, there is little discussion of the differences between stroke and TBI patients. In addition, different clinical management strategies for these patients may have contributed to the results. For instance, our analysis demonstrated a significant difference between TBI and stroke patients in terms of time between DC and CP, which may have been a confounder. Data analysis of this registry made it possible to identify the diagnosis as a potentially important criterion. Yet, a precise pathophysiologic rationale is still missing because the descriptive data of the clinical registry lack an answer to this question, but the answer could be drawn from further research in this area.

No implants were explanted from the patients in the miscellaneous diagnosis group, and only 1 complication leading to surgical revision was recorded. This is explained by the fundamental differences in the clinical characteristics of these patients compared with, for example, those of TBI patients (Supplemental Tables 2 and 3). The considerable age difference between stroke and TBI patients may explain why patient age played only a minor role in our study.

When we analyzed timing of first CP, which is still controversial,26 our findings demonstrated that shorter interval between DC and CP was associated with increased likelihood of surgical revision. This is consistent with earlier observations that identified early CP as a predictor of complications.15 In contrast, a previous retrospective study suggested the advantages of early CP, though the criteria for determining timing of CP still remain unclear.14 A recent consensus statement for TBI patients states that early CP (6 weeks to 3 months after DC) may have a positive impact on neurological outcome, although the right timing has to be chosen individually and take into account clinical conditions.27 The long-term evaluation of GCRR and future studies will provide further evidence on this topic.

Sinking skin flap syndrome and increased intraoperative blood loss were identified as risk factors for overall surgery-associated complications. This is because increased blood loss is strongly correlated with extended duration of operation, which is in turn associated with increased risk of surgery-related infection.12 Sinking skin flap syndrome is described as a complication after DC that is associated with deterioration of neurological status; however, its relevance to subsequent CP has not been clearly proven.10 Interestingly, this did not result in an increased revision rate.

This study was limited by some factors. First, we cannot exclude possible selection bias because the participating centers were not obligated to report every single CP. Second, because we did not influence or control for the implemented surgical techniques, a wide range of applied techniques can be assumed, which may have masked some variables. However, this study reflects a realistic picture of everyday clinical life in representative hospitals and provides relevant results for neurosurgical and neurological physicians.

Conclusions

We provide evidence-based (class II) multicenter results for this distinct patient group in the largest prospective patient cohort reported so far. Surgery-related complications are common after CP and are most likely linked to specific preexisting conditions, such as increased mRS score, that are beyond the scope of influence of the treating surgeons. Attention should be paid to influenceable factors, such as the time that CP is performed, the appearance of a sinking skin flap, the duration of the procedure, and intraoperative blood loss, which likewise influence postoperative complications after CP. Our study results, together with data from the UK Cranial Reconstruction Registry, provide reliable suggestions for the treatment of this patient cohort. Long-term neurological status and delayed surgical complications require further evaluation of the GCRR or similar databases.

References

8. Meyer RM IV, Morton RP, Abecassiss IJ, Barber JK, Emerson SN, Nerva JD, et al. Risk of complications with simultaneous Sinking skin flap syndrome and increased intraoperative blood loss were identified as risk factors for overall surgery-associated complications. This is because increased blood loss is strongly correlated with extended duration of operation, which is in turn associated with increased risk of surgery-related infection.22 Sinking skin flap syndrome is described as a complication after DC that is associated with deterioration of neurological status; however, its relevance to subsequent CP has not been clearly proven.10 Interestingly, this did not result in an increased revision rate.

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References


