Risk of Complications in Primary Versus Revision-Type Cranioplasty

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Introduction: Cranioplasty (CP) is a multifaceted procedure in a heterogenous patient population, with a high risk for complication. However, no previous large-scale studies have compared outcomes in primary (ie, first attempt) CP versus revision CP (ie, following previous attempts). The authors, therefore, analyzed long-term outcomes of 506 consecutive primary and revision CPs, performed by a single surgeon.

Methods: All CPs performed between 2012 and 2019 were analyzed under IRB protocol approval. Surgeries were categorized as either primary (no previous CP; n = 279) or revision CP (at least one previous CP; n = 227). Complications were defined as either major or minor. Subgroup analyses investigated whether or not CP complication risk directly correlated with the number of previous neuro-cranial surgeries and/or CP attempts.

Results: The primary CP group experienced a major complication rate of 9% (26/279). In comparison, the revision CP group demonstrated a major complication rate of 32% (73/227). For the revision CP group, the rate of major complications rose with each additional surgery, from 4% (1 prior surgery) to 17% (2 prior surgeries) to 39% (3–4 prior surgeries) to 47% (≥5 prior surgeries).

Conclusion: In a review of 506 consecutive cases, patients undergoing revision CP had a 3-fold increase in incidence of major complications, as compared to those undergoing primary CP. These results provide critical insight into overall CP risk stratification and may guide preoperative risk-benefit discussions. Furthermore, these findings may support a center-of-excellence care model, particularly for those patients with a history of previous neuro-cranial surgeries and/or CP attempts.

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There are numerous indications and benefits for performing cranioplasty (CP) reconstruction using customized cranial implants for large defects, including

(1) correcting impaired brain physiology in the setting of compromised intracranial hemodynamics,
(2) providing cerebral protection from trauma,
(3) reducing social stigma by restoring craniofacial symmetry, and
(4) removing normal cranial bone to inset biomedical devices.[1–7]

Furthermore, CP with synthetic implants permits novel applications, such as creating synthetic acoustic windows for trans-cranioplasty diagnostic and synthetic ultrasound.[8,9] However, a wide range of CP-associated complication rates have been published, with some reports approaching 35% to 40%.[10–12] Although significant heterogeneity in previous study designs limit direct comparisons, the observed variation in complication rates is likely confounded by aggregation of primary and revision CP surgeries.[13]

It is generally accepted that the risk of post-operative complications increases with the extent of prior surgical history.[14–17] Therefore, in order to accurately evaluate the risks of CP, we aimed to differentiate between complication risks in patients undergoing a primary CP versus revision CP. Given that CP patients often have a complicated surgical history, with extensive soft tissue scarring from numerous scalp openings/incisions, it is important to further stratify complication risk by surgical history. Therefore, we also aimed to assess the effect of increasing numbers of previous neuro-cranial surgeries on complication risk in both primary and revision CP procedures. With these aims in mind, we performed a retrospective analysis of 506 consecutive CPs performed by a single surgeon, to reduce cofounding variables associated with inconsistent CP techniques, materials and protocols found within previous studies.

MATERIAL AND METHODS

Data collection and statistical analyses were conducted under an IRB approved protocol. All CPs performed by the senior author (CG) between 2012 and 2019 were included. A previously described pericranial onlay technique, in which the implant was placed over a segment of vascularized pericranium, was used in both primary and revision type cranioplasties.[18] Soft tissue dissection and manipulation techniques were consistent in both cranioplasty groups.[19–22] Briefly, the skin was incised with a 15-blade scalpel, either utilizing a previous scar adjacent and parallel to the craniectomy defect, or if the previous incision was directly overlying the craniectomy defect, a new incision was made. This was done

such that the incisional wound would overly healthy bone instead of the newly placed cranial implant. The incision was then continued down to the bone using needle tip electrocautery. The scalp flap overlying the defect was then elevated in a subpericranial plane with a number 9 periosteal elevator, until the edge of the bone defect was reached. Importantly, at this point needle tip electrocautery was used to transition the dissection from subpericranial to subgaleal plane. This critical step of the procedure was performed under loupe magnification, to ensure the intact pericranium is left adherent to the underlying dura mater and thereby reducing the risk of dural injury. Care was taken to also prevent injuries or "buttonholing" through the overlying scalp tissue during this dissection. The selected implant, whether autologous or alloplastic, was then placed over the cranial defect and secured in a standard fashion with titanium plates and screws. A layered scalp closure was then performed, with meticulous attention to galeal closure.

CP implant material for each case was selected at the discretion of the senior author in a non-randomized, patient specific manner.[23] If the patient had available stored bone flap from the previous craniectomy, this was considered autologous cranioplasty. No bone grafts from remote sites were utilized in this cohort. Synthetic biomaterials used included titanium mesh (TM), porous polyethylene, polyetheretherketone (PEEK), liquid applied polymethylmethacrylate (LPMMA), solid prefabricated polymethylmethacrylate (PMMA) and clear prefabricated polymethylmethacrylate (CPMMA). LPMMA was used to correct temporal hollowing deficiencies by augmenting an existing cranioplasty or bone flap.

Abstracted patient variables included demographic information, medical history, surgical history, and post-operative course. CPs were categorized as either "primary" or "revision". The primary group included all cases where no cranial defect repair had been attempted between the initial craniectomy and the CP performed by the senior surgeon. The revision group consisted of patients who underwent at least one previous CP attempt, by either the senior surgeon or another surgeon.

Complications were defined as either major or minor. A major complication involved any outcome requiring unexpected surgical intervention such as implant removal, surgical drainage or surgical wound revision. Minor complications described any self-limiting or non-surgically managed unexpected event. To further stratify CP risk, the sum of all previous neuro-cranial surgeries was calculated to the extent allowed by available medical records. This value included all procedures in which a scalp incision was required, such as prior CPs, implant removal, wound debridement for infections, neurosurgical procedures, device insertion (i.e. shunt placement for hydrocephalus), and/or scalp augmentation procedures. If the cranial defect was created and repaired during the same surgical procedure (ie, single-stage cranioplasty), then the craniectomy was not considered a prior surgery.[24]

Statistical analyses were performed using Stata-14.0 (STATA, College Station, TX) and Excel (Microsoft, Redmond, WA). T-tests were used to assess significant difference across continuous variables. Significance across categorical variables was examined with chi-squared tests and, where appropriate, Fisher's exact tests. Odds-ratios and ninety-five percent confidence intervals assessed risk of post-CP complication types. In all analyses, statistical significance was defined as $P < 0.05$.

RESULTS

A total of 279 primary and 227 revision CPs were identified (Fig. 1). Patients were followed for an average of 22 months post-operatively. There was no significant difference between the groups with regard to age, BMI, smoking history, diabetes, surgical indication, post-CP radiation, presence of hydrocephalus shunts, preoperative

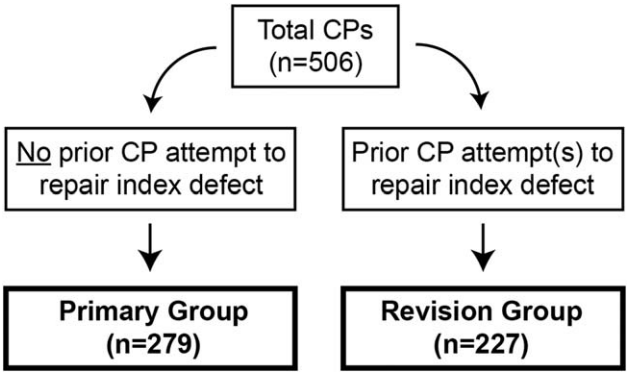

FIGURE 1. Study design. Primary cases included all cranioplasty (CP) surgeries performed in a patient without a previous cranioplasty to repair their index cranial defect. The revision group included all CPs performed in a patient with at least one prior CP to reconstruct their index cranial defect.

Glasgow outcome scale, cranial defect size, defect location, time interval of craniectomy-to-CP, procedure length, number of alloplastic implants, and number of autologous bone flap replacements. Of note, the primary CP group contained significantly more male patients (152 versus 94 patients, $P = 0.003$), greater number of CPs using PEEK (37 versus 14, $P = 0.004$), and fewer instances of pre-CP radiation (21 versus 45, $P < 0.001$). Group characteristics and demographics are summarized in Supplemental Digital Content, Table 1, http://links.lww.com/SCS/B56.

A 9% (26/279) major complication rate was identified following primary CP, compared to 32% (73/227) following revision CPs ($P < 0.001$). Rates of minor complications were not significantly different between groups (Supplemental Digital Content, Table 2, http://links.lww.com/SCS/B56). The odds-ratio for major complications was significantly different between groups (Supplemental Digital Content, Table 3, http://links.lww.com/SCS/B56). With regard to the specific major complications, the incidences of scalp dehiscence and surgical site infections were significantly higher in the revision group compared to the primary group ($P < 0.001$) (Fig. 2). Other complications, such as epidural collection, asymmetry, and temporal hollowing deformities for example, were not significantly different between the groups.

Odd-ratios of complications in revision CP were found to rise incrementally with increasing number of scalp-incision surgeries (Fig. 3A). This trend was not observed in the primary CP group. However, a history of two or more previous neuro-cranial surgeries in primary CP patients was associated with an increased risk of

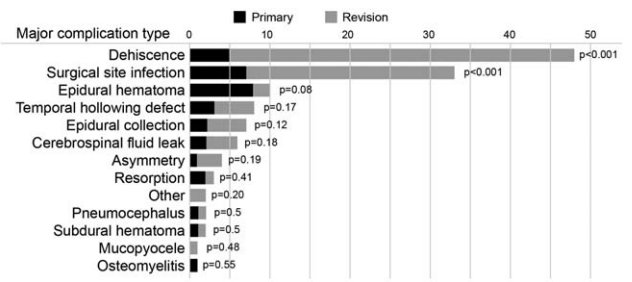

FIGURE 2. Relative proportions of specific post-cranioplasty major complications occurring in primary CP and revision CP cohorts. Each complication is shown as a fraction of all complications observed in the entire 506 CP series, and sub-divided to show the incidence in primary (black) and revision (grey) groups. *P* values denote statistical difference in complication incidences between primary and revision groups.

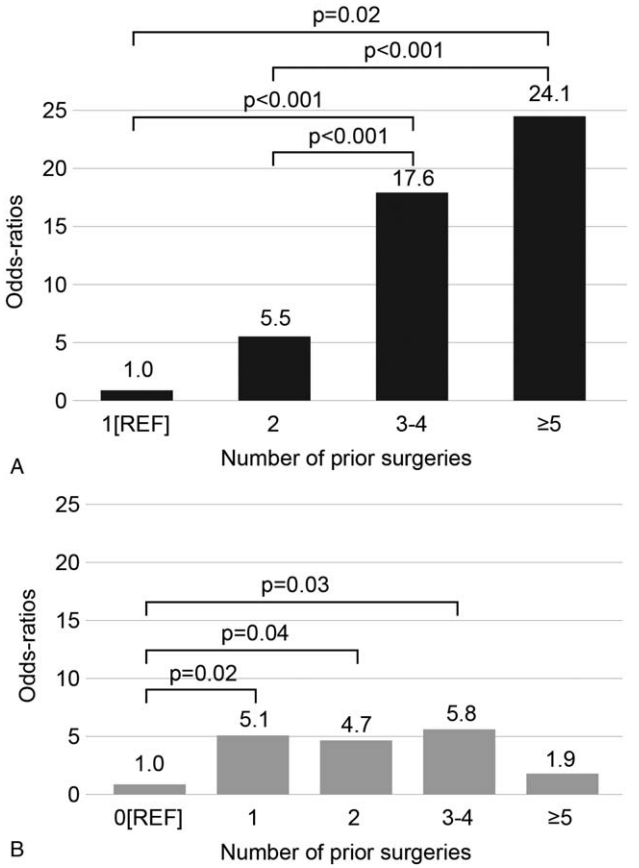

FIGURE 3. (A) Risk (odds-ratios) of post-cranioplasty major complications associated with number of prior surgeries among revision CP cohort. Any procedure requiring scalp incision was counted towards total [*REF = reference group]. (B) Risk (odds-ratios) of post-cranioplasty major complications associated with number of prior surgeries among primary CP cohort. Any procedure requiring scalp incision was counted towards total [∗REF = reference group].

complication when compared to primary CP patients with no previous neuro-cranial surgical history (Fig. 3B).

In order to determine whether preoperative scalp radiation independently affected the risk of complication in primary versus revision CP, sub-group analyses were performed. There were a total of 66 patients who underwent preoperative radiation (21 primary and 45 revisions). Of the variables tracked, no statistically significant difference in the composition of these sub-groups was observed (Supplemental Digital Content, Table 4, http://links.lww.com/SCS/B56). A statistically significant difference in incidence of major complications was observed between primary and revision CP patients who received preoperative radiation (3/21 versus 17/45, $P = 0.03$).

DISCUSSION

Multiple studies have demonstrated that the risk of complications in neurosurgical procedures such as microvascular decompression for trigeminal neuralgia and transsphenoidal hypophysectomy, increases with the number of surgical attempts.[14–16] For example, patients undergoing first versus second craniotomy for malignant glioma resection were observed to develop perioperative complications in 24% versus 33% of cases, respectively.[17] Similarly, several studies comparing primary versus revision surgery for ventriculoperitoneal shunt placement found significantly greater risk of complications in revision surgeries.[25–27] A 2003 case series by Gonzalez et al showed a greater incidence of complications following a single compared to a second CP, however the groups were not shown to be comparable and the results did not reach statistical significance.[28]

To our knowledge, no previous study has specifically evaluated the risk of complications in primary versus revision CP surgery. The goal of this study was to assess whether multiple CP attempts independently increases the risk for postoperative complication. The results of this study showed a three-fold overall increase in the rate of major complication in patients undergoing revision versus primary CP.

We observed that each previous neuro-cranial surgery significantly increased risk of complications in patients undergoing revision CP. This risk rose precipitously with each sequential procedure, from 4% (1 prior surgery) to 17% (2 prior surgeries) to 39% (3–4 prior surgeries) to 47% (≥5 prior surgeries). To our knowledge, this is the first study demonstrating this incremental increase in complication risk with revision CP. Furthermore, even in the primary CP group, the risk of complication was increased in patients who had two or more previous scalp incision surgeries. In parallel, these results suggest that preoperative risk-benefit discussions with patients and care teams should include the number of previous neuro-cranial surgeries as an independent risk factor for predicting major complication risk in CP surgery.

Although many neurosurgeons and plastic surgeons consider CP to be a routine and straightforward procedure, these findings highlight the fact that the best chance of a favorable outcome, with minimal complication risk, is associated with the first CP procedure. Therefore, we should consider the primary CP as the best opportunity for patients in need of CP reconstruction to attain an optimal result, and that following failure and/or major complication, the initial, relatively low-risk of 9% escalates dramatically in subsequent operations.

With respect to CP, previous studies have considered numerous risk factors. Reported modifiable risk factors include age,[29,30] BMI,[18,20] craniectomy-CP time interval,[23,31,32] and implant material.[13,31,33] Proposed non-modifiable risk factors include smoking,[30,34] diabetes,[29,35] surgical indication,[29,36] previous ventricular shunts,[37–39] pre-operative Glasgow outcome scale,[40] operative duration,[30,36] defect size,[34] and defect location including involvement of the frontal sinus.[33,41] The primary and revision groups studied here did not significantly differ in any of these risks. The revision group contained significantly fewer male patients (152 versus 94 patients, $P < 0.001$), however sex has not been shown to effect CP outcomes.[30,42] A greater number of CPs were performed using PEEK in the primary group (41 versus 15, $P = 0.004$), however published comparisons of CP complication rates using PEEK versus other biomaterials are inconsistent.[13,43–45] As such, pre-operative radiation exposure was the main significant risk factor disparity between the primary and revision groups.

Pre-CP radiation is known to increase CP complication risk; thus it would be predicted that the higher number of patients with pre-CP radiation in the revision CP group was primarily responsible for the increased incidence of complications.[11,33,46] However, sub-group analyses controlling for radiation demonstrated that the incidence of major complications remained significantly different between the primary and revision sub-groups ($P = 0.03$). Risk of major complications more than doubled in patients with a history of preoperative radiation who underwent a revision compared to a primary CP.

Although it would be expected that repeated neuro-cranial surgeries increases CP complication risk, the specific etiology is unclear and likely multifactorial. Disturbances to the soft tissue anatomy and subsequent scarring have been shown to affect

outcomes in the neurosurgical literature.[14–17] Histologic examination of scalp tissue following surgical dissection demonstrated changes in tissue architecture, cell composition and tissue cellularity.[47] Indeed, the majority of complications observed in our revision group (incisional dehiscence and surgical site infection) are likely related to scalp soft tissue disturbances from previous surgeries.

It is important to note that the rate of major complications identified within our CP database falls well within published ranges.[10,11,48] In fact, the average major complication rate in both neurosurgery and plastic surgery literature often approaches 40%.[11] The 9% risk in primary CP and 32% complication rate in revision CP presented here are both comparably lower. This may reflect derived benefits of our cranioplasty center-of-excellence, the use of a multidisciplinary team-based care model, and the application of tailored neuroplastic surgery principles and practices.

The study presented has several potential limitations. These results are specific to the surgical techniques, multidisciplinary approach and predominantly synthetic biomaterials used by the senior author and therefore may not be generalizable. The frequency or quantity of grafting and soft tissue manipulation was not collected therefore variations in these variables may influence the difference in outcomes between primary and revision CPs. The extent of neurosurgical involvement in each case was not specifically recorded and therefore may have also affected the results. Implant materials selection was not randomized, therefore a prospective randomized study is needed to evaluate the influence of implant material on complication rates in primary compared to revision CPs.

CONCLUSION

It is challenging to achieve a durable scalp closure and aesthetically pleasing, symmetric results in CP, while at the same time minimizing complications. In order to better evaluate best practices, a detailed risk stratification is required. This retrospective, case series of 506 consecutive patients identified a three-fold increased risk of major complication in those undergoing revision versus primary CP. Further stratification found complication risks in patients undergoing revision CP to approximately double with sequentially increasing numbers of previous neuro-cranial surgeries. These important findings may allow us to better counsel our patients in need of CP reconstruction. Furthermore, such results lend support for utilizing a center-of-excellence care model, especially for patients with an extensive history of neuro-cranial procedures and/or history of multiple revision CP procedures.

REFERENCES

1. Shahid AH, Mohanty M, Singla N, et al. The effect of cranioplasty following decompressive craniectomy on cerebral blood perfusion, neurological, and cognitive outcome. *J Neurosurg* 2018;128:229–235
2. Winkler PA, Stummer W, Linke R, et al. Influence of cranioplasty on postural blood flow regulation, cerebrovascular reserve capacity,;1; and cerebral glucose metabolism. *J Neurosurg* 2000;93:53–61
3. Ashayeri K, Jackson M, Huang E, et al. CR. Syndrome of the trephined: a systematic review. *Neurosurgery* 2016;79:525–534
4. Kuo J-R, Wang C-C, Chio C-C, et al. Neurological improvement after cranioplasty - analysis by transcranial doppler ultrasonography. *J Clin Neurosci Off J Neurosurg Soc Australas* 2004;11:486–489
5. Piazza M, Grady MS. Cranioplasty. *Neurosurg Clin N Am* 2017;28:257–265
6. Gordon CR, Wolff A, Santiago G, et al. First-in-human experience with integration of a hydrocephalus shunt device within a customized cranial implant. *Oper Neurosurg (Hagerstown)* 2019;17:608–615
7. Gordon CR, Santiago GF, Huang J, et al. First in-human experience with complete integration of neuromodulation device within a customized cranial implant. *Oper Neurosurg (Hagerstown)* 2018;15:39–45
8. Belzberg M, Shalom N Ben, Lu A, et al. Trans-Cranioplasty Ultrasound (TCU) through a Sonolucent Cranial Implant Made of Poly-methyl methacrylate (PMMA): phantom study comparing ultrasound, CT and MRI. *J Craniofac Surg* 2019(Accepted – In Press)
9. Belzberg M, Shalom NB, Yuhanna E, et al. Sonolucent cranial implants: cadaveric study and clinical findings supporting diagnostic and therapeutic transcranioplasty ultrasound. *J Craniofac Surg* 2019;30:1456–1461
10. Bobinski L, Koskinen L-OD, Lindvall P. Complications following cranioplasty using autologous bone or polymethylmethacrylate–retrospective experience from a single center. *Clin Neurol Neurosurg* 2013;115:1788–1791
11. Li A, Azad TD, Veeravagu A, et al. Cranioplasty complications and costs: a national population-level analysis using the marketscan longitudinal database. *World Neurosurg* 2017;102:209–220
12. Beauchamp KM, Kashuk J, Moore EE, et al. Cranioplasty after postinjury decompressive craniectomy: is timing of the essence? *J Trauma* 2010;69:270–274
13. van de Vijfeijken SECM, Munker TJAG, Spijker R, et al. Autologous bone is inferior to alloplastic cranioplasties: safety of autograft and allograft materials for cranioplasties, a systematic review. *World Neurosurg* 2018;117:443-452.e8. doi:10.1016/j.wneu.2018.05.193
14. Ugwuanyi UCPC, Kitchen ND. The operative findings in re-do microvascular decompression for recurrent trigeminal neuralgia. *Br J Neurosurg* 2010;24:26–30
15. Brell M, Ibanez J, Caral L, et al. Factors influencing surgical complications of intra-axial brain tumours. *Acta Neurochir (Wien)* 2000;142:739–750
16. Jahangiri A, Wagner J, Han SW, et al. Morbidity of repeat transsphenoidal surgery assessed in more than 1000 operations. *J Neurosurg* 2014;121:67–74
17. Chang SM, Parney IF, McDermott M, et al. Perioperative complications and neurological outcomes of first and second craniotomies among patients enrolled in the Glioma Outcome Project. *J Neurosurg* 2003;98:1175–1181
18. Gordon CR, Fisher M, Liauw J, et al. Multidisciplinary approach for improved outcomes in secondary cranial reconstruction: introducing the pericranial-onlay cranioplasty technique. *Neurosurgery* 2014;10(Suppl 2):179–190
19. Santiago G, Wolff A, Huang J, et al. Dural reconstruction with autologous rectus fascia: a new technique for addressing large-sized defects during cranioplasty. *J Craniofac Surg* 2018
20. Ibrahim Z, Santiago GF, Huang J, et al. Algorithmic approach to overcome scalp deficiency in the setting of secondary cranial reconstruction. *J Craniofac Surg* 2016;27:229–233
21. Wolff A, Santiago G, Weingart J, et al. Introducing the rectus fascia scalp augmentation technique: a new method for improving scalp durability in cranioplasty reconstruction. *J Craniofac Surg* 2018;29:1733–1736
22. Wolff AY, Santiago GF, Belzberg M, et al. Full-thickness skin grafting for local defect coverage following scalp adjacent tissue transfer in the setting of cranioplasty. *J Craniofac Surg* 2019;30:115–119
23. Wolff A, Santiago GF, Belzberg M, et al. Adult cranioplasty reconstruction with customized cranial implants: preferred technique, timing, and biomaterials. *J Craniofac Surg* 2018;29:887–894
24. Berli JU, Thomaier L, Zhong S, et al. Immediate single-stage cranioplasty following calvarial resection for benign and malignant skull neoplasms using customized craniofacial implants. *J Craniofac Surg* 2015;26:1456–1462
25. Gonzalez DO, Mahida JB, Asti L, et al. Predictors of ventriculoperitoneal shunt failure in children undergoing initial placement or revision. *Pediatr Neurosurg* 2017;52:6–12
26. Al-Tamimi YZ, Sinha P, Chumas PD, et al. Ventriculoperitoneal shunt 30-day failure rate: a retrospective international cohort study. *Neurosurgery* 2014;74:29–34
27. Piatt JHJ. Thirty-day outcomes of cerebrospinal fluid shunt surgery: data from the National Surgical Quality Improvement Program-Pediatrics. *J Neurosurg Pediatr* 2014;14:179–183
28. Moreira-Gonzalez A, Jackson IT, Miyawaki T, et al. Clinical outcome in cranioplasty: critical review in long-term follow-up. *J Craniofac Surg* 2003;14:144–153

29. Zanaty M, Chalouhi N, Starke RM, et al. Complications following cranioplasty: incidence and predictors in 348 cases. *J Neurosurg* 2015;123:182–188
30. Liu H, Dong X, Yin Y, et al. Reduction of surgical site infections after cranioplasty with perioperative bundle. *J Craniofac Surg* 2017;28:1408–1412
31. Yadla S, Campbell PG, Chitale R, et al. Effect of early surgery, material, and method of flap preservation on cranioplasty infections: a systematic review. *Neurosurgery* 2011;68:1124–1129discussion 1130
32. Morton RP, Abecassis IJ, Hanson JF, et al. Timing of cranioplasty: a 10.75-year single-center analysis of 754 patients. *J Neurosurg* 2018;128:1648–1652
33. Reddy S, Khalifian S, Flores JM, et al. Clinical outcomes in cranioplasty: risk factors and choice of reconstructive material. *Plast Reconstr Surg* 2014;133:864–873
34. Fischer JP, Sieber B, Nelson JA, et al. A 15-year experience of complex scalp reconstruction using free tissue transfer-analysis of risk factors for complications. *J Reconstr Microsurg* 2013;29:89–97
35. Abode-Iyamah KO, Chiang H-Y, Winslow N, et al. Risk factors for surgical site infections and assessment of vancomycin powder as a preventive measure in patients undergoing first-time cranioplasty. *J Neurosurg* 2018;128:1241–1249
36. von der Brelie C, Stojanovski I, Meier U, et al. Open traumatic brain injury is a strong predictor for aseptic bone necrosis after cranioplasty surgery: a retrospective analysis of 219 patients. *J Neurol Surg A Cent Eur Neurosurg* 2016;77:19–24
37. Chang V, Hartzfeld P, Langlois M, et al. Outcomes of cranial repair after craniectomy. *J Neurosurg* 2010;112:1120–1124
38. Piedra MP, Ragel BT, Dogan A, et al. Timing of cranioplasty after decompressive craniectomy for ischemic or hemorrhagic stroke. *J Neurosurg* 2013;118:109–114
39. Schwarz F, Dunisch P, Walter J, et al. Cranioplasty after decompressive craniectomy: is there a rationale for an initial artificial bone-substitute implant? A single-center experience after 631 procedures. *J Neurosurg* 2016;124:710–715
40. Krause-Titz UR, Warneke N, Freitag-Wolf S, et al. Factors influencing the outcome (GOS) in reconstructive cranioplasty. *Neurosurg Rev* 2016;39:133–139
41. Manson PN, Crawley WA, Hoopes JE. Frontal cranioplasty: risk factors and choice of cranial vault reconstructive material. *Plast Reconstr Surg* 1986;77:888–904
42. Riordan MA, Simpson VM, Hall WA. Analysis of factors contributing to infections after cranioplasty: a single-institution retrospective chart review. *World Neurosurg* 2016;87:207–213
43. Punchak M, Chung LK, Lagman C, et al. Outcomes following polyetheretherketone (PEEK) cranioplasty: Systematic review and meta-analysis. *J Clin Neurosci Off J Neurosurg Soc Australas* 2017;41:30–35
44. Thien A, King NKK, Ang BT, et al. Comparison of polyetheretherketone and titanium cranioplasty after decompressive craniectomy. *World Neurosurg* 2015;83:176–180
45. Rosinski CL, Patel S, Geever B, et al. A retrospective comparative analysis of titanium mesh and custom implants for cranioplasty. *Neurosurgery* 2019
46. Shonka DCJ, Potash AE, Jameson MJ, et al. Successful reconstruction of scalp and skull defects: lessons learned from a large series. *Laryngoscope* 2011;121:2305–2312
47. Rapp SJ, Jones DC, Billmire DA, et al. Dissection in the subgaleal and subperiosteal plane: implications on scalp wound healing. *J Plast Surg Hand Surg* 2013;47:163–168
48. Liang ES, Tipper G, Hunt L, et al. Cranioplasty outcomes and associated complications: A single-centre observational study. *Br J Neurosurg* 2016;30:122–127