Original Article

Fenestration of bone flap during interval autologous cranioplasty

Ha Son Nguyen, Ninh Doan, Christopher Wolfla, Glen Pollock

Department of Neurosurgery, Medical College of Wisconsin, Milwaukee, WI, USA

E-mail: *Ha Son Nguyen - hsnguyen@mcw.edu; Ninh Doan - ndoan@mcw.edu; Christopher Wolfla - cwolfla@mcw.edu; Glen Pollock - gpolloc1@hotmail.com
*Corresponding author

Abstract

Background: Symptomatic extra-axial fluid may complicate cranioplasty and require urgent evacuation. Fenestration (F) of the bone flap may encourage extra-axial fluid absorption; however, literature has not explored this technique.

Methods: Thirty-two consecutive patients who underwent interval autologous cranioplasty were divided into two groups: Fenestration, $n = 24$, and no fenestration (NF), $n = 8$. Fenestration involves placement of twist-drill holes 1–2 cm apart throughout the bone flap. Clinical data (age, sex, underlying pathology for cranioplasty, history of antiplatelet/anticoagulation [A/A], presence of drains, and length of Intensive Care Unit [ICU] stay) were collected. Postoperative volume and midline shift (MLS) were measured. Univariate analysis was performed for continuous variables; Fisher's exact test was performed for categorical variables.

Results: For postoperative volume, NF group exhibited 33.745 ± 48.701 cm^3; F group exhibited 20.832 ± 26.103 cm^3 ($P = 0.351$). For MLS, NF group exhibited 3.055 ± 0.472 mm; F group exhibited 0.75 ± 0.677 mm ($P = 0.009$). MLS for the NF group subset with drains was 1.235 ± 0.566 mm, ($P = 0.587$ when compared to F group). For ICU length of stay, NF group exhibited 1.958 ± 1.732 days; F group exhibited 2.290 ± 0.835 days ($P = 0.720$). In NF group, for patients with no A/A, no drain exhibited MLS 4.00 ± 0.677 mm while a drain exhibited 1.845 ± 0.605 mm ($P = 0.025$); with A/A, no drain exhibited 5.75 ± 1.353 mm while a drain exhibited 0.625 ± 0.957 ($P = 0.005$). Four NF patients required reoperation compared to zero F patients ($P = 0.550$).

Conclusion: Presumably, fenestrations augment surface area for extra-axial fluid absorption through the bone flap. Our results, regarding MLS and postoperative volume, provide support for this concept. Accordingly, bone flap fenestration has the potential to reduce extra-axial fluid accumulation.

Key Words: Autologous cranioplasty, bone flap, fenestration

INTRODUCTION

Cranioplasty involves repair of a cranial defect. Although the procedure is relatively straightforward, it has a high complication rate, including risks for infection, bone graft resorption, seizure, and extra-axial fluid accumulation.[9,22] The latter complication may require urgent reoperation for evacuation, leading to a longer length of stay, higher morbidity and mortality, and higher hospital costs.[1,6,22]

The fluid collection may be hemorrhage, which has been associated with persistent bleeding by a scalp artery or dural vein. The placement of drains, either deep to the bone flap or in the subgaleal (SG) space superficial to the bone flap, has been employed to mitigate this concern. At our institution, we have also fenestrated the bone flap to aid drainage of potential extra-axial fluid. A literature review does not elicit much description regarding this technique, which has the advantage of allowing extra-axial to drain into SG space where fluid absorption can occur.

METHODS

The approval of the Institutional Board Review at our institution was obtained prior to the study. Between fall 2012 and spring 2015, 32 patients underwent interval autologous cranioplasty at our institution. Eight neurosurgeons performed the surgeries. The patients were divided into two groups fenestration (F) and no fenestration (NF). Fenestration involves placement of twist-drill holes 1–2 cm apart throughout the bone flap [Figure 1]. Eight patients were in the F group. Patient clinical data (age, sex, underlying pathology for the cranial defect, history of antiplatelet/anticoagulation [A/A], the presence of a drain, and length of Intensive Care Unit [ICU] stay) were collected via medical chart review. Patient demographics are listed in Table 1. For patients who did not require reoperation, the postoperative computed tomography (CT) head (obtained within 1 day of the cranioplasty) was evaluated for postoperative volume and midline shift (MLS) using a picture archiving and communication system. For patients who did require reoperation, the CT prior to reoperation was evaluated. Postoperative volume was calculated based on the XYZ/2 method as previously described.[19] Briefly, this method involves using the product of the widest (X), longest (Y), and thickest (Z) dimensions of the extra-axial

fluid collection, divided by 2. The thickest dimension was calculated by multiplying the slices on which the collection was visible by the slice thickness (5 mm). The postoperative volume includes both hematoma and pneumocephalus. MLS was calculated at the axial CT slice that visualizes the foramen of Monro.

Data were entered into SPSS version 22 (IBM Corporation, Armonk, NY, USA) for analysis. Results were expressed as means ± standard error for all descriptive continuous variables. Univariate analysis was performed for continuous variables. Analysis of categorical variables was performed using Fisher's exact test. A $P < 0.05$ was considered statistically significant.

RESULTS

Table 1 summarizes the patient demographics. NF group consisted of 24 patients (14 males, 10 females); F group consisted of 8 patients (5 males, 3 females). Average age was 35.2 and 37.8 years, respectively ($P = 0.703$). Six patients had a history of A/A usage in the NF group, while no patients had such a history in the F group. Four patients required reoperation due to extra-axial fluid accumulation underneath their cranioplasty in the NF group; none required reoperation in the F group ($P = 0.550$). For drain placement, NF group had 14 patients with drains (11 with an SG drain only, three with an SG drain and a subdural drain [SDD]); F group had all 8 patients with SG drain only. Overall, the most common underlying pathology for subsequent interval cranioplasty was traumatic brain injury, followed by a vascular abnormality (arterio-venous malformation rupture or aneurysmal rupture).

Tables 2 and 3 summarizes the results. For postoperative volume, NF group exhibited 33.745 ± 48.701 cm³;

Figure 1: Lateral skull X-ray demonstrates fenestration of the bone flap

Table 1: Patient demographics

	NF	F
Age (years)	35.2	37.8
Total patients	24	8
Males	14	5
Females	10	3
History of antiplatelet/anticoagulation	6	0
Reoperation	4	0
Drains	14	8
SG drain	11	8
SG drain/SDD	3	0
TBI	18	3
Ischemic stroke	4	0
Aneurysmal rupture	1	2
Epilepsy	1	0
AVM rupture	0	3

F: Fenestration, NF: No fenestration, TBI: Traumatic brain injury, AVM: Arterio-venous malformation, SG: Subgaleal, SDD: Subdural drain

Table 2: Results

Parameters	NF		F		P
	Value	SD	Value	SD	
Postoperative volume (cm³)	33.745	48.701	20.834	26.103	0.351
Postoperative MLS (mm)*	3.055	0.472	0.750	0.677	0.009
Subset with drains (mm)*	1.235	0.566	0.750	0.677	0.587
ICU length of stay (days)	1.958	1.732	2.290	0.835	0.720

*Value is the same in F group since all patients had drains. MLS: Midline shift, ICU: Intensive Care Unit, SD: Standard deviation, F: Fenestration, NF: No fenestration

Table 3: Antiplatelet/anticoagulation, drain status, and MLS in NF group

Antiplatelet/anticoagulation	Drain	MLS (mm)	SD	P
Yes	No	5.75	1.353	0.258
No	No	4.00	0.677	
No	No	4.00	0.677	0.025
	Yes	1.845	0.605	
Yes	No	5.75	1.353	0.005
	Yes	0.625	0.957	

SD: Standard deviation, MLS: Midline shift, NF: No fenestration

F group exhibited 20.832 ± 26.103 cm³ (P = 0.351). For postoperative MLS, NF group exhibited 3.055 ± 0.472 mm; F group exhibited 0.75 ± 0.677 mm (P = 0.009). All F group had drains, while 14 patients in NF group had drains; All F group had drains, while 14 patients in NF group had drains; the MLS for this NF group subset was 1.235 ± 0.566 mm, (P = 0.587 when compared to F group). For ICU length of stay, NF group exhibited 1.958 ± 1.732 days; F group exhibited 2.290 ± 0.835 days (P = 0.720). No patients in the F group had a history of A/A therapy; NF group had 6 patients with that history. In that NF group, univariate analysis revealed that with no history of A/A, no drain exhibited MLS 4.00 ± 0.677 mm while a drain exhibited 1.845 ± 0.605 mm (P = 0.025); with history of A/A use, no drain exhibited 5.75 ± 1.353 mm while a drain exhibited 0.625 ± 0.957 (P = 0.005). In the NF group subset with no drains, those with a history of A/A exhibited MLS 5.75 ± 1.353 mm, while those without such history exhibited MLS 4.00 ± 0.677 mm (P = 0.258). Overall, standard deviations for values were skewed largely due to the 4 patients in the NF group who required reoperation. These 4 patients underwent an additional procedure due to deterioration of mental status (2 patients), new hemiparesis (1 patient), and seizure activity (1 patient) in the context of pronounced extra-axial fluid accumulation; two underwent bedside twist-drill craniostomy for epidural drain placement; two returned to the operating room for fluid evacuation.

DISCUSSION

The overall complication rates for cranioplasty range between 16% and 34% based on various studies.[1,6,9,12,22]

Complications include new-onset seizures, infection, implant extrusion, delayed hydrocephalus, intracranial hemorrhage (subdural, epidural, or intraventricular hemorrhage), and death.[12,22] In particular, the rates for postoperative surgical site hematoma/extra-axial fluid accumulation range from 1.65% to 46.7%; moreover, the reoperation rates for this subset have been as high as 22%.[1-3,6,8-13,16,17,21,22] Possible mechanisms have been postulated for postoperative extra-axial fluid. If the fluid is blood, the etiology may be persistent hemorrhage emanating from a scalp artery or dural vein, which can be perpetuated by a negative pressure from an SG drain.[17] However, the fluid may be a contribution of various factors. Cerebrospinal fluid may leak through dural openings from previously damaged dura or produced during the surgery by tack-up sutures.[11] Alternatively, postoperative exudate from the dissected SG space and muscle may accumulate; this may be compounded by dural stiffness secondary to dural calcification, which hamper brain re-expansion.[9,11] In addition, air bubbles within the epidural space may elicit an inflammatory response, leading to the production of exudate.[11]

Details regarding surgical technique for cranioplasty have been generalized through literature. To our knowledge, the modification for fenestration of the autologous bone flap has not been reported. Several synthetic implants possess fenestration through the implant, including polyether ether ketone implants and titanium mesh; however, limited data exists regarding reoperation rates due to extra-axial fluid accumulation.[15,20] Presumably, the fenestrations provide more surface area for drainage of extra-axial fluid through the bone flap. This increases the potential for drainage through an SG drain. Moreover, the galea does have the potential for fluid absorption. For example, ventriculo-SG shunts have been employed effectively for the short-term treatment of posthemorrhagic hydrocephalus for preterm infants.[14] In addition, the creation of communication between the subdural space and the subtemporalis area via a small temporal craniectomy has been shown to be effective for drainage of chronic subdural hematoma.[18] Consequently, fluid absorption may be persistent after drains are removed. In our study, the F group exhibited a lower residual postoperative volume compared to the NF group without reaching statistically significance. On the other hand, the difference regarding MLS did reach statistically significance. For the subset with drains in NF group, compared to the F group (where all patients had drains), MLS lower in the latter group without reaching statistically significance. The results imply that fenestration of the bone flap may reduce the potential for accumulation of extra-axial fluid.

The impact of drain placement during cranioplasty has not been heavily emphasized in literature. There is a

technical risk, as drains can be caught in superficial sutures, which require an additional procedure for removal.[12] Broughton *et al.*,[1] in a review regarding 7 years of cranioplasty, associated two deaths with drain placement; the authors postulated that suction from the drain lead to a lethal brain shift, especially if a sizable, sunken defect was present prior to surgery; however, no causal relationship was elucidated. Our technique may minimize this complication as the drain sits in the SG and exerts its negative pressure through the fenestrated bone flap, providing more of a global suction to the brain. Compared to an SDD, an SG drain avoids applying focal negative pressure directly on the brain surface or cortical vessels, which can be sources of complication. Klinger *et al.*[10] evaluated autologous and acrylic cranioplasty in 258 cases; SG and SDDs were utilized in 71% of cases but did not show a significant influence on the rate of hematoma formation (3.3% vs. 4%). The authors cautioned that evaluating the efficacy of drain placement is problematic since it may not predict a surgeon's bias for thorough hemostasis intraoperatively.[10] On the other hand, Chang *et al.*[2] analyzed 212 cases with cranial repair after craniectomy; the group found that the risk of fluid collection among patients with drains was 2.4% compared with 8.6% in those without drains, where the difference tended toward statistical significance on univariate analysis; however, on multivariate analysis, drain placement was a statistically significant protective factor.[2]

Prior large series did not explore the impact of antiplatelet therapy/anticoagulation on the accumulation of postoperative extra-axial fluid after cranioplasty. In our study, no obvious relationship can be studied with bone flap fenestration, as no patients in the F group had a history of A/A therapy. However, the NF group had 6 patients with that history. In NF group, univariate analysis revealed that with no history of A/A, no drain exhibited a statistically significant larger MLS compared to those with a drain. In addition, univariate analysis revealed that with a history of A/A use, a similar relationship existed regarding the presence of a drain. For NF patients without a drain, presence of antiplatelet therapy/anticoagulation exhibited a larger MLS without reaching statistical significance. An observation of higher MLS is reasonable since antiplatelet therapy/anticoagulation has been linked to higher bleeding risks in prior studies.[4,5,7] The results suggest that drain placement reduces postoperative MLS despite a history of antiplatelet therapy/anticoagulation, and may reduce the potential for the accumulation of postoperative extra-axial fluid accumulation.

Studies by Gooch *et al.*[6] and Broughton *et al.*[1] imply that postoperative complications from cranioplasty increased hospital length of stay and morbidity. Moreover, additional procedures may be associated with a higher mortality rate.[22] We elected to evaluate ICU length of stay as opposed to overall hospital length of stay, given that the latter can be influenced by social reasons (rehabilitation goals, insurance requirements, power-of-attorney status, etc.). After a cranioplasty, all patients at our facility stay overnight in the ICU for close observation. If the drain is kept in place, the patient remains in the ICU until the drain is removed. Our results show no statistical significance regarding overall ICU stays and bone flap fenestration.

The limitations of this study include the retrospective analysis, entailing possible selection bias, and loss of patient data. We did not have stratification related to hypertension, tobacco history, or diabetes. We did not study the timing of interval cranioplasty, use of dural adhesion preventive material, or size of the autologous bone flap. Primary pathology for initial craniectomy also varied among patients. Moreover, operative techniques were varied among surgeons; overall, the common practices to avoid fluid accumulation included meticulous hemostasis and avoidance of dural penetration. It is unclear, based on prior literature,[1-3,6,8-13,16,17,21,22] whether our patient population exhibited more extra-axial fluid than expected. No prior studies have quantified extra-axial fluid volume after cranioplasty. The available data only addressed the incidence of fluid accumulation and the rate of reoperation; no criteria exist regarding "threshold volume" that defines "fluid accumulation" in these studies.[1-3,6,8-13,16,17,21,22] Our study sought to measure any and all extra-axial fluid, even the minimal volume expected from postoperative changes which some may consider clinically benign and insignificant. Nevertheless, the reoperation rates (up to 22%) in literature are similar to our rate for the NF group (16.7%), which suggests that our patient population may exhibit comparable accumulation of extra-axial fluid compared to those of prior studies.[1-3,6,8-13,16,17,21,22]

CONCLUSION

Details regarding surgical technique for cranioplasty have been generalized through literature. To our knowledge, the modification for fenestration of the autologous bone flap has not been reported. Presumably, the fenestrations provide more surface area for drainage of extra-axial fluid through the bone flap. More importantly, potential complications due to the negative pressure and drain placement can be minimized, as the fenestrated bone flap acting as a grid allowing fluid to flow through and removed by the drain placed in the SG space. This technique avoids the drain from applying direct focal negative pressure on the brain surface or cortical vessels. Our results demonstrated a trend for lower postoperative extra-axial fluid accumulation, as well as a statistically smaller MLS, for patients with bone flap fenestration, as opposed to those without fenestration. Moreover, drain

placement, after accounting for the history of A/A use, appears to correlate with smaller MLS. Accordingly, we believe bone flap fenestration has the potential to reduce extra-axial fluid accumulation. Similar to ventriculo-SG shunts, fluid absorption may also persist after drains removed due to the continuous shunting of extra-axial fluid through the fenestrated bone flap into SG space, where fluid absorption can occur. Randomized control studies should evaluate this technique as a modification to cranioplasty procedure.

Financial support and sponsorship
Nil.

Conflicts of interest
There are no conflicts of interest.

REFERENCES

1. Broughton E, Pobereskin L, Whitfield PC. Seven years of cranioplasty in a regional neurosurgical centre. Br J Neurosurg 2014;28:34-9.
2. Chang V, Hartzfeld P, Langlois M, Mahmood A, Seyfried D. Outcomes of cranial repair after craniectomy. J Neurosurg 2010;112:1120-4.
3. Chun HJ, Yi HJ. Efficacy and safety of early cranioplasty, at least within 1 month. J Craniofac Surg 2011;22:203-7.
4. Connolly BJ, Pearce LA, Hart RG. Vitamin K antagonists and risk of subdural hematoma: Meta-analysis of randomized clinical trials. Stroke 2014;45:1672-8.
5. Flaherty ML. Anticoagulant-associated intracerebral hemorrhage. Semin Neurol 2010;30:565-72.
6. Gooch MR, Gin GE, Kenning TJ, German JW. Complications of cranioplasty following decompressive craniectomy: Analysis of 62 cases. Neurosurg Focus 2009;26:E9.
7. Jaben EA, Mulay SB, Stubbs JR. Reversing the effects of antiplatelet agents in the setting of intracranial hemorrhage: A look at the literature. J Intensive Care Med 2015;30:3-7.
8. Jaberi J, Gambrell K, Tiwana P, Madden C, Finn R. Long-term clinical outcome analysis of poly-methyl-methacrylate cranioplasty for large skull defects. J Oral Maxillofac Surg 2013;71:e81-8.
9. Kim SP, Kang DS, Cheong JH, Kim JH, Song KY, Kong MH. Clinical analysis of epidural fluid collection as a complication after cranioplasty. J Korean Neurosurg Soc 2014;56:410-8.
10. Klinger DR, Madden C, Beshay J, White J, Gambrell K, Rickert K. Autologous and acrylic cranioplasty: A review of 10 years and 258 cases. World Neurosurg 2014;82:e525-30.
11. Lee JW, Kim JH, Kang HI, Moon BG, Lee SJ, Kim JS. Epidural fluid collection after cranioplasty: Fate and predictive factors. J Korean Neurosurg Soc 2011;50:231-4.
12. Lee L, Ker J, Quah BL, Chou N, Choy D, Yeo TT. A retrospective analysis and review of an institution's experience with the complications of cranioplasty. Br J Neurosurg 2013;27:629-35.
13. Martin KD, Franz B, Kirsch M, Polanski W, von der Hagen M, Schackert G, et al. Autologous bone flap cranioplasty following decompressive craniectomy is combined with a high complication rate in pediatric traumatic brain injury patients. Acta Neurochir (Wien) 2014;156:813-24.
14. Nagy A, Bognar L, Pataki I, Barta Z, Novak L. Ventriculosubgaleal shunt in the treatment of posthemorrhagic and postinfectious hydrocephalus of premature infants. Childs Nerv Syst 2013;29:413-8.
15. Ng ZY, Ang WJ, Nawaz I. Computer-designed polyetheretherketone implants versus titanium mesh (± acrylic cement) in alloplastic cranioplasty: A retrospective single-surgeon, single-center study. J Craniofac Surg 2014;25:e185-9.
16. Piitulainen JM, Kauko T, Aitasalo KM, Vuorinen V, Vallittu PK, Posti JP. Outcomes of cranioplasty with synthetic materials and autologous bone grafts. World Neurosurg 2015;83:708-14.
17. Rammos CK, Cayci C, Castro-Garcia JA, Feiz-Erfan I, Lettieri SC. Patient-specific polyetheretherketone implants for repair of craniofacial defects. J Craniofac Surg 2015;26:631-3.
18. Sambasivan M. An overview of chronic subdural hematoma: Experience with 2300 cases. Surg Neurol 1997;47:418-22.
19. Sucu HK, Gokmen M, Gelal F. The value of XYZ/2 technique compared with computer-assisted volumetric analysis to estimate the volume of chronic subdural hematoma. Stroke 2005;36:998-1000.
20. Thien A, King NK, Ang BT, Wang E, Ng I. Comparison of polyetheretherketone and titanium cranioplasty after decompressive craniectomy. World Neurosurg 2015;83:176-80.
21. Walcott BP, Kwon CS, Sheth SA, Fehnel CR, Koffie RM, Asaad WF, et al. Predictors of cranioplasty complications in stroke and trauma patients. J Neurosurg 2013;118:757-62.
22. Zanaty M, Chalouhi N, Starke RM, Clark SW, Bovenzi CD, Saigh M, et al. Complications following cranioplasty: Incidence and predictors in 348 cases. J Neurosurg 2015;123:182-8.