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CLINICAL PAPER

Split Calvarial Grafting for Closure of Large Cranial Defects: The Ideal Option?

Priya Jeyaraj[1]

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Abstract Among the various cranioplasty options for reconstruction of large post-craniectomy defects, split calvarial grafting offers numerous significant advantages such as the provision of viable autogenous bone graft material comprising of living, immunocompatible bony cells that integrate fully with the skull bone bordering the cranial defect. Its potential for revascularization and subsequent integration and consolidation allows its successful use even in previously infected or otherwise compromised recipient sites. Its excellent contour match at the recipient site and low cost as compared to various alloplastic implant materials often makes it preferable to the latter. Surgeon's skill, dexterity, expertise and experience are important factors to be considered in this highly technique-sensitive procedure.

Keywords Cranioplasty · Split calvarial grafting · Corticocancellous calvarial bone strips · Decompressive craniectomy (DC)

Introduction

Cranioplasty is the surgical repair, replacement and restoration of a skull defect, thus restoring calvarial shape, symmetry, contour and continuity and achieving morphological and functional rehabilitation of the cranial vault [1].

A large bony calvarial defect can result from trauma, infection, ablative resection of a cranial tumor (e.g., astrocytoma, meningioma) or a cerebral decompression procedure [2]. Decompressive craniectomy (DC) is a potentially life-saving neurosurgical intervention performed in cases of head trauma or spontaneous intracranial hypertension or hemorrhage [3]. It is carried out by neurosurgeons either to evacuate an intracerebral hemorrhage or hematoma or to relieve the intractable intracranial hypertension which often accompanies traumatic brain injury (TBI) and sometimes occurs even spontaneously. Once performed, the resulting absence of a cranial shield or barrier makes the intracranial structures such as the brain and meninges, vulnerable to injury. Hence, post-craniectomy patients are obliged to undergo a second procedure, namely cranioplasty, for reconstruction of the resulting cranial defect. Also, a person with part of his or her head missing can be quite unsightly and sometimes even frightening to look at, making cranioplasty extremely important from a cosmetic and psychosocial point of view as well.

In addition to the cosmetic and protective roles, cranioplasty also has a definite therapeutic role by reversing the sensorimotor deficits and neurological deterioration that often accompanies large cranial defects, a condition commonly referred to as the 'Motor Trephine Syndrome' (MTS) [4] or 'Sinking Skin Flap syndrome'(SSFS) [5]. MTS is characterized by objective symptoms such as decline in cognitive behavior and motor functions, including development or worsening of a contralateral hemiparesis, neurosensory deficits and altered sensorium, e.g., a fall in GCS, loss of concentration and memory. Subjective symptoms of the MTS include vague pain and discomfort at the site of the cranial defect, intolerance to vibrations, undue fatigability, headache and dizziness, anxiety and apprehension, mental depression and mood swings. These neurological deficits result from an absence of a cranial cover, which allows the atmospheric pressure

✉ Priya Jeyaraj
jeyarajpriya@yahoo.com; jeyarajpriya@gmail.com

[1] Military Dental Centre (Gough Lines), Indian Army, Secunderabad, Telangana 500015, India

to bear down directly on the unprotected brain, causing its shrinkage and displacement with serious derangement in the cerebral hemodynamics like cerebrospinal fluid (CSF) pressure, cerebral blood flow (CBF) and cerebral perfusion [6]. On computed tomographic (CT) scans, the cranial contents exhibit a typical concavo-convex, kidney bean shape. The scalp flap overlying the craniectomy defect often becomes disfigured, indrawn and "sucked-in," creating a tense, non-pulsatile, gorge-like pit, hence the alternative name "Sinking skin flap syndrome (SSFS)".

Cranioplasty reverses the MTS by providing a cranial shield or cover, thus protecting the brain and cranial contents from the atmospheric pressure [7]. It allows expansion of the dura, meninges and the collapsed and shrunken brain, thus restoring their size, position and volume. It restores normal CSF pressure, volume and motion, i.e., CSF hydrodynamics in addition to restoring normal CBF, cerebral perfusion and metabolism [8]. It facilitates a rapid reversal of the sensorimotor deficits and cognitive functions and relieves the neurological symptoms of MTS/SSF, probably by increasing CBF on the side of the craniectomy as well as on the contralateral side [9]. Hence, cranioplasty can serve as a definite "therapeutic procedure," rather than a merely "cosmetic" one of restoration of cranial contour and symmetry [10].

Various autogenous graft materials have been used for reconstruction of cranial defects, such as split calvarial bone, rib [11] and the split iliac crest [12, 13]. Autogenous split calvarial bone has been used extensively for cranial reconstructions because of its numerous desirable characteristics such as excellent contour, minimal donor-site morbidity as well as its proximity to the surgical field, reasonably large amounts of harvestable bone with a variety of contours, lack of esthetic or functional deformity at the donor site, minimal postoperative pain, reduced hospital stay, and reduced overall cost [14].

Calvarial corticocancellous bone supplies living, immunocompatible bony cells that integrate fully with the skull bone by osteoinduction, osteoconduction as well as by osteogenesis [14]. Its potential for revascularization and subsequent integration and consolidation allows its successful use even in previously infected or otherwise compromised recipient sites [15].

This case report describes successful reconstruction of a large post-craniectomy defect using autogenous split calvarial bone grafting.

Case Report

A 50-year-old male patient was referred by the neurosurgeon for reconstruction of a large (10 × 9 cm), right-sided fronto-temporo-parietal post-craniectomy calvarial defect (Fig. 1).

History revealed that 2 years ago, he had developed spontaneous intracranial hemorrhages in the right temporal and bilateral frontal lobes with extensive subarachnoid hemorrhages in the right parieto-occipital lobe, all of which were evident on magnetic resonance imaging (MRI) of the brain (Fig. 2a). There was also seen a mass effect with compression of the right lateral ventricle and right lateral midbrain. CT scan of the brain (Fig. 2b) revealed a large subdural hematoma (SDH) of right temporo-parietal region, hemorrhagic contusions with perilesional edema in the right parietal lobe, severe diffuse cerebral edema with midline shift to the left to an extent of 9.6 mm. Magnetic resonance angiography (MRA) of the brain (Fig. 2c) revealed fusiform aneurysms of the middle cerebral artery (Rt) at its bifurcation incorporating its three branches, with normal blood flow in the internal cerebral arteries (ICA) and bilateral vertebral arteries (VA). A mass lesion was evident in the extra axial compartment of the right side of the cranium, displacing the right middle cerebral artery medially.

The patient underwent an emergency right-sided fronto-temporo-parietal decompressive craniectomy with evacuation of the intracranial hemorrhage and clipping of the aneurysm. The patient recovered well thereafter with resolution of his neurological symptoms (Fig. 2d).

The excised calvarial flap had been preserved in the subcutaneous fat pocket of the patient's abdominal following craniectomy; however, the bone flap had subsequently become infected and had to be retrieved and discarded six months later.

The patient had gradually developed a left-sided hemiparesis after a year and was presently confined to a wheelchair. In addition to the motor deficit, he had also developed subjective symptoms such as headache, dizziness, seizures, anxiety attacks, depression, memory loss and mood swings, all typical features of the motor trephine syndrome, attributable to the large cranial defect. Hence, he was referred for an urgent cranioplasty to alleviate the neurological deterioration and reverse the features of the MTS.

Compute Tomographic scans (Fig. 3a–l) showed the large (10 × 9 cm) Rt fronto-temporo-parietal bone defect, with displacement of the intracranial structures to the left due to compression by the atmospheric pressure brought to bear down directly upon the unprotected brain. 3-D reformatting and reconstruction of the CT images (Fig. 3m–p) revealed the morphology and dimensions of the bone defect to be reconstructed by cranioplasty.

The cranial defect was quite large. As there was no autologous bone flap available for easy retrieval and replacement over the defect, split calvarial grafting was planned for the reconstruction. The donor site selected was the parietal bone of the opposite side. Routine workup of

Fig. 1 **a–d** A 50-year-old patient with a large (10 × 9 cm), right-sided fronto-temporo-parietal post-craniectomy defect, referred for its reconstruction by cranioplasty. **e–h** The scalp flap overlying the calvarial defect appeared indrawn, sunken in, producing a tense gorge-like pit, suggestive of the 'Sinking skin flap syndrome (SSFS)'

the patient was carried out for surgery under general anesthesia.

The calvarial corticocancellous strips were planned to be harvested from the region of the parietal bone between the midline, that is, the sagittal suture and the temporal line, as this is the thickest and safest area for outer table harvesting. This part of the skull is most easily accessible, has the best diploic differentiation and gives a good yield of cortico-cancellous bone. After local infiltration of 2% lignocaine with 1:80,000 Adrenalin into the scalp, hemostatic sutures (Fig. 4a–f) were placed on either side of the proposed incision line, in order to reduce the intraoperative bleeding from the scalp flap. A full-thickness flap was raised exposing both, the defect (Fig. 4g, h) and the donor sites (Fig. 4i). A malleable aluminum sheet was used as a template to record the morphology of the defect. It was then cut into sections approximately 6–7 cm in length and 1.5–2 cm in width, and these were used to mark the outlines of the corticocancellous strips to be harvested from the parietal bone of the opposite side (Fig. 4j, k, l). Care was taken during harvesting of the grafts, to avoid proximity to suture lines as the bone thins down here and the dura is tightly adherent to the undersurface. A safe distance was also maintained from the sagittal suture to avoid inadvertent injury to and bleeding from the superior sagittal sinus that lies just beneath. The graft was then harvested as narrow strips, around 7 cm long and 2 cm wide, and several strips were laid adjacent to each other spanning the defect.

The first graft strip to be harvested was outlined using the aluminum template strip as a guide, with the help of a small round (1.5 mm diameter) tungsten carbide bur, going through the outer cortical table alone (Fig. 4l). Then, a pear-shaped vulcanite trimmer was used to remove bone along the outer border of the strip, thus creating a bevel (Fig. 4m–o), which would permit placement of a straight fissure bur to undermine the edges of the graft. The bur was held as parallel to the cranial surface as possible (Fig. 4p), and its depth of penetration was limited to the diploe, which seemed slightly softer and exhibited a slight cancellous ooze. The care so taken was to prevent inadvertent intracranial penetration by the bur.

An osteotome was now placed at the undermined edge and advanced along the diploic space. The mallet was used

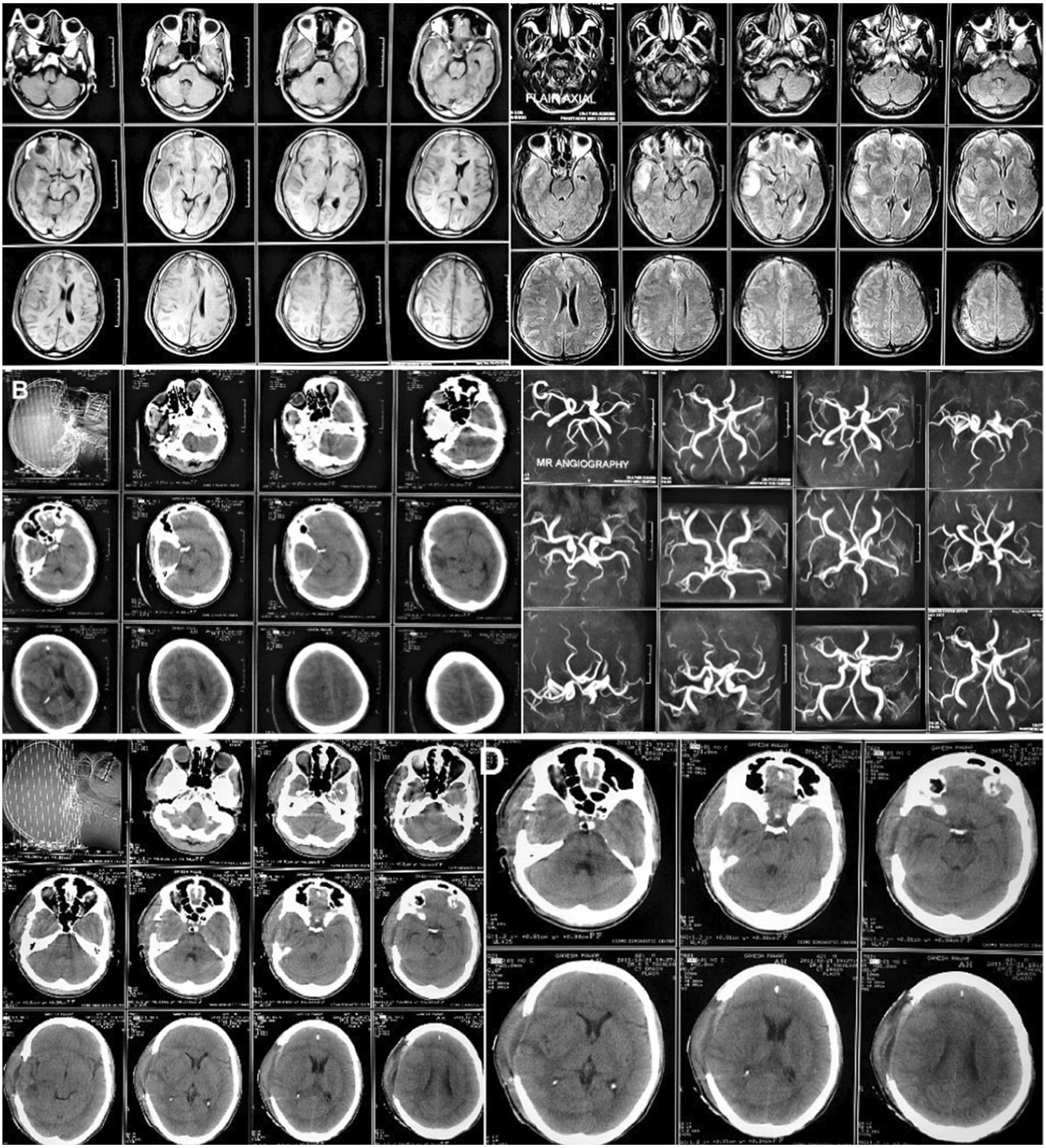


Fig. 2 **a** Magnetic resonance imaging (MRI) of the brain was carried out 2 years ago, prior to craniectomy, showing spontaneous intracranial hemorrhages in the right temporal lobe and bilateral frontal lobes and extensive spontaneous subarachnoid hemorrhages in the right parieto-occipital lobe. A mass effect was evident, with compression of the right lateral ventricle and right lateral midbrain. **b** Computed tomographic (CT) scan of brain revealed subdural hematoma (SDH) of right temporo-parietal region, hemorrhagic contusions with perilesional edema in the right parietal lobe, severe diffuse cerebral edema with midline shift to the left by 9.6 mm. **c** Magnetic resonance angiography (MRA) of the brain revealed fusiform aneurysms of the right middle cerebral artery (MCA) at its bifurcation incorporating its three branches. A mass lesion was evident in the extra axial compartment of the right side of the cranium, displacing the right MCA medially. **d** Immediate post-craniectomy CT scan showing the temporo-parietal bone defect, resolution of the intracranial bleed and hematoma, no evidence of pneumocephalus or shift of the midline structures and persistence of mild focal edema in the right temporal lobe

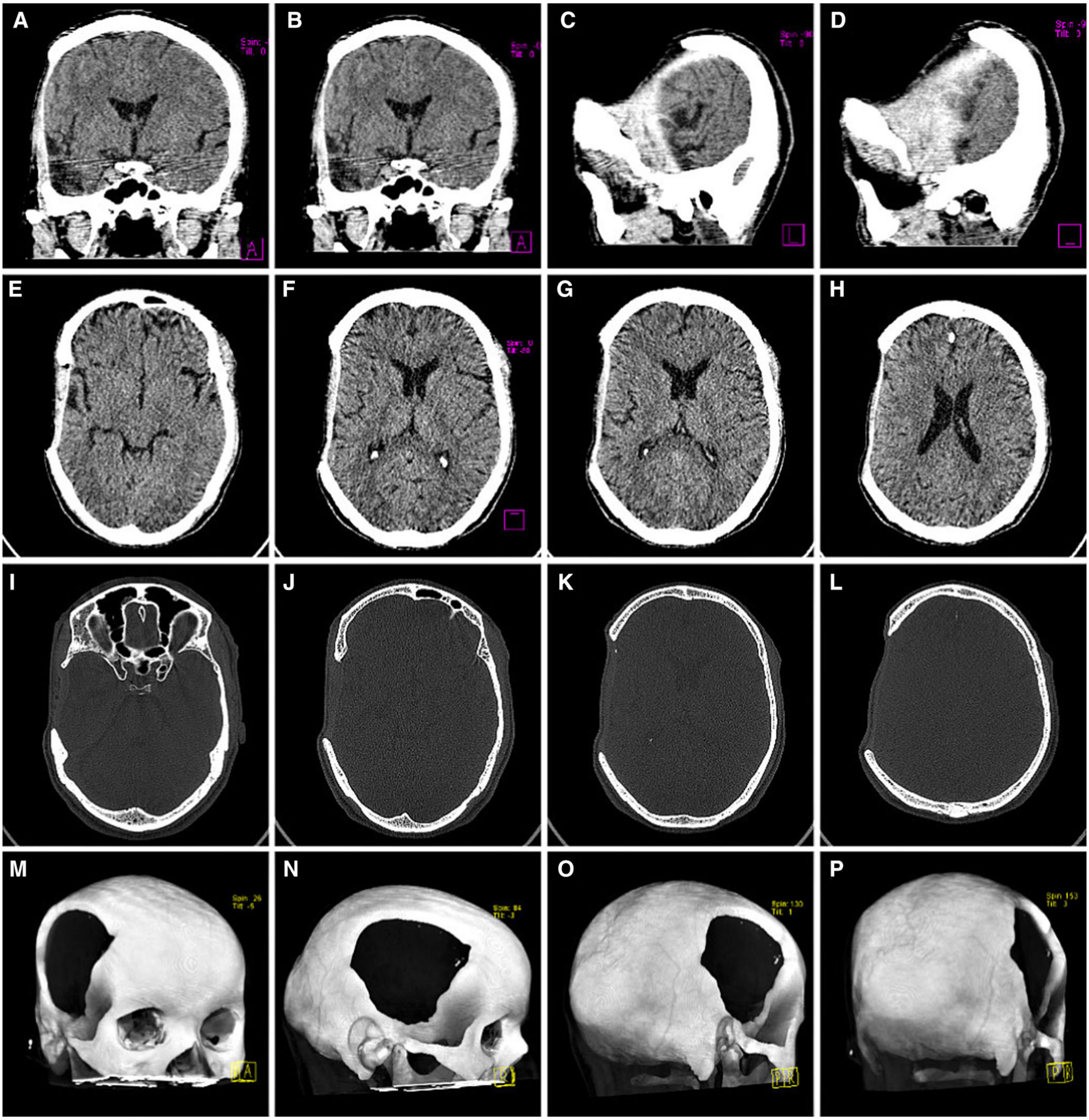
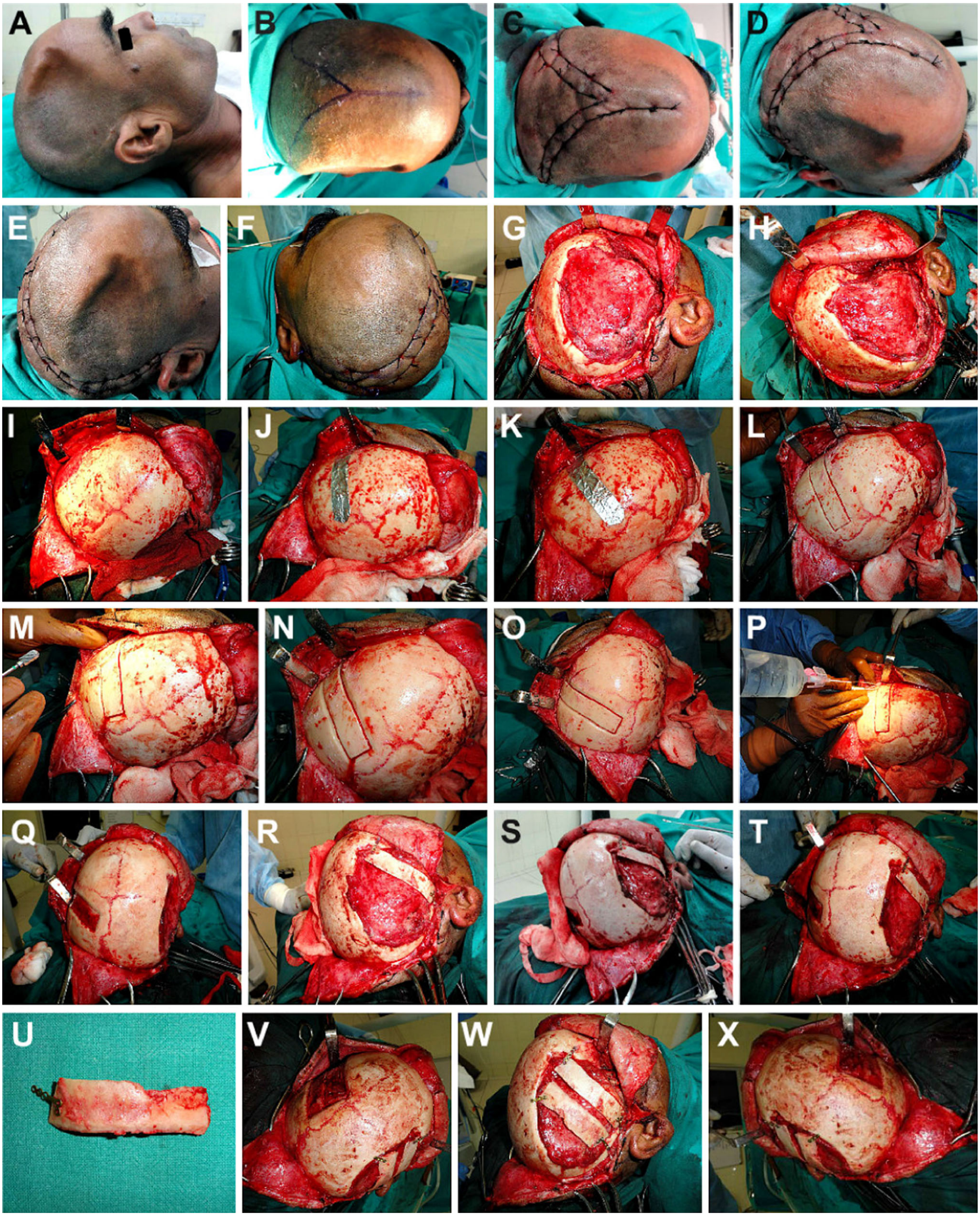


Fig. 3 **a–l** CT scan head showing the large (10 × 9 cm) Rt fronto-temporo-parietal bone defect, with displacement of the intracranial structures to the left due to compression by the atmospheric pressure brought to bear down directly upon the unprotected brain due to the absence of the protective cranial shield in the region. **m–p** 3-D reformatting and reconstruction of the CT images, showing the morphology and dimensions of the bone defect to be reconstructed by cranioplasty

with a carefully controlled force, and the leading edge of the osteotome was maintained under constant direct vision, in order to prevent penetration through the inner cortex. Once the edges had been sufficiently undermined, the osteotome was changed to a curved or spatula osteotome, again maintaining it as parallel to the cranial surface as possible. At this stage, the graft could be seen starting to lift up from one end. Care was taken not to lever the graft upwards, as it is delicate and sure to crack upon application of any undue force. Now, 2 or even 3 osteotomes could be placed at different locations of the strip to complete the split. The graft was then lifted and placed in a blood soaked sponge to preserve the vitality of its cells. The harvested corticocancellous strip was then transposed to the defect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◀**Fig. 4** **a**–**f** Proposed incision line marked and hemostatic sutures placed on either side of it, to limit the extent of intraoperative bleeding from the scalp flap. **g**, **h** Full-thickness scalp flap raised along the subgaleal plane, exposing the cranial defect. **i** Flap raised from the contralateral temporo-parietal region exposing the donor-site region. **j**–**l** Template of the calvarial strips to be harvested, positioned over the donor site for marking of its outlines using a small round tungsten carbide bur. **m**–**p** Pear-shaped vulcanite trimmer used to bevel the outer edge of the groove created to allow placement of a straight fissure TC bur to deepen the groove further and undermine its edges to allow subsequent placement of the osteotome. **q** Outer table of the cortical strip split along the diploe, leaving the inner table intact. **r**–**t** Harvested corticocancellous strip, measuring approximately 7 × 2 cm, transposed to the opposite side, positioned over the cranial defect and secured in place using titanium micro screws and plates. **u**–**x** Second strip harvested and laid across the defect alongside the first strip and fixed in place. **y**–**aa** Third corticocancellous strip harvested, transposed and fixed over the defect. **ab**, **ac** Integrity of the inner cortical table at the donor site maintained intact. Meticulous used of bone wax and Gelfoam to control cancellous ooze prior to closure. **ad**, **ae** Vacuum-assisted closed suction drain was placed to eliminate chances of postoperative hematoma formation. Scalp flap replaced and closed in layers. **af** Restoration of the contour in the defect area, evident

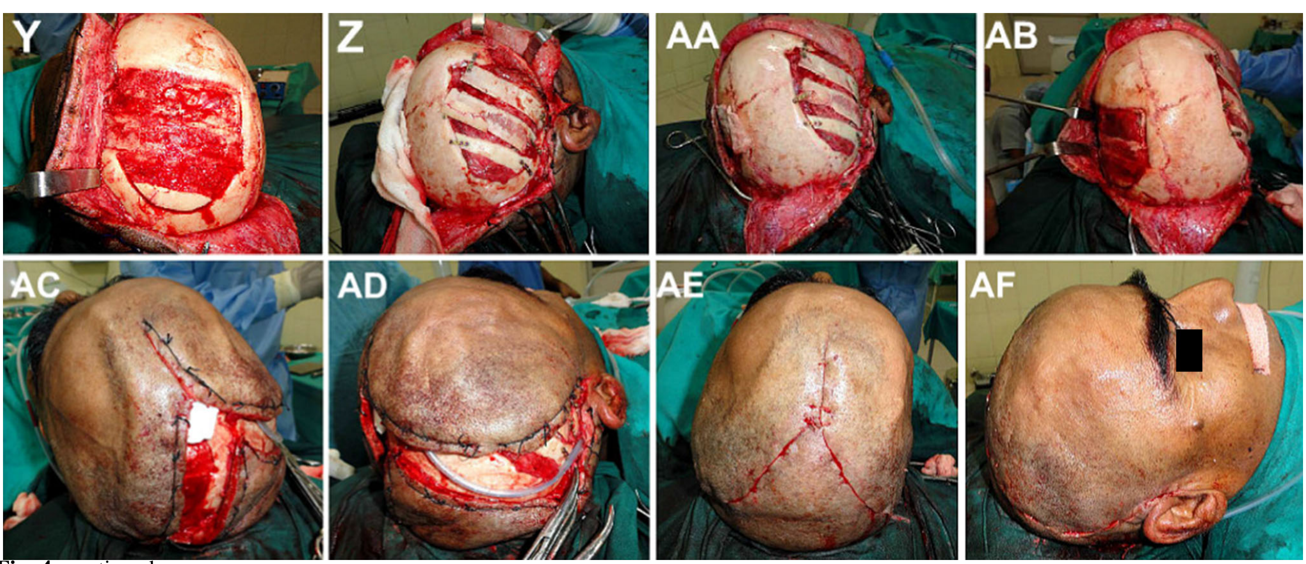
site, where it was carefully laid across it and secured in place using Titanium microplates of profile thickness of 1.5 mm and titanium microscrews of 4 mm length and 1.4 mm diameter (Fig. 4q–u). Subsequent strips were then carefully harvested from the adjacent area, transposed to the opposite side, laid alongside the previous graft and fixed in place, bridging the defect (Fig. 4v–ab). Bone wax was used judiciously to staunch any excessive cancellous ooze. Meticulous care was taken at all times to maintain the integrity of the inner cortical table, thus avoiding any dural exposure or injury to the meninges (Fig. 4y–ac).

The osteogenic potential and osteoinductive influence of the corticocancellous grafts would recruit and induce pluripotent cells of the dura and pericranium to differentiate into osteoblasts and to lay down bone in the gaps in between the grafted adjacent corticocancellous strips, for consolidation of the graft which would take about 12–36 months.

A vacuum-assisted closed suction drain was placed to prevent the formation of a postoperative hematoma (Fig. 4ac). A layered closure of the scalp flap was carried out to eliminate all dead space (Fig. 4ad–af). This began with deep interrupted resorbable sutures for the pericranium and galea, followed by surgical staples for the cutaneous closure.

The postoperative recovery of the patient was smooth and uneventful. The healing of the operated sites proceeded swiftly (Fig. 5a–c). The surgical staples were removed on the 10th postoperative day. There were no complications encountered in either the immediate or late postoperative period. There was an excellent restoration of the cranial contour and shape with even reversal of the subjective symptoms of the MTS that the patient suffered from prior to the cranioplasty (Fig. 5d–f).

Postoperative CT scans showed a good restoration of the cranial shape and contour. The curvatures of the grafts harvested from the outer cortical table from the opposite side of the cranium were able to closely match and reproduce the desired curvature and contour at the defect site (Fig. 6a–e). There was no visible breach of the inner cortical table at the donor site (Fig. 6f–h). The previously collapsed and shrunken cranial contents were seen to have restored their size, position and volume following reconstitution of the integrity of the cranial vault (Fig. 6i–l).



◀**Fig. 4** continued

Fig. 5 **a–c** Fifth postoperative day showing a good healing of the operated site and the surgical skin staples in situ. Minimal postoperative edema in the temporal region. **d–f** 2 weeks post-cranioplasty, showing a good restoration of the calvarial contour and continuity, adequate hair growth over the operated scalp camouflaging the incision lines and a good structural and functional integrity of the reconstructed cranial vault

The patient was followed up for a period of 20 months. On comparison of the immediate and 18 months post-cranioplasty facial appearance (Fig. 7a–c, e–g, i–k), the good cranial contour and shape that had been achieved by the split calvarial cranioplasty procedure was seen to be maintained, with no visible evidence of graft resorption. On palpation, the surface of the restored side seemed smooth and even with no irregularities or gaps. The donor site too was smooth with no rough edges palpable. Careful placement of the incision lines at the time of surgery had helped to achieve a good camouflage of the scar, well within the hairline. The patient's thick hair growth further enhanced the esthetic outcome. On comparing the CT scans taken immediately following the cranioplasty with those taken 18 months later, it was found that good consolidation of the graft was in progress, with visible widening of the graft strips and their merging with each other and with the adjacent skull bone, thus restoring the lost cranial shield and barrier (Fig. 7d, h, l).

Discussion

The objective of Cranioplasty is to obtain a durable and stable reconstruction of the missing part of the cranium, covered with a healthy skin layer to restore protection to important visceral components like the brain and meninges, improve esthetics and function, and importantly, to reverse the MTS by restoring shape and position of the shrunken and displaced brain, normalizing intracranial pressure and volume relationships and restoring cerebral perfusion and hemodynamics [8].

Since the end of the nineteenth century, a number of different methods have been introduced for the management of cranial defects; among these, two major methods

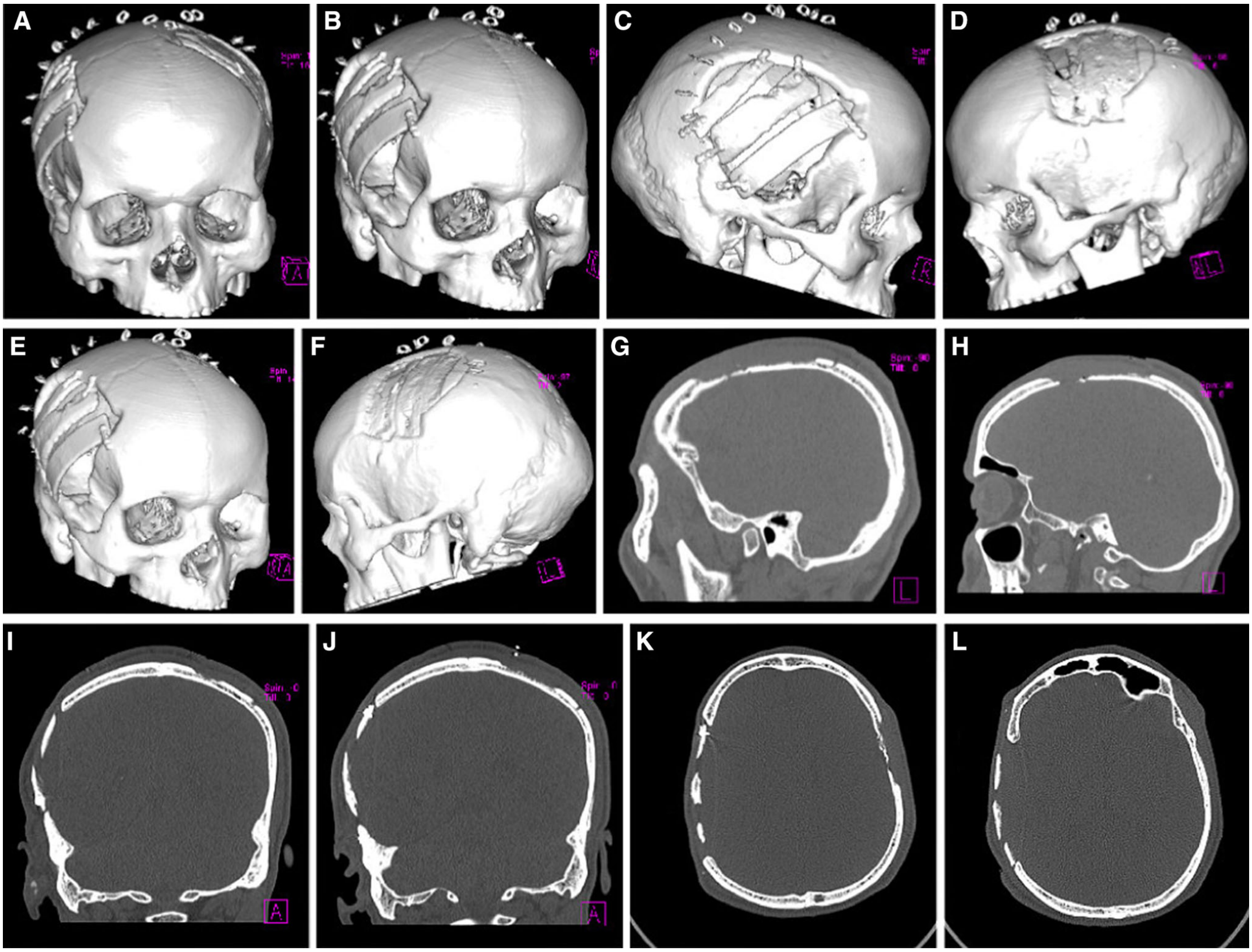


Fig. 6 **a–e** Post-cranioplasty CT scans exhibiting an excellent match between the curvature of the grafts harvested with the contour desired at the defect site, hence producing gratifying results. **f–j** Mild surface irregularity and thinning. **k**, **l** Restoration of the previously collapsed and shrunken cranial contents back to their original size, position, dimensions and volume following reconstitution of the spatial and structural integrity of the cranial vault

for cranioplasty are in vogue these days: autogenous osteoplastic reconstruction and restoration with alloplastic implants [16, 17]. Various autogenous graft materials for reconstruction of cranial defects that are available are split calvarial bone, rib and the split iliac crest, while alloplastic implant materials include 3-D dynamic titanium mesh implants, poly methyl methacrylate (PMMA) implants, Medpor implants, and combinations of the above. An ideal cranioplasty material should be bio-compatible, stable, inert, non-thermoconductive, radio-transparent, non-ferromagnetic, lightweight, rigid, simple to prepare, easily applicable and inexpensive [17]. No single graft qualifies all these prerequisites in totality. The autogenous split calvarial graft has proved its worth to be used as one of the best choices in the world literature.

Fresh autologous bone is the most suitable material for reconstruction of cranial defects in view of its perfect histocompatibility, optimal mechanical properties and good anatomico-functional fusion of the graft with the adjacent bone, as well as the potential for partial or total revitalization of the graft itself [18]. Live tissue is biologically active and quickly fuses with adjacent bone, giving excellent results. Autologous bone ensures the best physiological and cosmetic results. It has the ability to be incorporated as living tissue matrix with reparative capabilities [19]. Rib grafts and iliac bone grafts carry risks such as pneumothorax, prolonged postoperative pain, unsightly scarring, nerve injury, hernia, bowel perforation and graft fracture [20]. Split calvarial grafting/calvarial bone graft (CBG) is free from the above complications [21, 22].

The calvarium is composed of two parallel layers of cortical bone separated by a thin layer of cancellous bone. The skull reaches 75% of its thickness by the age of 5 years and full adult thickness by the age of 17 years [23]. The mean thickness of the adult skull ranges from 6.80 to

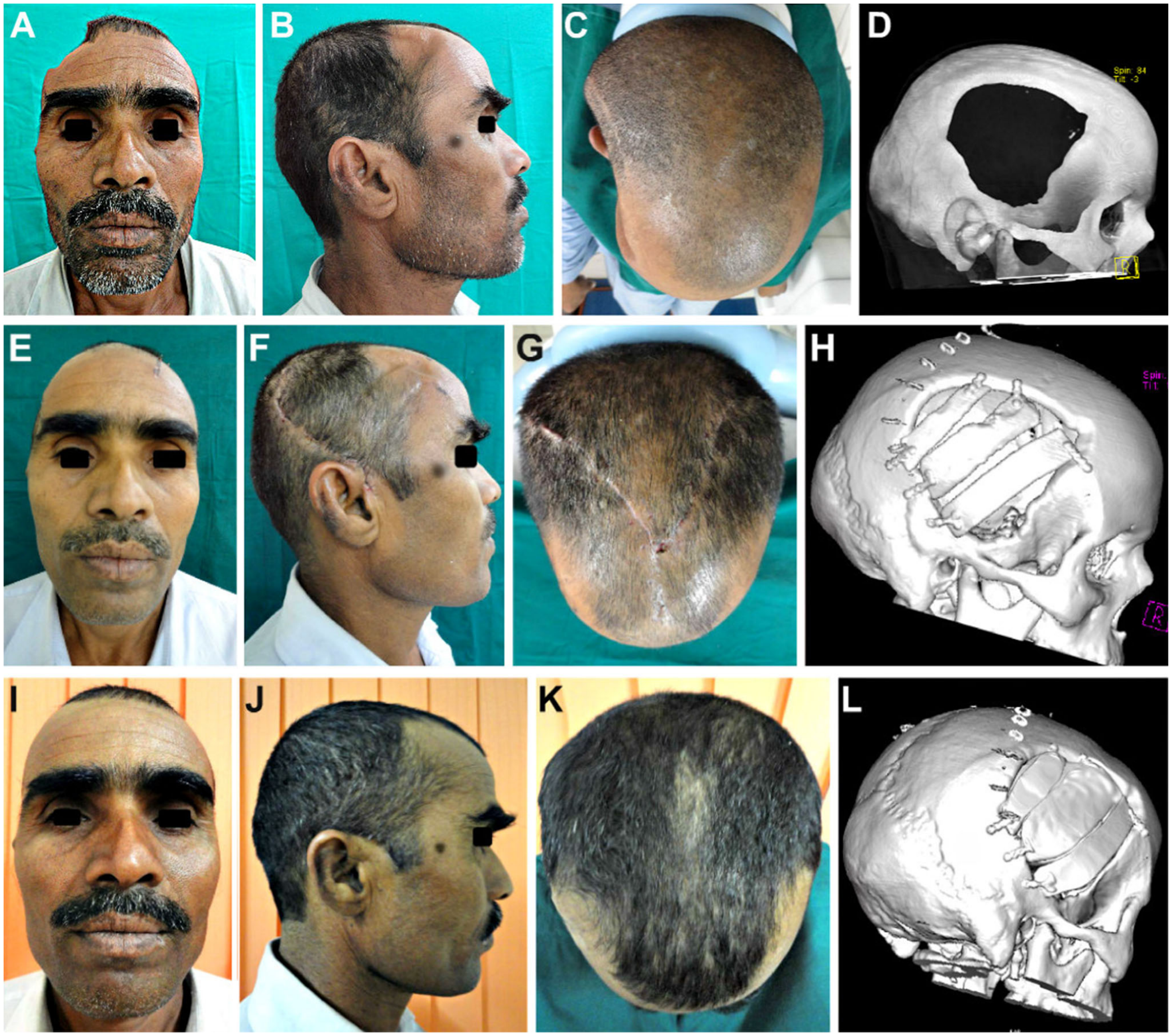


Fig. 7 **a–d** Pre-cranioplasty facial appearance and NCCT head; **e–h** immediate post-cranioplasty appearance and NCCT head; and **e–h** 18 months post-cranioplasty facial appearance and NCCT head. The good cranial contour and shape that was achieved by the cranioplasty procedure (**e–g**) was found to be well maintained even 18 months later (**i–k**), with no evidence of graft resorption. NCCT showed evidence of good graft consolidation in progress 18 months later (**l**), with widening of the graft strips and their merging with each other and with the surrounding skull bone

7.72 mm but varies by 3.0 and 2 mm at different locations. From a selected donor site, the outer table of the cranium can be split from the inner table and this outer table can be applied to cover or bridged the craniectomy defect site, leaving the inner table intact. The thickest and safest area for outer table CBG harvesting is a central 8 × 10 cm region on the parietal bone between the midline and the temporal line. Grafts must not be harvested from too close to the mid-sagittal suture, as an accidental breach of the inner cortical table in this region could result in severe bleeding from the Superior Sagittal Sinus, which is positioned just beneath the suture line. The Superior sagittal sinus is largest of the venous sinuses, and it receives blood from the frontal, parietal, and occipital superior cerebral veins and the diploic veins. Grafts taken below the temporal line put the dura at greater risk because the skull becomes thin. Unpredictable anatomic variables include emissary veins, the middle meningeal artery, and variable inner table width [24].

Calvarial bone can be harvested at three levels: partial-thickness outer cortex, full-thickness outer cortex, and bicortical. Partial-thickness outer cortex can be harvested using a very sharp osteotome to curl off a sheet of cortical bone from the outer cortical plate. This technique can be used in children between the age of 4 and 8 years and can yield enough bone to fill a small defect.

In adults, full-thickness outer cortex can safely be harvested and is therefore the most commonly used calvarial graft. If a craniotomy has already been performed, the inner cortex can be harvested from the bone flap and used in the reconstruction, leaving the outer cortex to be placed back in its original position [25]. This technique maintains the contour of the calvarium. If large quantities of bone are needed, bicortical grafts may be harvested, followed by splitting of the two cortices to double the surface of the graft. It is obvious that harvesting a bicortical calvarial graft would have the most complications hazard [26].

The temporo-parietal region provides more curved bone, while straight grafts can be harvested more posteriorly (i.e., from the occipito-parietal region). In any case, the bone is typically harvested as narrow strips (5–6 cm long × 1.5–2 cm wide) to avoid graft fracture during harvest. Then, several strips can be fixed together and used as one graft [27].

Endochondral and membranous bones have different embryologic origins and physical characteristics. Endochondral bone arises from a pre-existing cartilaginous framework and composes most of the axial skeleton. Membranous bone forms from a fibrous membrane with no intervening cartilaginous stage. Membranous bone occurs only in the calvarium, mandible, and facial skeleton [28]. Endochondral bone resorption rates are as high as 60% to 80%, whereas membranous bone resorption rates range from 17% to 20%. Outer table membranous CBGs have this superiority over endochondral bone grafts for head and neck surgery [29].

Autogenous split calvarial graft, being mesenchymal in origin with the potential of revascularization and subsequent consolidation provides an added advantage over alloplasts in previously infected or otherwise compromised recipient sites [30]. Autologous Split calvarial bone is a more physiologic and less expensive option as compared with alloplastic implants such as three-dimensional titanium mesh [31].

Another attractive feature of split calvarial grafts is that the curvature of the grafts harvested has an excellent match with the contour desired at the defect site, hence producing esthetically gratifying results. There is minimal donor-site morbidity and no additional discomfort for the patient. Bone of the appropriate contour is available in abundant supply directly in the same field of operation zone, thus entailing no separate or distant site of donor-site morbidity.

In spite of the numerous advantages, split thickness calvarial grafts carry a few disadvantages and limitations as well. A possible drawback is that the quantity of calvarial graft that can be harvested is limited, and may be inadequate when the defect is too extensive [32]. In such cases, it might need to be supplemented with an alloplastic implant, such as 3-D dynamic titanium mesh implant. There is also the risk of fracture and violation of the inner table with subsequent intracerebral hematoma and subarachnoid hemorrhage, dural tears and subsequent CSF leaks. If the dura is injured, the tear should be totally exposed, by expanding the bone defect with a rongeur, and patched with a temporalis fascia or a synthetic graft [33].

The most concerning complication of outer table graft harvest is intracranial penetration. Although this infrequently causes significant sequelae, the potential exists for sagittal sinus injury, brain injury, cerebrospinal fluid leak, and meningitis. If intracranial extension of the defect is identified as emergent, an intraoperative neurosurgery consultation to evaluate the wound is mandatory [34].

Contour abnormalities of the skull are sometimes bothersome to the patient. Care should be taken to smooth the contour of the harvest site. Some degree of bone resorption of free bone grafts is to be anticipated [35]. Over years, this resorption may be substantial. In many cases, the bone is replaced with fibrous tissue, and the structural integrity of the reconstruction remains. However, patients should be aware that bone resorption does occur and may result in contour changes with time [36]. Hematoma is a possibility, and it is recommended a surgical drain be used appropriately. Generally, this just remains overnight and can be removed the next day.

Another common complication encountered intraoperatively is graft fracture during harvest. The delicate graft strips sometimes crack into several pieces. Splitting of the calvarial bone requires expertise and may get quite arduous and time consuming, especially while reconstructing large cranial defects [37].

Following split calvarial bone grafting, both the donor and recipient sites are less biomechanically stable than adjacent normal skull [38]. Residual surface deformity at the donor and/or recipient site is also common. Although graft rejection may not occur as it is not a foreign object, graft resorption and failure of consolidation between the skull and the graft has been observed on long term follow up. Deformational stresses having been shown to accumulate around the donor site at the defect edges, weakening them and making them vulnerable to trauma [38]. However, once the graft consolidates (a process which might take from 1 to 3 years), and bone is deposited over the donor site restoring its original corticocancellous thickness, (which takes 6–12 months), the impact resistance as well as biomechanical and structural integrity of both these sites are restored [39].

Although split calvarial grafts are usually harvested from the cranium from the side contralateral to the defect, there is a risk of propagating and radiating stress fractures of the calvarium, at the time of harvesting, especially in a recently traumatized and compromised head injury case. This is the reason why case selection plays a very vital role, and it may be wiser to use alloplastic implants in such cases when the cranioplasty is carried out early (that is, within three months of the Craniectomy procedure).

However, in late cranioplasty repairs, that is more than three to six months following the craniotomy, split calvarial grafting could be the ideal option, provided there are no residual or persisting intracranial hematoma, cerebral edema or effusions [40].

A study carried out by Sahoo NK et al. has shown that as compared to alloplastic materials such as dynamic titanium mesh implants and polymethylmethacrylate (PMMA) plates, autogenous calvarial bone grafts have better mechanical, biologic, and immunologic properties. Split calvarial grafting allows the surgeon to reconstruct moderately large cranial defects with ease of access, within a single incision or one that is adjacent incision to the operating site, with minimal postoperative morbidity and discomfort. Donor-site proximity to the surgical field is a distinct advantage, which reduces the operating time when compared to other autogenous grafts harvested from distant areas such as the iliac crest or the rib [41]. Split calvarial grafts have been described as suitable materials for various kinds of craniofacial reconstruction. Their embryological origin, thickness, and shape are ideal for the restoration of craniomaxillofacial defects, such as orbital floor reconstruction, cranial defect reconstruction and alveolar cleft grafting [42].

The main contraindications for split thickness calvarial grafting are: very large defects, extremes of age and compromising medical and neurological status of the patient. Moreover, when using any autogenous bone, other disadvantages must be taken into consideration such as a need for a second operative site, donor-site morbidity, limited supply of graft material available, an increased operating time, the risk of postoperative infection and resorption of the graft with the loss of its physical properties [43].

Conclusion

Autogenous outer table split thickness corticocancellous calvarial bone grafting is a valuable option in the closure of large cranial defects. It is superior to alloplastic reconstruction in that it possesses an inherent potential for revascularization and subsequent consolidation, integrating itself with the surrounding cranial bone. It also entails a much lower cost than either custom made or prefabricated implants. There is no fear of graft rejection or infection, although graft resorption has been occasionally reported. The curvature of the graft harvested has an excellent match with the contour desired at the defect site, hence producing esthetically gratifying results. Limiting factors in its use include a definite learning curve for the operator to achieve the desired finesse, dexterity and expertise and to gain adequate experience and confidence in this highly technique-sensitive graft harvesting procedure. Intraoperative complications are a distinct possibility, especially, violation of the inner cortical table leading to dural tear, brain injury, intracranial hemorrhage, cerebrospinal fluid leak, and meningitis. The quantum of harvestable graft is limited, and may be inadequate to bridge large calvarial defects, in which case it may have to be supplemented by alloplastic implants.

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Compliance with Ethical Standards

Conflict of interest The author of this article has not received any research grant, remuneration, or speaker honorarium from any company or committee whatsoever, and neither owns any stock in any company. The author declares that she does not have any conflict of interest.

Ethical approval This article does not contain any new studies with human participants or animals performed by the author.

Informed consent Informed consent was obtained from all the individual participants in this study.

Research involving human participants and/or animals All procedures performed on the patients (human participants) involved were in accordance with the ethical standards of the institution and/or national research committee, as well as with the 1964 Helsinki declaration and its later amendments and comparable ethical standards.

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