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Technical Note

The floating anchored craniotomy

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Received: 19 November 16 Accepted: 01 February 17 Published: 27 June 17

Abstract

Background: The "floating anchored" craniotomy is a technique utilized at our tertiary neurosurgery institution in which a traditional decompressive craniectomy has been substituted for a floating craniotomy. The hypothesized advantages of this technique include adequate decompression, reduction in the intracranial pressure, obviating the need for a secondary cranioplasty, maintained bone protection, preventing the syndrome of the trephined, and a potential reduction in axonal stretching.

Methods: The bone plate is re-attached via multiple loosely affixed vicryl sutures, enabling decompression, but then ensuring the bone returns to its anatomical position once cerebral edema has subsided.

Results: From the analysis of 57 consecutive patients analyzed at our institution, we have found that the floating anchored craniotomy is comparable to decompressive craniectomy for intracranial pressure reduction and has some significant theoretical advantages.

Conclusions: Despite the potential advantages of techniques that avoid the need for a second cranioplasty, they have not been widely adopted and have been omitted from trials examining the utility of decompressive surgery. This retrospective analysis of prospectively collected data suggests that the floating anchored craniotomy may be applicable instead of decompressive craniectomy.

Key Words: Anchored floating craniotomy, decompressive craniectomy, floating bone craniotomy, trauma craniotomy

Access this article online
Website:
www.surgicalneurologyint.com
DOI:
10.4103/sni.sni_460_16
Quick Response Code:

INTRODUCTION

Primary and secondary decompressive craniectomy is an accepted treatment modality for raised intracranial pressure (ICP) for a variety of indications,[1,2,8,19,22,31] including that of severe traumatic brain injury.[20] Traditional techniques involve removing a large segment of bone combined with dural expansion, followed by hemostatic skin closure. It theoretically improves brain compliance and cerebral blood flow, decreases ICP, and may reduce the incidence of secondary brain injury.[17,29] If the patient survives, a return to theatre is usually required for a cranioplasty.

This article describes a single tertiary neurosurgery unit's experience with the floating anchored craniotomy. The hypothesized advantages of this technique include adequate

How to cite this article: Gutman MJ, How E, Withers T. The floating anchored craniotomy. Surg Neurol Int 2017;8:130.
http://surgicalneurologyint.com/The-floating-anchored-craniotomy/

cranial decompression and reduction in ICP, obviating the need for a secondary cranioplasty, maintaining bone protection, preventing the syndrome of the trephined, and a potential reduction in axonal stretching. Controversy regarding the true utility and timing of decompressive craniectomy in trauma and other populations has intensified.[7,11,17,19] Reducing the morbidity associated with craniectomy could potentially improve overall patient outcomes.

MATERIALS AND METHODS

We have retrospectively analyzed the records of all trauma patients who presented to our hospital that underwent decompression with the "floating anchored" craniotomy from 1st of December 2004 to the 1st of December 2013. Patients were initially identified via the electronic ORMIS database, and individual records and operation reports were individually analyzed. Out of a total of 705 operative neurosurgical procedures performed in the context of trauma (44 decompressive craniectomies, 354 standard craniotomies), 57 patients were identified as having undergone the floating anchored craniotomy. None were excluded from analysis.

One senior (full time) consultant routinely performed this procedure over the 10-year period studied. As preliminary positive results of this technique emerged with good clinical outcomes, additional senior neurosurgeons began to adopt this technique. Registrars were also trained and supervised to perform this technique.

Where appropriate, patients were medically treated based on the principles of Brain Trauma Foundation guidelines in intensive care.[4] There were 43 survivors, and post-discharge they were followed up in the outpatients department for a mean of 21.7 months, except for 10 patients who were followed up externally.

Patients' records were analyzed for mean preoperative and postoperative intracranial pressure (calculated via graphical interpretation of recorded data for the duration of ICP monitor insertion), Rotterdam score[18] and change in midline shift on cranial computerized tomography (defined by the distance of septum pellucidum from the midline, measured by a radiologist and member of the neurosurgical team), length of sedation, survival rates, and postoperative disability (modified Rankin score). Data was analyzed with the Statistical Package for the Social Sciences ver. 13.0 software (IBM Software Group's Business Analytics Portfolio, Armonk, NY, USA), and chi square tests were used. Institutional ethics approval was sought and met.

Description of technique

The technique for "floating bone" decompression craniotomy has been developed by the senior neurosurgeon and the requirements for the procedure is adhered to by the trainees in the unit.

Standard set-up, positioning and shaving of the affected side was performed. Preparation and marking of a standard trauma flap, aiming for a large (> 12 x 15cm) frontotemporoparietal craniotomy. A crucial step was to dissect the skin flap with a 10cm clearance around skin edges, which allows the skin to expand to accommodate the elevated intracranial pressure [Figure 1]. The bevel of the craniotomy was angled to the centre of the craniotomy during drilling to ensure the superficial outer table was drilled with wider margins than the inner table to avoid delayed bone sinking. In cases where skin proximity to the craniotomy edge did not allow for inward drill angulation, a standard cranial fixation titanium plate (maximum of 3) was affixed to the craniotomised bone [Figure 2].

The dura was opened at the last moment once all preparation was performed [Figure 3], in case malignant cerebral oedema necessitates rapid skin closure. Haematomas were evacuated expediently and closure commenced promptly.

A high speed drill with a fine craniotome piece is utilized to perform 3-4 small holes on the bone edge and symmetrically drill on the bone flap. These are connected and aligned with loose vicryl ties, which were threaded through the bone edge and craniotomy plate, and then clipped together loosely.

The dura was then incised and evacuation of clot performed if required. The dural flap was loosely re-placed over the brain, with any gap covered with gelfoam or a dural substitute. In most cases, an ICP monitor was placed in adjacent parenchyma. The bone was then placed in the appropriate position and the vicryl loosely tied (with 1-2cm of slack) allowing for controlled brain expansion and ensuring the bone plate remains in anatomical alignment [Figure 4]

Subgaleal drains were routinely inserted. Skin was closed haemostatically forgoing routine temporalis approximation to avoid impediment to adequate cranial expansion. Routine dressings were applied with a label indicating "floating bone" as an alert to avoid pressure over the area.

RESULTS

This case series represents all the patients undergoing the 'floating anchored' craniotomy in the 10-year period. The

Table 1: Patient demographics

Category	Value
Male-to-female Ratio	3.9:1
Mean age (years)	37.2±23.4
No. of patients with preoperative GCS ≤8	32
Mean CT Rotterdam Score[17]	3.6±1.2
Mean preoperative MLS (mm) (n=48)	7.3±5.57
Mean preoperative ICP (mmHg)	32.2±7.3

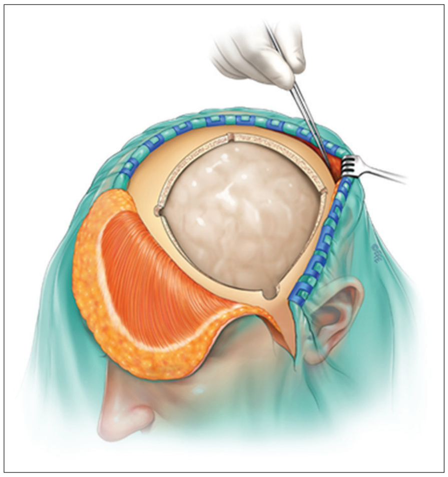

Figure 1: Subgaleal pocket raised with 10 cm clearance around all edges to allow scalp stretching when bone re-placed

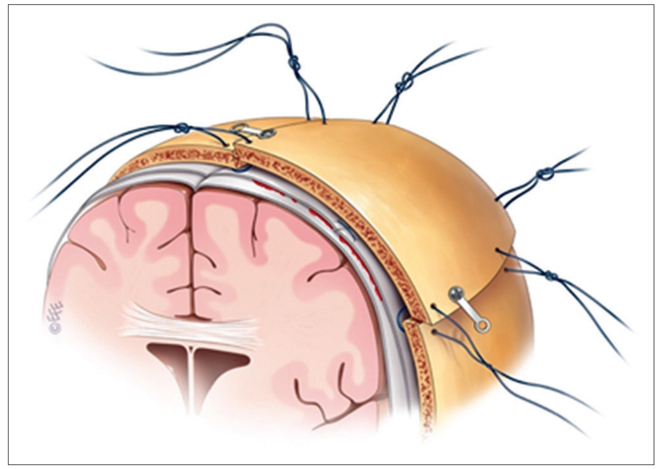

Figure 2: Placement of craniotomy bone with loose vicryl ties. Note the presence in this case of the affixed titanium plates to prevent bone sinking

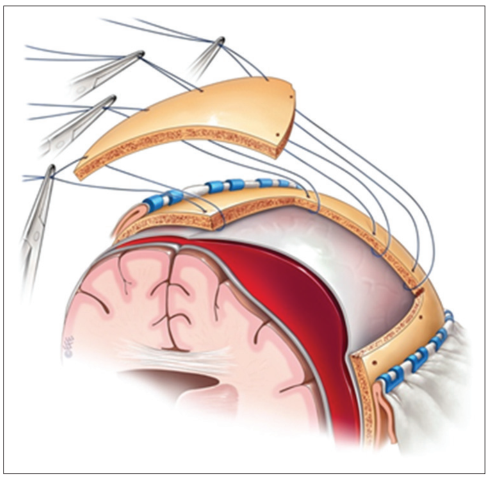

Figure 3: Vicryl sutures and bone drilled prepared and attached prior to dural opening

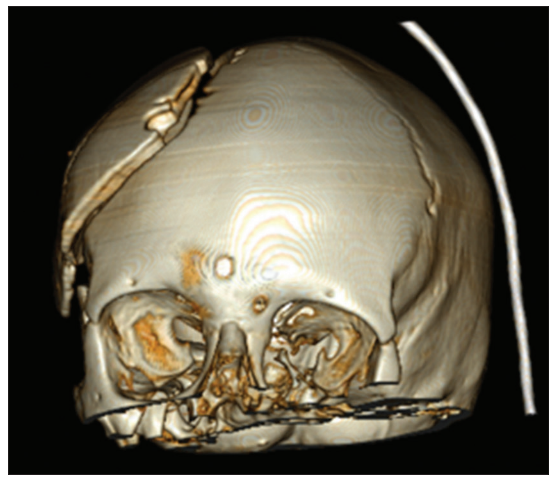

Figure 4: Three-dimensional reconstruction computerized tomography of postoperative result demonstrating cranial vault expansion

key demographics of patients are summarized in Table 1 and survival rates and key outcomes summarized in Table 2.

Eleven patients had ICP monitors inserted on admission, followed by craniotomies for intractable elevated intracranial pressure (mean 32.2 ± 7.3 mmHg). Nine of those patients had ongoing intracranial pressure monitoring post floating anchored craniotomy. A significant reduction in intracranial pressure was achieved from 32.7 ± 8.1 mmHg to 17.2 ± 4.7 mmHg, with a mean improvement of 15.4 ± 7.4 mmHg ($P < 0.001$).

An additional twenty-one patients had ICP monitors only inserted during the craniotomy. The mean recorded of all post-craniotomy ICP was 16.0 ± 12.1 mmHg. Only 1 patient had a mean ICP >25mmHg post operatively, and the patient did not survive [Figure 5].

Pre and post craniotomy images of 41 patients were reviewed. Eight had a pre-craniotomy midline shift of 0mm. Of the remaining 33 patients, the mean improvement in midline shift was 5.9 ± 4.4 mm ($P < 0.001$) [Figure 6].

Overall, 7 patients had a return to theatre post floating anchored craniotomy. There were no cases of malposition requiring revision surgery during follow-up. Patient 1 originally underwent a right floating anchored craniotomy for an ICP of 38 mmHg. The ICP improved to a mean of 24 mmHg, however, blossoming of a right temporal contusion caused a rise in ICP, peaking at 32 mmHg. An external ventricular drain (EVD) was then inserted, which reduced the ICP to a mean of 17 mmHg. Patient 2 suffered a traumatic right subdural hematoma and intraventricular hemorrhage. He underwent a right floating anchored craniotomy for evacuation of the subdural hematoma, and postoperative ICP was 26 mmHg. He unfortunately developed delayed hydrocephalus 2 days later, and an EVD was inserted with satisfactory ICP correction. Patient 3 jumped into a rockpool and suffered complex right facial and skull fractures with an underlying extradural hemorrhage. Post evacuation and floating anchored craniotomy, he returned to theatre 21 days later for a washout and debridement of a superficial wound infection over his craniotomy site. The bone plate was washed and replaced with the floating anchored technique again with no further complication. Patient 4 suffered a right subdural hematoma and a left compound parietal skull fracture. She underwent a right floating anchored craniotomy and left craniectomy given the compound fracture. She returned to theatre 1 week later for washout and debridement of a superficial infection of the left craniectomy site. Patient 5 initially underwent a right frontal floating anchored craniotomy and returned to the theatre 1 day later for a left-sided craniotomy and evacuation of left subdural hematoma. Patient 6 had a limited left floating anchored craniotomy (temporal fossa not adequately decompressed) and evacuation of a subdural hematoma. He had to return to the theatre 3 hours later for an increasing ICP and had a re-drainage of the hematoma as well as an extended craniectomy. His ICP subsequently improved to 6 mmHg. Patient 7 presented with a GCS of 6 and had a right acute on chronic SDH, which was evacuated via a floating anchored craniotomy. He returned to theatre the next day for evacuation of a large subgaleal hematoma. He died from ventilator-associated pneumonia. Of the remaining 6 patients requiring a return to theatre, all survived with a mean modified Ranking score of 2 on discharge.

Fourteen patients did not survive the postoperative period. The mean GCS preoperatively of these patients was 5 (range: 3–14).

Postoperative ICP wase not significantly higher in the nonsurvivor group ($P = 0.4$). There was also no significant difference in ICP improvement between survivors and nonsurvivors (16.6 ± 6.9 mmHg vs 6 mmHg, $P = 0.2$). There was no significant difference between improvement of midline shift between survivors and nonsurvivors (6.0 ± 4.6 mm vs 5.8 ± 3.9 mm, $P = 0.9$).

There were a total of 44 survivors. On discharge from the hospital, only 2 patients had a modified Rankin Score of 4 and 5 (4.5%). On outpatient follow-up, 21 patients demonstrated an improvement in modified Rankin score to 0–2 [Table 3].

Table 2: Patient survival rates and key outcomes

Category	Value
No. of survivors	44 (77.2%)
Mean postoperative MLS (mm)	2.6±3.8
Mean postoperative ICP (mmHg)	16.0±12.1
Mean postoperative ICP (mmHg) in survivors	14.0±5.0
Mean postoperative ICP (mmHg) in non-survivors	20.6±20.9
No. of patients with mRS <4 at discharge	40

Table 3: Breakdown of modified Rankin score (mRS) of the survivors at discharge and follow up

mRS	Pre-discharge	Post-discharge
0	3	10
1	14	16
2	14	6
3	9	2
4	1	1
5	1	0
6	13	13
N/A	2	10

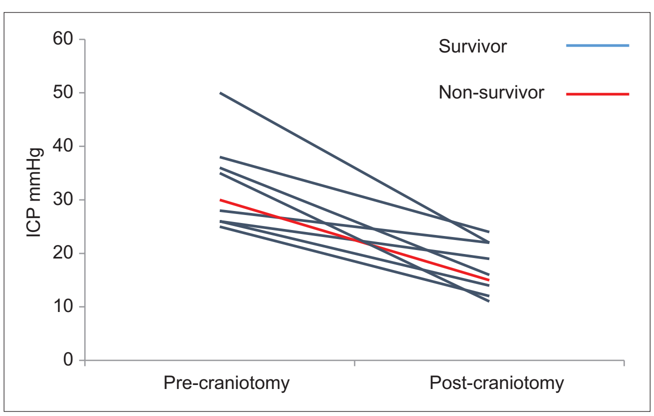

Figure 5: Change in intracranial pressure pre and post floating anchored craniectomy

DISCUSSION

Decompressive craniectomy has been widely utilized for treating malignant raised ICP since first described by Kocher in 1901 and Cushing in 1908. Decompressive craniotomy is a traditional neurosurgical procedure, but can be associated with significant complications. These include hemorrhagic blossoming of intracranial

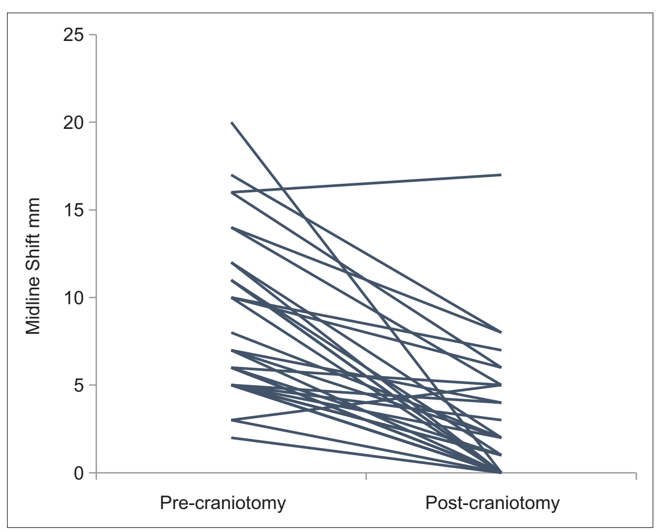

Figure 6: Improvement in midline shift

hematomas, external herniation and infarction, subdural hygromas, infection, and the syndrome of the trephined.[29] Modern modifications to this technique have aimed to minimize morbidity.[20] An example is the “hinge craniotomy” that utilizes hinged titanium plates to allow cerebral decompression while maintaining cerebral protection and reducing postoperative complications[26] and is comparable to decompressive craniectomy in ICP reduction.[20] Other techniques utilizing custom modified resin implants,[3] titanium hinged devices,[25] and free placement of the bone without affixation to the skull,[30] have also been explored and reported aiming to minimize craniectomy or cranioplasty-associated morbidity. The technique of “floating” the bone allows controlled volume expansion while minimizing stretching and damage to edematous brain. It differs from the hinged craniotomy and osteoplastic craniotomy in that bone floats symmetrically. The crucial area to ensure decompression is the temporal fossa to alleviate the pressure on the uncus.

A potential limitation of this technique is the possibility for malposition of the bone flap or pseudoarthrosis requiring surgical intervention. There were no cases requiring fixation with titanium plates in our series, however, one patient did complain of malposition of the flap, which was manually re-positioned in the outpatient setting, avoiding the need for surgical intervention. Limiting the “slack” of the vicryl sutures to 1–2 cm with three symmetrical fixation points likely facilitates correct anatomical alignment.

The floating anchored craniotomy appears comparable to decompressive craniectomy for ICP reduction but has some significant potential advantages.

Elimination of the need for secondary cranioplasty and storage of the bone flap

The incidence of complications after cranioplasty is significant, reportedly ranging 12–50%.[23,31] Early cranioplasty in particular is associated with higher risks of infection and osteomyelitis, while delayed cranioplasty associated with higher bone resorption rates,[13] development of subdural hygromas,[19] and increased incidence of hydrocephalus in the stroke and traumatic brain injury populations.[29,32] Additional general anesthetic in a potentially physiologically fragile individual could also be a major delay to potential neurorecovery, resulting in significant increase in hospital stay and morbidity. There are even reports of patient deaths post cranioplasty.[15,16,35] Storing autologous bone or creating an artificial construct are costly and carries significant infection risk with re-implantation.[31]

Potential for reduced axonal stretching

It has been speculated that axonal stretch may be a contributing factor to morbidity post decompressive craniectomy in the trauma population.[9] This hypothesis is based upon clinical outcomes[7] and *in-vitro* analysis,[6] and it has been reported that the central nervous system will sustain potential damage under a long duration of stretch such as in the post-craniectomy state which may result in unfavorable clinical outcomes.[14] By leaving the bone *in situ* with self-adjusting control (via the 2–3 cm loose vicryl ties) reduction in ICP may be achieved while reducing potential axonal stretch and subsequent neurologic damage.

Reduced craniectomy associated syndromes

Subdural hygromas are the most common complication after decompressive craniectomy[3] thought to be a disturbance of cerebrospinal fluid dynamics by the extensive craniectomy.[29] They occur in 50% of patients with decompressive craniectomy, and approximately 13% may require intervention with burr hole drainage.[34] Hemorrhagic contusions are also a common occurrence after decompressive craniectomy following traumatic brain injury. Any tamponade effect is potentially lost once the bone flap is removed, which may initiate blossoming of contusions or intracranial hematomas causing mass effect and ongoing raised pressure.[10,29]

Syndrome of the trephined

Syndrome of the trephined is a common delayed complication of craniectomy.[29] The constellation of symptoms include severe headache, dizziness, psychiatric symptoms, irritability, memory disturbance, poor concentration, and undue fatigue.[12,29,33] Many of these symptoms are reversible with cranioplasty. Post-craniectomy changes in atmospheric pressure, altered cerebrospinal fluid (CSF) circulation or changes in cerebral blood flow are possible explanations for this phenomenon.[28] Patients with “motor trephine syndrome,” who develop delayed motor weakness following decompressive craniectomy, have even been reported to experience rapid, dynamic improvement in their weakness within a few days of cranioplasty.[29] This phenomenon may be reduced or avoided by utilizing a technique in which bone removal is not performed.

The mortality rate of 25% with the floating anchored craniotomy is comparable to traditional craniectomy series. Yang *et al*. performed an analysis of surgical complications secondary to traditional decompressive craniectomy in severe head injury, with 23% not surviving the first month.[33] Qunitard *et al*. reported that decompressive craniectomy was only performed in 2% of their studied population presenting with severe traumatic brain injury; of these 20 patients, mortality was 50%.[24] Danish *et al*. performed a systematic review examining neurological outcome of 1422 patients after hemi-craniectomy performed in adults for severe traumatic brain injury and uncontrollable intracranial hypertension. Mean 6-month postoperative mortality in this series was 28.2%.[27]

The floating anchored craniotomy has the potential to offer safe acceptable decompression, reducing both ICP and subsequent complications, avoiding the complications and cost associated with routine second stage surgery.

CONCLUSION

Despite the potential advantages of techniques that avoid the need for a second cranioplasty, they have not been widely adopted and have been omitted from trials examining the utility of decompressive craniectomy.[5,7,21] This retrospective analysis of a single neurosurgical unit's case experience and suggests that the floating anchored craniotomy may be applicable in place of decompressive craniectomy in certain cases. Long-term prospective investigation is warranted to better ascertain its ultimate utility and safety, including comparative analysis to traditional craniectomy.

Financial support and sponsorship
Nil.

Conflicts of interest
There are no conflicts of interest.

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