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Autologous versus synthetic cranioplasty. Single centre study and literature review

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Abstract

Background. Cranioplasty has been described in history as far back as the 16th century. The use of autologous cranioplasty has been published since 1821 and is still under practice today worldwide. Recent evidence however has suggested increased complication and revision rates with the use of autologous bone. We compared our results of autologous cranioplasty versus synthetic material.

Methods. A retrospective study was carried out of cranioplasty procedures at our unit between August 2009 and March 2018. Bone flaps were placed in a sterile sealed plastic container and stored at -81 degrees. Swabs and bone chips were used for cultures and bone flap disposed if positive. On re-implantation, the bone was thawed at room temperature and soaked in gentamicin. Synthetic cranioplasties were constructed using thin-slice CT to design a custom flap for each patient.

Results. 144 cranioplasties were studied. 51 own bone and 93 synthetic. The average delay in cranioplasty was 286 days (Range 16 – 1264 days). The overall complication rate for all 144 cranioplasties was 20.8%; Autologous 31.4% and synthetic 15.1%; p 0.031. Bone flap infection rate overall for all 144 cases was 9.7% - Autologous 11.8% and Synthetic 8.6%; p 0.565. The revision rate was found to be 13.2% overall; 23.5% for autologous and 7.5% for synthetic. The difference in revision rate was found to be statistically significant (p 0.01).

Conclusion. Revision rate and overall complication rate were higher in the own bone group with P<0.05. There was no difference in infection. Our results mirror recent publications and should be considered when undertaking a cranioplasty.

Keywords
cranioplasty,
autologous cranioplasty,
synthetic cranioplasty,
bone flap

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Introduction

The practice of cranioplasty is well documented in history and records date back to the 16th century when gold plates were used in reconstruction. There is also evidence of the practice of trephination and cranioplasty from as early as 3000 BC. The first reported use of bone for reconstruction was in 1668 when a canine bone was described to have been used to repair a cranial defect in a Russian male. Walther in 1821 was reported to be the first to practice autograft cranioplasty. This technique was subsequently popularised by Macewen in 1885 who began routinely replacing trephined bone plugs back into the defects. Wagner in 1889 took this one step further by describing the osteoplastic

craniotomy in which bone was left attached to underlying muscle[1,2].

The practice of successful delayed cranioplasty in its earliest form was described by Sedel in 1889 who used pieces of tibia to repair a parietal defect and later Axhausen used this technique successfully for multiple cases[1]. This technique became popular in early 1900s with multiple authors reporting good results. Muller and Konig in 1890[3] described their technique of split local graft of skin, periosteum and outer table to reconstruct defects, and later Hacker modified this to include only periosteum and outer table[4].

Subsequent to this, various anatomical sites have been used for autografts including ribs, scapula, ilium and sternum with varying popularity[5]. Cadaver allografts have also been used in the past but were noted to be susceptible to infection and resorption[1].

Aluminium was the first metal in the development of modern cranioplasty but was found to be locally irritant and epileptogenic[6]. Silver and gold[7] were also used with good results being reported with gold cranioplasties however this practice was not considered cost efficient. Lead has also been used but abandoned due to the obvious risk of toxicity. Platinum revealed very little reaction but again abandoned due to cost. Use of alloys showed promising results and Vitallium (cobalt, chromium and molybdenum)[8] and Ticonium (cobalt, chromium, nickel, molybdenum)[9] became popular prior to the second world war. Tantalum, an inert metal with good results in animal models, became popular and used widely to treat combat injuries in the second world war[10] but due to the difficulties in acquiring and purifying this, it remained an expensive metal. Zirconium was also shown to have minimal tissue reaction in studies[11].

The use of titanium was first described by Simpson in 1965[12]. The author reported that although the material was not perfect and less malleable than tantalum, it was radiolucent when used in an appropriate thickness and cheaper as a material in his experience of 7 cases.

Non-metallic compounds have also been long explored in a bid to find an ideal cranioplasty material. Celluloid was first used in 1890 and subsequently gained popularity due to its elasticity and resilience[13]. This material lost favour as there was noted to be considerable tissue reaction sometimes causing fistula formation. Acrylic gained increasing popularity around 1940 when its use in dental implants was recognised to show no tissue reaction. Methyl methacrylate (also known as Lucite, Vitacrylic, Plexiglass, Crystallite, Craniolast and Perspex) was felt to be considerably malleable and radiolucent and could be easily used to reconstruct large defects[14]. Use of other inert compounds such as Polyethylene[15] and silicon rubber[16] have been considered but did not gain popularity due to their soft structure.

[1] Abhay S, Haines SJ. Repairing holes in the head: a history of cranioplasty. Neurosurgery. 1997 Mar 1;40(3):588-603.

[2] Feroze AH, Walmsley GG, Choudhri O, Lorenz HP, Grant GA, Edwards MS. Evolution of cranioplasty techniques in neurosurgery: historical review, pediatric considerations, and current trends. Journal of neurosurgery. 2015 Oct;123(4):1098-107.

[3] Grant FC, Norcross NC. Repair of cranial defects by cranioplasty. Annals of surgery. 1939 Oct;110(4):488.

[4] Roka YB. Review of the History of Materials Used With Experience with Bone Cement Cranioplasty. Nepal Journal of Neuroscience.;14(1):7-13.

[5] Aydin S, Kucukyuruk B, Abuzayed B, Aydin S, Sanus GZ. Cranioplasty: review of materials and techniques. Journal of neurosciences in rural practice. 2011 Jul;2(2):162.

[6] Booth JA, Curtis BF. I. Report of a case of tumor of the left frontal lobe of the cerebrum; operation; recovery. Annals of surgery. 1893 Feb;17(2):127.

[7] Mitchell AB. Repair of injuries to the skull by perforated plates. British Journal of Surgery. 1917;5(17):40-1

[8] BECK CS. Repair of defects in skull by ready made vitallium plates. Journal of the American Medical Association. 1942 Mar 7;118(10):798-9.

[9] Campbell E, Meirowsky A, Hyde G. Studies on the use of metals in surgery. Annals of surgery. 1941 Sep;114(3):472.

[10] Mayfield FH, Levitch LA. Repair of cranial defects with tantalum. The American Journal of Surgery. 1945 Feb 1;67(2):319-32.

[11] Bates JI, Reiners CR. The Repair of Cranial Defects with Zirconium: An Experimental Study. Journal of neurosurgery. 1948 Jul;5(4):340-8.

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[13] Pringle JH. Remarks on the closure of gaps in the skull, with notes of cases. British Medical Journal. 1906 Feb 3;1(2353):246.

[14] Gurdjian ES, Webster JE, Brown JC. Impression technique for reconstruction of large skull defects. Surgery. 1943 Dec 1;14(6):876-81.

[15] INGRAHAM FD, Alexander E, MATSON DD. Polyethylene, a new synthetic plastic for use in surgery: experimental applications in neurosurgery. Journal of the American Medical Association. 1947 Sep 13;135(2):82-7.

[16] Courtemanche AD, Thompson GB. Silastic cranioplasty following cranio-facial injuries. Plastic and reconstructive surgery. 1968 Feb 1;41(2):165-72.

It was however noted that the acrylic plates could be prone to fracture and therefore Galicich and Hovind in 1967 described stainless steel mesh reinforced acrylic cranioplasty[17]. This was later modified by Malis to use a titanium mesh instead of stainless steel due to multiple reasons including the artefact produced on CT and compatibility issues with MRI[18].

Hydroxyapatite is a more recent development in cranioplasty materials and is a calcium phosphate compound. This is a natural mineral found in bone but can be synthesised as a hexagonal structure creating a ceramic. The material has shown minimal tissue reaction. It has also shown increased bone repair and osteointegration to its advantage. However if used alone it can be very brittle and prone to fracture. It has been used in oral and maxillofacial surgery for many years[19],[20] and Pompili et al published one of the first series in use of this material for cranioplasty[21]. A total of 11 cases underwent cranioplasty with a material composed of hydroxyapatite, combined with a gel, and laid on titanium mesh or micronets. Post operatively the patients were reported to have good outcomes with impressive levels of osteo-integration according to the authors.

Polyetheretherketone (PEEK) is another organic compound which has gained popularity as it is inert and radiolucent. It is a semicrystalline thermoplastic which has been shown to have similar strength to bone and can be used to print accurate 3D reconstructions of the required implant. One main disadvantage is the cost involved as PEEK implants can often be expensive[22].

The debate between autologous versus synthetic cranioplasty has been ongoing with various publications and authors arguing advantages and risks of both. In our unit we practice both autologous and synthetic cranioplasty and historically this has been done with surgeon preference in cases where both options were available. We chose to look at our outcomes for these groups.

Method

A retrospective study was carried out of all cranioplasty procedures at our unit between June 2009 and March 2018. The patients were identified from a combination of electronic theatre records for a cranioplasty coded procedure and from our bone bank register. Once patients were identified, information was collected via their electronic patient records, theatre notes and all available imaging.

Bone flaps sent to the bank were placed in sterile saline solution during the period of operation until a decision was made regarding replacement. Once a decision was made, swabs and bone chips were taken prior to the bone being placed in a double sterile sealed plastic container (one sealed container within another). Swabs and bone chips were used for cultures and sensitivity. If any positive cultures were found, the bone was disposed. The plastic containers were wrapped in a further plastic bag before being stored in a deep freezer at -81 degrees. Prior to re-implantation, the bone was thawed at room temperature and soaked in either gentamicin in sterile saline or aqueous betadine based on surgeon preference and/or patient allergies. This was undertaken while incision and exposure were taking place.

Decision for material used for synthetic cranioplasty was based on surgeon preference. There are no established protocols within our department for choice of material however in general if a bone flap can be salvaged (i.e. It is not deemed immediately infected or fragmented due to trauma), then an autologous cranioplasty is usually undertaken in the future. There are however exceptions in even these cases whereby a consultant may choose to select synthetic materials out of personal preference or experience.

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[18] Malis LI. Titanium Mesh and Acrylic Cranioplasty. Neurosurgery. 1989 Sep 1;25(3):351-5.

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[22] Shah AM, Jung H, Skirboll S. Materials used in cranioplasty: a history and analysis. Neurosurgical focus. 2014 Apr;36(4):E19.

Each cranioplasty was custom manufactured using thin slice CT. A combination of Titanium, Ceramic, Acrylic and hydroxyapatite plates were used, all pre-manufactured and delivered in a sterile pack which was opened just prior to surgery. These too were placed in either gentamicin in sterile saline or aqueous betadine prior to placement. All cranioplasties were fixed with 5mm self-tapping titanium screws with mini plates. Figure 1 demonstrates the common synthetic materials used within our department.

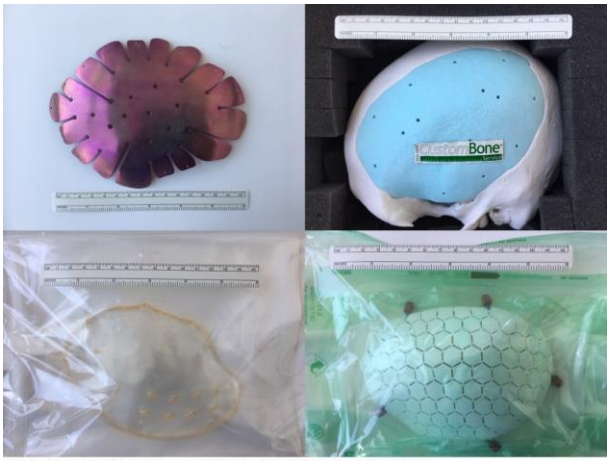

Figure 1: Examples of cranioplasty materials. Titanium *(top left)*, Ceramic *(top right)*, Acrylic *(bottom left)*, Hydroxyapetite *(bottom right)*

Primary outcome was need for revision. Information was also collected for other complications including infection, timing of cranioplasty and original diagnosis. Fisher 2 tailed tests were conducted at 5% significance level to confirm statistical significance for revision rates and multiple factors. Odds ratios were calculated for various factors.

Results

145 patients were identified. 1 patient with synthetic cranioplasty was exclude as the implant had to be removed due to failure of a complex advancement skin flap

One patient had own bone cranioplasty which was complicated by resorption of the bone flap. This complication was included under autologous group. The defect was then repaired using a synthetic implant which was placed overlying the partially absorbed autologous flap. However, this was further complicated by infection and necessitated removal of the partially resorbed bone and synthetic implant. As it was not clear as to what caused the infection, this was excluded from infection rate of both groups.

81 males and 63 females were included in the study with an average age of 51.6 years (Range 18.1 – 85.3 years). Overall 51 cranioplasties were performed using own bone and 93 synthetic. Table 1 details the synthetic cranioplasty materials used. Average delay in cranioplasty was 268 days (Range 16 – 1264 days). The most common reason for craniectomy was Acute Subdural Haemorrhage (23.6%), post operative infection (19.4%) and intracranial haemorrhage (15.3%). Table 2 illustrates patient characteristics for those undergoing cranioplasty.

Cranioplasty Material	No. of Patients
Titanium	52
Acrylic	18
Ceramic	14
Hydroxyapetite	9

Table 1: Synthetic cranioplasty materials

		Bone	Synthetic
Age *(Years)*	Range	20.5 - 74.8	18.1 - 85.3
	Average	49	53.1
Male		32	49
Female		19	44
Reason for Craniectomy *(No. of Patients)*	Non-Traumatic		
	Post op infection	N/A	28
	ICH	9	13
	MCA infarct	10	4
	Intra-osseous tumour	N/A	10
	Post op haematoma	1	2
	Post op subdural empyema	0	3
	Post op swelling	1	1
	SAH Haematoma	2	0
	Spontaneous subdural empyema	0	2
	Post SAH infarct	1	0
	SAH	1	0
	Traumatic		
	ASDH	20	14
	TBI	2	6
	Extradural	3	4
	Large Contusion	1	5
	Depressed skull Fracture	0	1
Time from Craniectomy to Cranioplasty *(Days)*		194.6	325.3

Table 2: Patient characteristics

Overall complication rate was 20.8% (30 cases) with 16 cases in the own bone group (31.4%) and 14 cases in the synthetic group (15.1%). There were significantly more complications in the autologous group as compared to the synthetic group (p 0.031). Bone flap infection rate for all 144 cases was 9.7% (14 cases) with 6 cases in the autologous group (11.8%) and 8 cases in the synthetic group (8.6%). Difference

in Infection rate was not found to be statistically significant (p 0.542). Other complications are shown in Table 3. The only significant difference was found to be in post operative extra-dural haematoma (EDH) with 3 cases (5.9%) in autologous group and none in synthetic group (p 0.043). Resorption was not included as a comparative complication risk for analysis as this would not apply to synthetic cranioplasty and therefor was analysed as part of revision rates.

	Overall	%	Autologous	%	Synthetic	%	P-Value
Infections	14	*9.72*	6	*11.76*	8	*8.60*	0.5654
Hydrocephalus	4	*2.78*	3	*5.88*	1	*1.08*	0.1273
Pseudomeningocele	4	*2.78*	3	*5.88*	1	*1.08*	0.1273
Extradural Haematoma	3	*2.08*	3	*5.88*	0	*0.00*	0.0427
Wound breakdown	2	*1.39*	0	*0.00*	2	*2.15*	0.5393
DVT	1	*0.69*	1	*1.96*	0	*0.00*	0.3542
CSF Leak	1	*0.69*	0	*0.00*	1	*1.08*	1
Chronic pain	1	*0.69*	0	*0.00*	1	*1.08*	1
Superficial Wound infection	1	*0.69*	0	*0.00*	1	*1.08*	1

Table 3: Complications of cranioplasty

Overall resorption rate for autologous cranioplasty was 27.5%. Of these 14 cases, 6 required revision due to significant resorption of the bone flap, however 8 cases only had partial resorption, hence did not need revision. Resorption was deemed significant if it resulted in either gross anatomical or aesthetic defect necessitating revision. Partial resorption included those patients with evidence of radiological bone resorption without a substantial anatomical deficiency or concerns from the patient. If bone resorption is included in the complication, the complication rate in autologous group becomes 31.4% if only revised flaps were included. The total complication rate for autologous group was 54.9% including all bone flaps which showed any resorption (either partial or near total).

Revision rate was found to be 13.2% overall with 12 revisions in the autologous group (23.5%) and 7 in the synthetic group (7.5%). All revisions in the synthetic group took place due to infection, including 1 case of subdural empyema. 6 cases within the autologous group were revised due to infection and the remaining 6 cases due to resorption. Difference in revision rate was found to be statistically significant (p 0.01). The significant increase in revision rate was found to be due to bone resorption in the autologous group. Risk of requiring revision of cranioplasty in autologous group was 3.5 times (Range1.5 – 8.1) that of synthetic group.

Discussion

Autologous cranioplasty remains practiced across the world but is losing popularity due to growing belief in increased complication rates and the inherent risk of resorption. One study of 125 patients undergoing autologous cranioplasty estimated complication rate at 9.2% and resorption rate at 19.7%[23]. There has also been some dispute as to the best solution for storing autologous cranioplasties and some have argued that different techniques can contribute to complication risks.

In one study, the infection rate following re-implantation of cranioplasty stored subcutaneously was 5.6% and 2 further bone flaps (2.2%) were removed for resorption. 2 haematomas were noted, one extradural and one within the abdominal pocket. The remaining results were deemed to be acceptable however follow up was only for 1 year at the time of publication[24]. The authors felt the subcutaneous storage was a viable and acceptable means of storage.

Another study of 53 patients undergoing cranioplasty following subcutaneous storage reported 3 bone flap infections (6%). One was noted to be infected in the subcutaneous space where it was stored and had to be discarded. Two were infected post cranioplasty and needed removal[25]. The paper does however report that 8 of the cranioplasties (15%) required immediate augmentation with synthetic material but do not specify whether this was for resorption or other reasons. They also do not specify whether infections occurred within the augmented cranioplasties or entirely autologous grafts. Morina et al reported only 2 revisions needed out of 75 cases for infection for bone stored in an abdominal subcutaneous pocket[26]. Again, 9 of their cases required

[23] Brommeland T, Rydning PN, Pripp AH, Helseth E. Cranioplasty complications and risk factors associated with bone flap resorption. Scandinavian journal of trauma, resuscitation and emergency medicine. 2015 Dec;23(1):75.

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[26] Morina A, Kelmendi F, Morina Q, Dragusha S, Ahmeti F, Morina D, Gashi K. Cranioplasty with subcutaneously preserved autologous bone grafts in abdominal wall—Experience with 75 cases in a post-war country Kosova. Surgical neurology international. 2011;2.

augmentation with synthetic material and the authors do not comment on whether the infection was in autologous alone or combined cranioplasties.

Hauptli and Segantini report their change in practice after observing frequent osteolysis in their cryopreserved bone flaps, particular at edges, in up to 60%. Following changing their method of preservation to subcutaneous pocket, they reported improved bone resorption rates with only 2 bone flaps showing signs of resorption following implantation and one removed for infection[27]. The paper however does only quote a 2 year follow up.

Cryopreservation is another method widely employed of storing bone flaps. In a large retrospective study, Fan et al reported their experience of cryopreserved bone flaps over a 12-year period[28]. A total of 946 cases of cranioplasties were assessed and re-implantation took place between 67 – 641 days (average 194 days). Bone flaps were stored after gentile irrigation with sterile saline, wrapped in 2 layers of sterile plastic and then placed in a storage medium (including dimethyl sulfoxide, DMSO) and slowly cooled by various methods to a final temperature of -196 degrees in liquid nitrogen. Swabs were sent prior to storage and if any positive growth found, the flaps were discarded. Through their storage process the authors reported that microscopically the bone retained features of normal bone including good osteocyte activity as compared to fast freezing or autoclaving. Overall infection rate was 4.06% (39 flaps) and resorption rate was 4.28% (42 flaps). All infected bone flaps were removed however the authors do not report their outcomes with resorbed flaps. The use of bioactive materials such as those used by Fan et al have been argued to improve bone flap viability during cryopreservation and in a laboratory study of mice femoral tissue, storing in DMSO solution was shown to have improved cell proliferation as compared to a control solution[29].

Hng et al discussed their results of 187 patients with cryopreserved cranioplasty over a 10-year period[30]. Bone was wrapped in a sterile plastic sheath and stored at -30 degrees. Prior to re-implantation the bone was thawed at room temperature and soaked in betadine. The authors also recommend against autoclaving due to the higher risk of bone resorption. 64.7% of cranioplasties were undertaken within 90 days (range 10 – 390 days) and overall complication rate was 34.2% (64 cases). Bone flap infection requiring removal was noted in 11.2% and revision of bone flap due to resorption occurred in 5.34%. Other complications included superficial wound infection (3.21%), hydrocephalus 3(.21%) and seizures (2.67%)

Iwama et al also reported good outcomes with their experience of cryopreserved bone flaps in 49 patients[31]. They stored bone in 3 sterile vinyl plastic bags at either -35 or -84 degrees and flaps were washed in sterile saline and Tobramycin prior to re-implantation (4 – 168 days, average 50.6 days). Only 2 complications were noted (4%), one case of infection and one case of revision needed for bone resorption. Grossman et al reported no complications in their 12 cases of cryopreserved cranioplasties[32]. In their series the bone was irrigated with saline and neomycin antibiotic, wrapped in 2 sterile plastic wraps and stored at -80 degrees. An extended point in this series was the average re-implantation duration was 9.25 months (0.25 to 27 months) however despite this duration, no complications were reported in this, albeit small sample.

Lu et al published their experience with 16 cases of cryopreserved bone flaps at -80 degrees[33]. The bone flaps were wrapped in 2 sheets of sterile plastic

[27] Häuptli J, Segantini P. New tissue preservation method for bone flaps following decompressive craniotomy. Helvetica chirurgica acta. 1980 Jun;47(1-2):121-4.

[28] Fan MC, Wang QL, Sun P, Zhan SH, Guo P, Deng WS, Dong Q. Cryopreservation of Autologous Cranial Bone Flaps for Cranioplasty: A Large Sample Retrospective Study. World neurosurgery. 2018 Jan 1;109:e853-9.

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[31] Iwama T, Yamada J, Imai S, Shinoda J, Funakoshi T, Sakai N. The use of frozen autogenous bone flaps in delayed cranioplasty revisited. Neurosurgery. 2003 Mar 1;52(3):591-6.

[32] 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 and tissue banking. 2007 Sep 1;8(3):243-6.

[33] Lu Y, Hui G, Liu F, Wang Z, Tang Y, Gao S. Survival and regeneration of deep-freeze preserved autologous cranial bones after cranioplasty. British journal of neurosurgery. 2012 Apr 1;26(2):216-21.

before being placed into an "ultra low freezer" at -80 degrees. Prior to replacement, they were soaked in providone-iodine for 30 minutes and average delay in cranioplasty was 117 days (Range 63 – 289 days). They reported no infection or other complication with their re-implanted bone and conducted post operative SPECT imaging which the authors reported showing equal radioactive uptake in re-implanted bone as compared to native bone.

This is in contrast to some studies that have suggested that bone flap viability becomes limited following a period of storage. A laboratory study by Bhaskar et al revealed no cell growth in bone flaps stored at -30 degrees for over 6 months rendering the bone flaps non-viable[34]. Another study however, revealed no effect on the biomechanical properties of human skull bone when comparing fracture loading, tested by bending forces until the sample fractured. The bones were tested following storage at -20 degrees for up to 3 months[35].

In a paper comparing subcutaneously stored (SC) bone versus cryopreservation (CP) at -70 degrees following betadine soaking, there was no statistical difference in infection rates between the groups. Of the 39 cranioplasty stored in subcutaneous pocket and 31 cryopreserved, there were 2 (5.1%) and 5 (16.1%) infections respectively. In the SC group, one infection occurred in the abdomen and one on re-implantation. On infection within the CP group was considered superficial only and treated with intravenous antibiotics. A subgroup analysis however revealed significantly higher infection in cryopreserved bone for those undergoing craniectomy for traumatic brain injury (TBI)[36].

Cheng et al also compared subcutaneous versus cryopreservation of bone flaps of patients undergoing decompression over a 10-year period[37]. 290 patients were included with 110 preserved subcutaneously and 180 cryopreserved. The bones were immersed in betadine for 30 mins and then vancomycin for another 30 mins prior to being stored. Microbiology swabs were sent. Overall infection rate was 13.8% with 20 cases of infection in each group (11.11% SC, 18.18 CP) with no statistically significant difference. In the subcutaneous pocket group, 12 of these were as a result of cranioplasty and the remainder were within the stored pocket requiring disposal of bone flap. The authors also studied bone resorption by comparing frontal bone thickness and found that there was statistically significant decreased thickness in the CP group, but they do not comment on whether any revisions were needed as a result.

Another method of bone flap preservation used by some surgeons is subgaleal storage on the opposite side of the craniectomy. Goel and Deogaonkar reported their outcome of subgaleal bone flap preservation[38]. 8 cases were included however only 4 of the bone flaps were replaced with very unclear indication within the paper as to the reason for this. The authors concluded that within the replaced bone flaps, there were no complications with bone flaps being stored for anywhere between 3-16 months.

Krishnan et al described 55 cases of subgaleal preserved bone flap and reported only 2 complications related to wound or skin breakdown from pressure[39]. Korfali and Aksoy reported no complication following 27 cases of replacement of bone flaps stored under the galea. Both papers felt subgaleal storage was an easy and cost-effective method of storage.

A review paper comparing multiple techniques of bone flap storage concluded that there was no statistically significant difference between technique of bone flap preservation and post operative

[34] Bhaskar IP, Yusheng L, Zheng M, Lee GY. Autogenous skull flaps stored frozen for more than 6 months: do they remain viable?. Journal of Clinical Neuroscience. 2011 Dec 1;18(12):1690-3.

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[39] Krishnan P, Bhattacharyya AK, Sil K, De R. Bone flap preservation after decompressive craniectomy-Experience with 55 cases. Neurology India. 2006 Jul 1;54(3):291.

outcome[40]. This was however not a systematic review. Yadla et al conducted a systemic review on subcutaneous storage versus extracorporeal and found no statistical difference[41].

Many papers have also attempted to compare autologous bone flaps with synthetic materials. Piitulainen et al studied their results over a 10-year period with 100 cranioplasties[42]. 20 were performed using autologous bone and the remainder with various synthetic material. Bone flaps were stored at -80 degrees and swabs were taken to ensure no growth prior to re-implantation. Overall complication rates were 60% for autografts and 25% for synthetic material. Revision rates were 40% for autografts and 14% for synthetic materials. The paper reports there was no significant difference between autologous cranioplasty and synthetic subgroups but do not undertake an overall comparison. From their data a chi squared test reveals a p value of 0.02. Serious infection rate was 25% in autologous and 5% in synthetic group with a resorption rate of 15%. There were no specific risk factors shown to be significant including time of implantation.

Klinger et al also published their experience of 258 cranioplasties over a 10-year period[43]. Autologous bone was stored between -40 to -80 degrees following swabs being undertaken to ensure no growth. Synthetic cranioplasty was undertaken with acrylic flaps. A total of 138 (53%) procedures were with autologous bone and 120 (47%) with acrylic. The authors reported an overall 10.9% complication rate and reported no significant difference between the two groups. In their series, only 2 (1.4%) bone flaps underwent significant bone resorption.

A systemic review looking at impact of cranioplasty material on infection rates concluded that there was no significant difference between autologous and synthetic flaps[41]. Another systemic review and meta-analysis comparing PEEK cranioplasty to other materials including autologous again did not find any significant difference in complication rates[44]. However, they analysis only included 2 studies in their review.

Time of cranioplasty has long been debated as an independent risk factor for revision. A large retrospective study reported that cranioplasty undertaken between 15 to 30 days post craniectomy were associated with a lower infection, seizure and resorption rate[45]. Cranioplasty after 90 days was associated with lower hydrocephalus rates but higher risk of seizures.

A recent systemic review found that although early cranioplasty (<90 days) was associated with higher incidence of hydrocephalus, there was no statistical difference between any other complication[46]. Overall infection rate was reported between 0 to 24% with an average of 7.4%. This systemic review echoed a previous study which concluded the same results with no significant difference between early and late groups but a significantly higher hydrocephalus rate in the early group[47]. Although the several systemic reviews have concluded that there is no increase in complication rates, evidence has suggested neurological outcome may be improved with early cranioplasty[48]. A

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Cochrane registered article by a German team concluded in their abstract that ultra-early (within 6 weeks) cranioplasty improved neurological outcome[49]. However, the remaining article is in German and therefore we could not critique their methods.

Another Cochrane registered prospective multinational trial concluded that there was no increase in risks by early cranioplasty (under 12 weeks) but did not establish a significant benefit[50]. The authors admit that they only recruited 70 patients into their study and potentially was underpowered to obtain statistically significant results.

In our study the average delay in cranioplasty was 268 days with a range of 16 to 1264 days with a median of 224 days. There are no specific established protocols within our department to specify the timing of cranioplasty however most surgeons' preference is to undertake this procedure after 3 to 6 months to judge clinical recovery. With cases of infection, the surgery is usually undertaken after a period of observation on completion of antibiotic therapy, which is usually continued for a minimum of 6 weeks. 31.3% of cranioplasties occurred within 6 months and 69.4% within 1 year. Some cases had an unusually long delay mainly due to patient factors with regards to clinical recovery however due to the retrospective nature of our study, in some cases the delay was unclear.

In view of paucity of data, a recent randomised control trial has been published comparing autologous flaps with titanium cranioplasty[51]. 64 patients were recruited and outcomes assessed at 1 year. Bone flaps were preserved at -80 degrees in double layer of sterile plastic and on the day of procedure, were thawed in warm saline solution. All patients underwent post operative CT on day 1. The authors reported no infection of primary cranioplasty however 1 case of infection in a patient requiring titanium cranioplasty following own bone resorption. Complete resorption was reported in 7 (22%) of cases but only 5 of these patients agreed to a revision cranioplasty as the other 2 were still satisfied with overall cosmesis. Resorption was observed more commonly in younger patients (32 vs 45, p 0.013 and a further 12 cases were noted to have some degree of resorption. There was no difference between complication rates including post op haematoma requiring surgery which was reported as 5% in own bone and 6% in titanium group. The authors also conducted a cost analysis and found no statistical difference and thus concluded that primary titanium cranioplasty should be considered in all patients, especially young to improve cosmesis and reduce need for revision.

A follow up article by this author looking at 24 months outcome reported that the 2 patients who chose for conservative management of their resorbed bone flaps changed their minds due to increasing postural headaches and another patient progressed from moderate to severe resorption needing revision. Therefore, over the 24-month period, 25% of own bone cranioplasty required revision versus none in the titanium group (p 0.001)[52]. A recent systematic review and meta-analysis also reported similar finding of significantly increased revision rate with autologous cranioplasty primarily due to resorption, which was reported as 20% overall[53]. The article reported no significant difference in other complications including infection.

Our series reflects the findings of the randomised control trial and recent systematic review in that significantly greater revisions were needed with own bone cranioplasties. There were also greater number of complications overall as compared to the

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synthetic group. This raises the question of continuation of own bone cranioplasties and whether all patients should receive synthetic flaps.

In our series the only statistically significant complication was extradural haematoma however the significance of this is uncertain. No previous study has highlighted a significant increase in post operative EDH and this may be purely artefactual. No factors could be clearly identified in relation to this complication, including placement of drain which is routinely practiced regardless of cranioplasty material.

One consideration for choice is cost of cranioplasty. In our unit, the storage cost of bone flaps are negligible and cost of theatre and ward stay are the same regardless of the choice of material. Therefore there is a significant cost disparity between the groups and use of synthetic cranioplasty in all patients would increase costs for the unit. A formal cost analysis was not undertaken and when accounting for increased complication rates with autologous cranioplasty, the difference may not be significant.

Conclusions

Our study reflects results from previous publications showing increased revision rates with autologous cranioplasty as compared to synthetic materials. Although there may be a cost implication, the increased risks should be strongly considered when deciding the best method of cranioplasty for any patient. In keeping with other recent publications, we would recommend synthetic cranioplasty should be favoured over autologous unless patient factors, cost implications or local resources influence otherwise.

Abbreviations

3D - Three-dimensional
CP - Cryopreservation
CT - Computed Tomography
DMSO - Dimethyl sulfoxide
EDH – Extra-dural Haematoma
MRI - Magnetic Resonance Imaging
PEEK - Polyetheretherketone
SC - Subcutaneously stored
SPECT - Single-photon emission computed tomography
TBI - Traumatic Brain Injury

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