Complications of cranioplasty following decompressive craniectomy: analysis of 62 cases

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Object. Decompressive craniectomy is a potentially life-saving procedure used in the treatment of medically refractory intracranial hypertension, most commonly in the setting of trauma or cerebral infarction. Once performed, surviving patients are obligated to undergo a second procedure for cranial reconstruction. The complications following cranial reconstruction are not well described in the literature and may very well be underreported. A review of the complications would suggest measures to improve the care of these patients.

Methods. A retrospective chart review was undertaken of all patients who had undergone cranioplasty during a 7-year period. Demographic data, indications for craniectomy, as well as preoperative, intraoperative, and postoperative parameters following cranioplasty, were recorded. Perioperative and postoperative complications were also recorded. Patients were classified as having no complications, any complications, and complications requiring reoperation. The groups were compared to identify risk factors predictive of poor outcomes.

Results. The authors identified 62 patients who had undergone cranioplasty. The immediate postoperative complication rate was 34%. Of these, 46 patients did not require reoperation and 16 did. Of those requiring reoperation, 7 were due to infection, 2 from wound breakdown, 2 from intracranial hemorrhage, 3 from bone resorption, and 1 from a sunken cranioplasty, and 1 patient's cranioplasty procedure was prematurely ended due to intraoperative hypotension and bradycardia. The only factor statistically associated with need for reoperation was the presence of a bifrontal cranial defect (bifrontal: 8 [67%] of 12, requiring reoperation; unilateral: 8 [16%] of 49 requiring reoperation; $p < 0.01$).

Conclusions. Cranioplasty following decompressive craniectomy is associated with a high complication rate. Patients undergoing a bifrontal craniectomy are at significantly increased risk for postcranioplasty complications, including the need for reoperation. (DOI: 10.3171/2009.3.FOCUS0962)

KEY WORDS • cranioplasty • craniectomy • cranial reconstruction • cerebral decompression • intracranial hypertension

DECOMPRESSIVE craniectomy is a potentially life-saving procedure used in the treatment of medically refractory intracranial hypertension, most commonly in the setting of trauma or large-vessel infarct and less frequently in the settings of aneurysmal subarachnoid hemorrhage, intraoperative brain swelling, and encephalitis.^{21,59} Decompressive craniectomy, however, remains controversial. Its efficacy is currently being investigated with respect to survival and quality of life in multicenter, prospective, randomized trials in the setting of traumatic brain injury²² and middle cerebral artery infarction.^{27,66}

Once patients undergo decompressive craniectomy, those who survive are obligated to undergo a second procedure for surgical cranial reconstruction, that is, cranioplasty. Much of the modern literature regarding cranioplasty following decompressive craniectomy is based on case series that emphasize the technical aspects of the procedure such as the use of materials,^{2,3,9,10,12,14,26,30,33,35,50-52,54,55,60,63,68,70,71} the use of techniques to store the bone flap prior to reconstruction,^{16,19,24,25,43,48,49,72} the timing of sur-

gical intervention,^{6,37} or other specific modifications to either the craniectomy or cranioplasty procedure, which may influence the cranioplasty.^{20,28,34,36,38,41,47,67} There are relatively few modern-day large clinical series describing the clinical outcomes and perioperative complications of cranioplasties in the setting of nonpenetrating traumatic brain injury and large vessel infarction.^{40,42} Complications after cranial reconstruction, often viewed as a straightforward neurosurgical procedure, may very well be underreported. Furthermore, traditional neurosurgical dictums regarding certain aspects of cranioplasty such as timing of surgery may not be appropriate in the modern era of neurosurgical care. A review of the complications would suggest measures to improve the care of these patients.

In the current study, our goal was to provide a complete review of all perioperative complications, defined as any potentially adverse event within 30 days of surgery, as well as identify any risk factors that may be associated with the need for reoperation after a primary cranioplasty.

Methods

The study was approved by the institutional review board of Albany Medical Center, a Level 1 trauma, tertiary care, teaching hospital. After approval, the billing and discharge databases of the neurosurgical service were reviewed to identify all patients who had undergone cranioplasty following a decompressive craniectomy during a 7-year period (January 1, 2002–December 31, 2008). This series only included patients who underwent craniectomies for cerebral swelling and excluded those undergoing craniectomy for meningioma resection and craniosynostosis. Once identified, the available hospital charts and clinic records were reviewed retrospectively to abstract relevant data.

Abstracted data included age at time of cranioplasty (years), sex (male or female), medical comorbidities (hypertension, diabetes, and tobacco use), indications for craniectomy (trauma, stroke, infection, and intraoperative swelling), laterality of craniectomy (bilateral, unilateral, or bifrontal), time between craniectomy and cranioplasty (days), type of prosthesis if used (titanium, methylmethacrylate, or porex), storage of bone flap if used (subcutaneous or tissue bank), operative time (minutes), identification of intraoperative CSF leak (yes or no), estimated blood loss (ml), intraoperative fluid administration (ml), length of stay after cranioplasty (days), and disposition before and after the cranioplasty (home, hospital, or inpatient nursing facility).

Any potentially adverse medical or surgical events identified within 30 days of surgery were recorded as early complications. Late complications were unsatisfactory events directly related to the cranioplasty occurring > 30 days postoperation. Patients were classified as having no complication, any complication, and complication requiring reoperation. Specifically, our 2 outcomes of interest were complications after cranioplasty and the need for reoperation after cranioplasty. Both variables were dichotomized, and all patient- and surgery-related factors were assessed as risk factors for each of the 2 outcomes of interest via bivariate analysis. Chi-square analysis and the Fisher exact test were used to assess the association between the categorical risk factors and the outcomes. The Wilcoxon rank-sum test was used to assess if the distribution of the continuous variables was different among those who did and those who did not have the outcomes of interest. To assess complication rates associated with time to cranioplasty, patients were divided into quartiles, and ORs were calculated. All tests were 2-tailed. All associations were assessed at a level of 0.05 of statistical significance. Statistical analysis was performed using STATA 10 software (StataCorp LP).

Results

We identified 109 patients who had undergone a cranioplasty following cerebral decompression via craniectomy. Of these, 23 charts were incomplete for the purpose of this study, and 24 patients were lost to follow-up in the early postoperative period. As a result, 62 patients were identified who had undergone a decompressive craniectomy

TABLE 1: Demographic and operative details in 62 patients undergoing craniectomy and cranioplasty

Characteristic	No. of Patients (%) [*]
no. of patients	62
male	34 (55)
female	28 (45)
craniectomy	
mean age (yrs)	31.5 ± 2.4
indication	
trauma	41 (66)
stroke	15 (24)
infection	2 (3)
intraop swelling	4 (6)
type	
unilat	49 (79)
bifrontal	12 (19)
bilat	1 (2)
cranioplasty	
mean age (yrs)	31.9 ± 2.4
type of prosthesis	
autologous	57 (92)
titanium	2 (3)
methylmethacrylate	3 (5)
mean no. of days btwn craniectomy & cranioplasty	133 ± 18.2
mean op room time (min)	173 ± 10
mean estimated blood loss (ml)	238 ± 28
mean intraop intravenous fluids (ml)	1881 ± 138
mean length of stay (days)	11 ± 2.1

^{*} Unless otherwise indicated, mean values are presented as the means ± SEMs.

tomy and subsequent cranioplasty with a minimum of 4 months of follow-up. Even among this population, some variables could not be reliably extracted from the medical records including medical comorbidities, disposition before and after cranioplasty, and intraoperative CSF leakage. The baseline patient characteristics and perioperative factors are shown in Table 1. The majority of the patients in this review were male (34 [55%]), and the most common indication for craniectomy was trauma (41 [66%]). Other reasons for decompressive craniectomy included stroke, infection, and intraoperative swelling. Most craniectomies were unilateral (49 [79%]). In addition, 12 patients (19%) underwent a bifrontal craniectomy, and 1 (2%) underwent a bilateral decompression. Regarding the cranioplasty procedure, the overwhelming majority of repairs used autologous bone (57 [92%]), and all autologous bone was stored in a tissue bank. Titanium and methylmethacrylate repairs were performed much less frequently (2 [3%] and 3 [5%] cases, respectively).

Surgical Complications

Perioperative and postoperative complications are summarized in Table 2. Of the 62 patients undergoing

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TABLE 2: Complications in 62 patients undergoing craniectomy and cranioplasty*

Complication	No. of Patients (%)		
	Early (≤ 30 days postop)	Late (> 30 days postop)	No. Requiring Reop
wound	3 (4.8)	6 (9.7)	9
infection	2 (3.2)	5 (8.1)	7
dehiscence	1 (1.6)	1 (1.6)	2
hematoma	2 (3.2)	0	2
epidural	1 (1.6)	0	1
subdural	1 (1.6)	0	1
bone resorption	0	4 (6.5)	3
sunken bone plate	0	1 (1.6)	1
intraop hemodynamic instability	1 (1.6)	0	1
status epilepticus	1 (1.6)	0	0
hydrocephalus	1 (1.6)	0	0
deep vein thrombosis	2 (3.2)	0	0
upper extremity	1 (1.6)	0	0
lower extremity	1 (1.6)	0	0
	0	0	0
total	10 (16.1)	11 (17.7)	16/21 (76.2)

* Of 62 patients, 21 (33.8%) had some complication and 16 (25.8%) required a reoperation.

cranioplasty, 41 (66%) experienced no complications and 21 (34%) experienced at least 1 complication. Complications included infection (7), wound dehiscence (2), epidural hematoma (1), subdural hematoma (1), bone resorption (4) which was diagnosed clinically and confirmed on CT scanning, sunken bone plate (1), status epilepticus (1), hydrocephalus (1), deep vein thromboses (2), and intraoperative bradycardia and hypotension necessitating a premature end to the cranioplasty procedure (1). Ten patients (16.1%) had early complications and 11 (17.7%) had late complications. After statistical analysis, the only measured variable found to be significantly associated with complication after cranioplasty was a bifrontal defect compared with a unilateral defect (bifrontal: 8 [67%] of 12, with complications; unilateral: 13 [27%] of 49, with complications; $p < 0.05$). Suffering a postoperative complication resulted in a longer duration of inpatient hospitalization, but this difference was not statistically significant (uncomplicated: mean 5.0 days vs any complication: mean 7.4 days, $p > 0.05$).

Complications Requiring Reoperation

Complications requiring reoperation are summarized in Table 2. Sixteen patients (26%) had complications that required an additional surgery to address their primary cranioplasty site. Such complications included infection, wound dehiscence, intracranial hemorrhage, bone resorption, and sunken bone plate. In 1 patient, the initial procedure was aborted midoperation due to hemodynamic in-

TABLE 3: Data regarding reoperation and laterality

Characteristic	No. of Patients (%)	
	No Reop	Reop
no. of patients	46 (74)	16 (26)
laterality of cranioplasty		
unilat	41 (84)	8 (16)
bifrontal	4 (33)	8 (67)
bilat	1 (100)	0 (0)
no. of days btwn craniectomy & cranioplasty*	129 $\pm$ 22	143 $\pm$ 34

* Presented as the means $\pm$ SEMs.

stability. After statistical analysis, the only variable found to be significantly associated with a need for reoperation was the presence of a bifrontal cranial defect (bifrontal: 8 [67%] of 12 requiring reoperation; unilateral: 8 [16%] of 49 requiring reoperation; $p < 0.01$) (Table 3).

Time to Cranioplasty

The 62 patients who underwent cranioplasty were divided into 4 groups, each containing approximately the same number of patients, based on duration of time between craniectomy and cranioplasty. Odds ratios calculating the likelihood of complications and complications requiring reoperation with respect to timing of cranioplasty are presented in Table 4. For complications and complications requiring reoperation, ORs were highest in the 100- to 136-day group (OR 1.67 and 3, respectively).

Discussion

Cranioplasty following decompressive craniectomy is a conceptually intuitive procedure from the perspective of safety and cosmesis. More recent reports have suggested that the procedure may help optimize neurological recovery, both physiologically and/or clinically.^{1,4,11,13,15,18,23,31,32,44-46,57,58,61,64,65,69} However, there is no specific technique or material that has consistently stood alone as superior, and postoperative complication rates vary widely.⁶² In the modern era, most reports in the literature regarding cranioplasty have focused on technical aspects of the procedure and have not emphasized overall surgical complications.^{2,3,9,10,12,14,20,26,28,30,33-36,38,41,50-52,54,55,60,63,67,68,70,71} Because decompressive craniectomy is now being reevaluated in large, prospective, randomized trials,^{22,27,66} an analysis of complications for cranioplasty is particularly important. As almost all patients surviving a decompressive craniectomy will require cranioplasty, the complications of this second operative intervention should be acknowledged.

Complications Following Cranioplasty

The current report suggests that cranioplasty following decompressive craniectomy is associated with a high complication rate (33.8%). Of those patients who did experience complications, 5 (24%) of the 21 did not require

TABLE 4: Data regarding time between craniectomy and cranioplasty and ensuing complications

No. of Days Btwn Craniectomy & Cranioplasty	No. of Patients	Complications		Complications Requiring Reoperation	
		No. (%)	OR	No. (%)	OR
0–48	16	6 (38)	0	4 (25)	0
49–99	15	3 (20)	0.42	0 (0)	—
100–136	16	8 (50)	1.67	8 (50)	3
≥137	15	4 (27)	0.61	4 (27)	1.1

a subsequent operation. However, these complications could not all be classified as “minor.” Specifically, one such patient was found to be in status epilepticus immediately postoperatively. Of the patients with complications, 76% required another operation to address their previous cranioplasty. Such complications included infection, bone resorption, wound dehiscence, sunken bone flap, hematoma, and intraoperative hemodynamic instability necessitating a premature end to the primary cranioplasty procedure. Of note, our infection rate (11.3%) appears to be similar to that previously reported in large series of patients undergoing cranioplasty.^{7,29,40,42}

Complications Requiring Reoperation Following Cranioplasty

In the current analysis, complications requiring reoperation occurred in 16 patients (26%) and in 76% of those who had any complication (16 of 21). This overall reoperative complication rate is surprisingly high, considering the perceived straightforward nature of this procedure.

In our series, all patients who experienced wound complications as defined by infection and wound dehiscence required reoperation. Three of these patients initially presented with wound dehiscence without gross evidence of infection. All 3 were treated with primary closure. Two of the patients received scalp tissue expanders prior to this procedure. The third patient underwent uneventful revision of his scalp flap, but bacterial cultures taken from the operating room eventually revealed methicillin-resistant *Staphylococcus aureus*. He was subsequently treated with intravenous antibiotics. None of these patients was treated by removal of the bone plate. Our review demonstrated that patients undergoing a bifrontal cranioplasty were significantly more likely to have complications. The complications in this group included infection (in 4 patients), wound dehiscence (in 1), sunken bone plate (in 1), resorption (in 1), and hemodynamic instability during cranioplasty (in 1). All complications for these patients led to reoperation. Several factors may have contributed to this observation, including a longer incision in the case of a bifrontal defect, less available temporalis muscle to provide soft-tissue coverage, possible violation of the frontal sinus, and perhaps a longer operative time. Of these, violation of the frontal sinus has previously been described as a definitive risk factor for infection after cranioplasty.^{5,39} Unfortunately, because of the retrospective nature of this study we were unable to reliably quantify any of these potentially contributing variables.

Time to Cranioplasty

According to traditional neurosurgical dictum, a shorter time from craniectomy to cranioplasty is associated with poor outcome.^{17,53,62} While often recommended in neurosurgical texts, the basis of this recommendation is not well cited. The rationale for this waiting period is most likely based on the large series of patients reported by Rish and colleagues⁵⁶ in 1979. This group found that cranioplasties taking place 1–6 months after craniectomy had the highest complication rate (7.9%) and those performed 12–18 months after craniectomy had the lowest complication rate (4.5%). The purported advantage of this waiting period includes avoidance of operating on a potentially contaminated wound.⁵⁶ However, because this study included only patients with penetrating head injuries, the results may not apply to patients who have undergone decompressive craniectomy in the setting of nonpenetrating injury. Recently Carvi et al.⁶ and Liang et al.³⁷ have suggested that cranioplasty following decompressive craniectomy for blunt injury can be performed sooner than previously suggested. The possible advantages of performing cranioplasty in a more timely fashion may include easier dissection of tissue planes, as well as prevention of negative postcraniectomy sequelae including posttraumatic hydrocephalus,⁸ syndrome of the trephined,^{31,46} or other neurological complications.^{32,61,64}

Our analysis in regard to time between craniectomy and cranioplasty revealed a higher risk of both postoperative complications and need for reoperation in those patients treated between 100 and 136 days. It is difficult to rectify this point clinically, and our small number of events in each group limits the strength of any conclusions to be made regarding these data. Most significant may be the fact that those patients treated early (0–48 days) or those treated late (≥ 137 days) did not have a significantly increased risk. This finding, along with the reports by Carvi et al.⁶ and Liang et al.,³⁷ may negate previous dictum suggesting cranioplasty needing to be performed during a certain time point postcraniectomy. Again, this conclusion is limited and requires further analysis in a prospective study.

Critique of the Current Study

The current study is a retrospective analysis of the complications of cranioplasty following decompressive craniectomy. Accordingly, the study suffers from all the anticipated deficiencies of a retrospective analysis including loss of patient information, poor follow-up, inconsis-

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tent operative indications for craniectomy, and inconsistent techniques for cranioplasty. These deficiencies may lead to an inaccurate estimation of the true complication rate.

In an effort to accurately estimate the complication rate, any potentially adverse event in this series was identified as a complication. This method may have falsely inflated the observed complication rate. On the other hand, in a review of cranioplasties in 75 children, Blum et al.,⁵ did not identify any complications until 2.5 years postoperatively. Given that our patients were included with only a minimal follow-up of 4 months, it is possible we may actually be underreporting the total number of complications. Despite these limitations, the current study is important as it highlights the fact that a significant number of complications do occur following cranioplasty, including complications that may necessitate reoperation.

Conclusions

Patients undergoing decompressive craniectomy are obligated to undergo a second procedure for cranial reconstruction. This second surgery has a remarkably high rate of complications. Additionally, patients undergoing bifrontal craniectomies are at a significantly increased risk for postcranioplasty complications including the need for an additional operation. The time between craniectomy and cranioplasty does not appear to be associated with complications; however, our data are too limited to make definitive conclusions as to this point. Prospective studies are needed to further evaluate cranioplasty complications.

Disclaimer

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

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References

1. Agner C, Dujovny M, Gaviria M: Neurocognitive assessment before and after cranioplasty. *Acta Neurochir (Wien)* **144**:1033–1040, 2002
2. Aziz TZ, Mathew BG, Kirkpatrick PJ: Bone flap replacement vs acrylic cranioplasty: a clinical audit. *Br J Neurosurg* **4**:417–419, 1990
3. Azmi A, Latiff AZ, Johari A: Methyl methacrylate cranioplasty. *Med J Malaysia* **59**:418–421, 2004
4. Bijlenga P, Zumofen D, Yilmaz H, Creisson E, de Tribolet N: Orthostatic mesodiencephalic dysfunction after decompressive craniectomy. *J Neurol Neurosurg Psychiatry* **78**:430–433, 2007
5. Blum KS, Schneider SJ, Rosenthal AD: Methyl methacrylate cranioplasty in children: long-term results. *Pediatr Neurosurg* **26**:33–35, 1997
6. Carvi Y, Nieves MN, Höllerhage HG: Early combined cranioplasty and programmable shunt in patients with skull bone defects and CSF-circulation disorders. *Neurol Res* **28**:139–144, 2006
7. Cheng YK, Weng HH, Yang JT, Lee MH, Wang TC, Chang CN: Factors affecting graft infection after cranioplasty. *J Clin Neurosci* **15**:1115–1119, 2008
8. Choi I, Park HK, Chang JC, Cho SJ, Choi SK, Byun BJ: Clinical factors for the development of posttraumatic hydrocephalus after decompressive craniectomy. *J Korean Neurosurg Soc* **43**:227–231, 2008
9. Datti R, Cavagnaro G, Camici S: Stainless steel wire mesh cranioplasty: ten years' experience with 183 patients (100 followed up). *Acta Neurochir (Wien)* **78**:133–135, 1985
10. Ducic Y: Titanium mesh and hydroxyapatite cement cranioplasty: a report of 20 cases. *J Oral Maxillofac Surg* **60**:272–276, 2002
11. Dujovny M, Agner C, Aviles A: Syndrome of the trephined: theory and facts. *Crit Rev Neurosurg* **9**:271–278, 1999
12. Dujovny M, Aviles A, Anger C: An innovative approach for cranioplasty using hydroxyapatite cement. *Surg Neurol* **48**:294–297, 1997
13. Dujovny M, Fernandez P, Alperin N, Betz W, Misra M, Maffee M: Post-cranioplasty cerebrospinal fluid hydrodynamic changes: magnetic resonance imaging quantitative analysis. *Neurol Res* **19**:311–6, 1997
14. Durham SR, McComb JG, Levy ML: Correction of large (>25 cm²) cranial defects with "reinforced" hydroxyapatite cement: technique and complications. *Neurosurgery* **52**:842–845, 2003
15. Erdogan E, Düz B, Kocaoglu M, Izci Y, Sirin S, Timurkaynak E: The effect of cranioplasty on cerebral hemodynamics: evaluation with transcranial Doppler sonography. *Neurol India* **51**:479–481, 2003
16. Flannery T, McConnell RS: Cranioplasty: why throw the bone flap out? *Br J Neurosurg* **15**:518–520, 2001
17. Foster RD, Antonyshyn OM, Lee C, Holland M, Fazl M: Cranioplasty: Indications, techniques, and results, in Schmidek HH (ed): *Schmidek and Sweet Operative Neurosurgical Techniques*. Philadelphia: WB Saunders, 2000, pp 29–44
18. Gottlob I, Simonsz-Tóth B, Heilbronner R: Midbrain syndrome with eye movement disorder: dramatic improvement after cranioplasty. *Strabismus* **10**:271–277, 2002
19. Grossman N, Shemesh-Jan HS, Merkin V, Gideon M, Cohen A: Deep-freeze preservation of cranial bones for future cranioplasty: nine years of experience in Soroka University Medical Center. *Cell Tissue Bank* **8**:243–246, 2007
20. Horaczek JA, Zierski J, Graewe A: Collagen matrix in decompressive hemicraniectomy. *Neurosurgery* **63** (1 Suppl 1):ONS176–ONS181, 2008
21. Hutchinson P, Timofeev I, Kirkpatrick P: Surgery for brain edema. *Neurosurg Focus* **22**(5):E14, 2007
22. Hutchinson PJ, Corteen E, Czosnyka M, Mendelow AD, Menon DK, Mitchell P, et al: Decompressive craniectomy in traumatic brain injury: the randomized multicenter RESCUE-icp study (www.RESCUEicp.com). *Acta Neurochir Suppl (Wien)* **96**:17–20, 2006
23. Isago T, Nozaki M, Kikuchi Y, Honda T, Nakazawa H: Sinking skin flap syndrome: a case of improved cerebral blood flow after cranioplasty. *Ann Plast Surg* **53**:288–292, 2004
24. Iwama T, Yamada J, Imai S, Shinoda J, Funakoshi T, Sakai N: The use of frozen autogenous bone flaps in delayed cranioplasty revisited. *Neurosurgery* **52**:591–596, 2003
25. Jho DH, Neckrysh S, Hardman J, Charbel FT, Amin-Hanjani S: Ethylene oxide gas sterilization: a simple technique for storing explanted skull bone. Technical note. *J Neurosurg* **107**:440–445, 2007
26. Joffe JM, McDermott PJ, Linney AD, Mosse CA, Harris M: Computer-generated titanium cranioplasty: report of a new

- technique for repairing skull defects. **Br J Neurosurg** 6:343–350, 1992
27. Jüttler E, Schwab S, Schmiedek P, Unterberg A, Hennerici M, Woitzik J, et al: Decompressive Surgery for the Treatment of Malignant Infarction of the Middle Cerebral Artery (DESKTOP): a randomized, controlled trial. **Stroke** 38:2518–2525, 2007
 28. Kawaguchi T, Hosoda K, Shibata Y, Koyama J: Expanded polytetrafluoroethylene membrane for prevention of adhesions in patients undergoing external decompression and subsequent cranioplasty. **Neurol Med Chir (Tokyo)** 43:320–324, 2003
 29. Kim YW, Yoo DS, Kim DS, Huh PW, Cho KS, Kim JG, et al.: The infection rate in case of cranioplasty according to used materials and skull defect duration **J Korean Neurosurg Soc (2 Suppl)** 30:216–220, 2001
 30. Kriegel RJ, Schaller C, Clusmann H: Cranioplasty for large skull defects with PMMA (Polymethylmethacrylate) or Tuto-plast processed autogenic bone grafts. **Zentralbl Neurochir** 68:182–189, 2007
 31. Kumar GS, Chacko AG, Rajshekhar V: Unusual presentation of the “syndrome of the trephined.” **Neurol India** 52:504–505, 2004
 32. Kuo JR, Wang CC, Chio CC, Cheng TJ: Neurological improvement after cranioplasty—analysis by transcranial doppler ultrasonography. **J Clin Neurosci** 11:486–489, 2004
 33. Kyoshima K, Gibo H, Kobayashi S, Sugita K: Cranioplasty with inner table of bone flap. Technical note. **J Neurosurg** 62:607–609, 1985
 34. Lee CH, Cho DS, Jin SC, Kim SH, Park DB: Usefulness of silicone elastomer sheet as another option of adhesion preventive material during craniectomies. **Clin Neurol Neurosurg** 109:667–671, 2007
 35. Lee SC, Wu CT, Lee ST, Chen PJ: Cranioplasty using polymethyl methacrylate prostheses. **J Clin Neurosci** 16:56–63, 2009
 36. Li G, Wen L, Zhan RY, Shen F, Yang XF, Fu WM: Cranioplasty for patients developing large cranial defects combined with post-traumatic hydrocephalus after head trauma. **Brain Inj** 22:333–337, 2008
 37. Liang W, Xiaofeng Y, Weiguo L, Gang S, Xuesheng Z, Fei C, et al: Cranioplasty of large cranial defect at an early stage after decompressive craniectomy performed for severe head trauma. **J Craniofac Surg** 18:526–532, 2007
 38. Liao CC, Kao MC: Cranioplasty for patients with severe depressed skull bone defect after cerebrospinal fluid shunting. **J Clin Neurosci** 9:553–555, 2002
 39. Marchac D, Greensmith A: Long-term experience with methylmethacrylate cranioplasty in craniofacial surgery. **J Plast Reconstr Aesthet Surg** 61:744–753, 2008
 40. Matsuno A, Tanaka H, Iwamuro H, Takanashi S, Miyawaki S, Nakashima M, et al: Analyses of the factors influencing bone graft infection after delayed cranioplasty. **Acta Neurochir (Wien)** 148:535–540, 2006
 41. Missori P, Polli FM, Peschillo S, D’Avella E, Paolini S, Miscusi M: Double dural patch in decompressive craniectomy to preserve the temporal muscle: technical note. **Surg Neurol** 70:437–439, 2008
 42. Moreira-Gonzalez A, Jackson IT, Miyawaki T, Barakat K, DiNick V: Clinical outcome in cranioplasty: critical review in long-term follow-up. **J Craniofac Surg** 14:144–153, 2003
 43. Movassaghi K, Ver Halen J, Ganchi P, Amin-Hanjani S, Mesa J, Yaremchuk MJ: Cranioplasty with subcutaneously preserved autologous bone grafts. **Plast Reconstr Surg** 117:202–206, 2006
 44. Muramatsu H, Nathan RD, Shimura T, Teramoto A: Recovery of stroke hemiplegia through neurosurgical intervention in the chronic stage. **NeuroRehabilitation** 15:157–166, 2000
 45. Muramatsu H, Takano T, Koike K: Hemiplegia recovers after cranioplasty in stroke patients in the chronic stage. **Int J Rehabil Res** 30:103–109, 2007
 46. Ng D, Dan NG: Cranioplasty and the syndrome of the trephined. **J Clin Neurosci** 4:346–348, 1997
 47. Oh CH, Park CO, Hyun DK, Park HC, Yoon SH: Comparative study of outcomes between shunting after cranioplasty and in cranioplasty after shunting in large concave flaccid cranial defect with hydrocephalus. **J Korean Neurosurg Soc** 44:211–216, 2008
 48. Osawa M, Hara H, Ichinose Y, Koyama T, Kobayashi S, Sugita Y: Cranioplasty with a frozen and autoclaved bone flap. **Acta Neurochir (Wien)** 102:38–41, 1990
 49. Paşaoğlu A, Kurtsoy A, Koc RK, Kantaş O, Akdemir H, Oktom İS, et al: Cranioplasty with bone flaps preserved under the scalp. **Neurosurg Rev** 19:153–156, 1996
 50. Pate AR: Cranioplasty—a review of 31 cases. **Ir Med J** 67:635–637, 1974
 51. Petty PG: Cranioplasty: a follow-up study. **Med J Aust** 2:806–808, 1974
 52. Poetker DM, Pytynia KB, Meyer GA, Wackym PA: Complication rate of transtemporal hydroxyapatite cement cranioplasties: a case series review of 76 cranioplasties. **Otol Neurotol** 25:604–609, 2004
 53. Prolo DJ: Cranial defects and cranioplasty, in Wilkins RH, Rengachary SS (eds): **Neurosurgery**, ed 2. New York: McGraw-Hill, 1996, pp 2783–2795
 54. Raja AI, Linskey ME: In situ cranioplasty with methylmethacrylate and wire lattice. **Br J Neurosurg** 19:416–419, 2005
 55. Replogle RE, Lanzino G, Francel P, Henson S, Lin K, Jane JA: Acrylic cranioplasty using miniplate struts. **Neurosurgery** 39:747–749, 1996
 56. Rish BL, Dillon JD, Meirrowsky AM, Caveness WF, Mohr JP, Kistler JP, et al: Cranioplasty: a review of 1030 cases of penetrating head injury. **Neurosurgery** 4:381–385, 1979
 57. Sakamoto S, Eguchi K, Kiura Y, Arita K, Kurisu K: CT perfusion imaging in the syndrome of the sinking skin flap before and after cranioplasty. **Clin Neurol Neurosurg** 108:583–585, 2006
 58. Schiffer J, Gur R, Nisim U, Pollak L: Symptomatic patients after craniectomy. **Surg Neurol** 47:231–237, 1997
 59. Schirmer CM, Ackil AA, Malek AM: Decompressive craniectomy. **Neurocrit Care** 8:456–470, 2008
 60. Scott M, Wycis H, Murtagh F: Long term evaluation of stainless steel cranioplasty. **Surg Gynecol Obstet** 115:453–461, 1962
 61. Segal DH, Oppenheim JS, Murovic JA: Neurological recovery after cranioplasty. **Neurosurgery** 34:729–731, 1994
 62. Shaffrey ME, Persing JA, Shaffrey CI, Delashaw JB, Jane JA: Craniofacial reconstruction, in Apuzzo MLJ (ed): **Brain Surgery: Complication and Avoidance Management**. New York: Churchill Livingstone, 1993, pp 1373–1398
 63. Staffa G, Nataloni A, Compagnone C, Servadei F: Custom made cranioplasty prostheses in porous hydroxy-apatite using 3D design techniques: 7 years experience in 25 patients. **Acta Neurochir (Wien)** 149:161–170, 2007
 64. Stiver SI, Wintermark M, Manley GT: Reversible monoparesis following decompressive hemicraniectomy for traumatic brain injury. **J Neurosurg** 109:245–254, 2008
 65. Suzuki N, Suzuki S, Iwabuchi T: Neurological improvement after cranioplasty. Analysis by dynamic CT scan. **Acta Neurochir (Wien)** 122:49–53, 1993
 66. Vahedi K, Vicaut E, Mateo J, Kurtz A, Orabi M, Guichard JP, et al: Sequential-design, multicenter, randomized, controlled trial of early decompressive craniectomy in malignant middle cerebral artery infarction (DECIMAL Trial). **Stroke** 38:2506–2517, 2007
 67. Vakis A, Koutentakis D, Karabetsos D, Kalostos G: Use of polytetrafluoroethylene dural substitute as adhesion preven-

Complications of cranioplasty after decompressive craniectomy

- tive material during craniectomies. **Clin Neurol Neurosurg** **108**:798–802, 2006
68. Vanaclocha V, Bazan A, Saiz-Sapena N, Paloma V, Idoate M: Use of frozen cranial vault bone allografts in the repair of extensive cranial bone defects. **Acta Neurochir (Wien)** **139**:653–660, 1997
69. Winkler PA, Stummer W, Linke R, Krishnan KG, Tatsch K: The influence of cranioplasty on postural blood flow regulation, cerebrovascular reserve capacity, and cerebral glucose metabolism. **Neurosurg Focus** **8**(1):e9, 2000
70. Wurm G, Tomancok B, Holl K, Trenkler J: Prospective study on cranioplasty with individual carbon fiber reinforced polymer (CFRP) implants produced by means of stereolithography. **Surg Neurol** **62**:510–521, 2004
71. Yamashita T: Modern cranioplasty with hydroxylapatite ceramic granules, buttons, and plates. **Neurosurgery** **33**:939–940, 1993
72. Zingale A, Albanese V: Cryopreservation of autogenous bone flap in cranial surgical practice: what is the future? A grade B and evidence level 4 meta-analytic study. **J Neurosurg Sci** **47**:137–139, 2003

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