Two-Staged Cranial Reconstruction: Tissue Expansion, Galeocapsular Flaps, and CAD/CAM Three-Dimensional Titanium Implants

Yasir Vural, MD, Can Koç, MD, Bilge Kağan Aysal, and Kemalettin Yıldız, MD

Abstract: Reconstruction of cranial defects after prior surgery remains aesthetically and technically challenging, particularly when osseous deficiency is accompanied by limited soft-tissue coverage. Recent advances in computer-aided design/computer-aided manufacturing have expanded the role of patient-specific implants in late cranial reconstruction and provided alternatives in cases in which revision osteotomy or repeat cranioplasty is not suitable. A 19-year-old male with residual cranial deformity after fronto-orbital advancement for unilateral anterior plagiocephaly underwent a 2-stage procedure. Imaging demonstrated frontal and parietal bone defects without increased intracranial pressure. A novel 2-stage reconstructive approach was planned to improve frontal projection and restore the frontoparietal contour. In the first stage, a 550-mL rectangular tissue expander was placed in the left parietal region and gradually expanded. In the second stage, a patient-specific titanium implant was designed using preoperative virtual planning based on contralateral anatomy and combined with a galeocapsular flap elevated from the expander capsule-galea complex. The implant corrected frontal and parietal depression as well as supraorbital retrusion, whereas the galeocapsular flap and expanded scalp provided vascularized soft-tissue coverage and enabled tension-free closure. At 12-month follow-up, cranial contour and frontal projection were satisfactory, with no complications including infection, wound dehiscence, implant exposure, or displacement. This 2-stage technique may represent a safe and effective option for selected patients requiring late cranial contour reconstruction after previous cranial surgery.

Key Words: CAD/CAM, cranioplasty, galeocapsular flap, late cranial reconstruction, tissue expander

(*J Craniofac Surg* ;00: 000–000)

Reconstruction of cranial defects presents significant aesthetic and functional challenges. In large defects, patient-specific solutions are often required.[1] In revision cranial reconstruction surgeries, the osteotomized bone segment is technically limited due to both underlying bone defects and the thinned calvarium resulting from previous surgical interventions.

In the management of cranial deformities, achieving cosmetically satisfactory outcomes and contour correction using titanium implants, instead of revision osteotomy surgery, has become feasible from the patient's perspective.

In recent years, the production of customized titanium implants using three-dimensional (3D) printing technologies and computer-aided design/computer-aided manufacturing (CAD/CAM) techniques has made substantial contributions to overcoming these challenges.[2]

In this study, we present an approach for late-stage cranial reconstruction performed in a patient who had previously undergone fronto-orbital advancement surgery for unilateral anterior plagiocephaly. The patient exhibited marked retrusion and depression on the plagiocephalic side, along with a frontoparietal cranial defect that precluded revision surgery. Since no increase in intracranial pressure was detected on the patient's radiological imaging, surgical intervention was planned with the aim of frontal contour correction.

In this novel technique, the surgical treatment was designed in 2 stages, targeting the enhancement of the frontal projection of a titanium implant. Due to the anticipated insufficiency of the scalp tissue and soft tissue coverage, a 2-stage surgical approach was planned using a galeocapsular flap obtained from the expander's capsule tissue. The defect was reconstructed using a patient-specific 3D titanium implant combined with a galeocapsular flap prepared with tissue expanders.

METHODS

This approach is used for patients who have undergone fronto-orbital advancement surgery and present with severe frontoparietal contour deformity. Delayed treatment is also a concerning factor for osteotomy-based surgery. This approach is suitable for implant-based reconstruction in patients of advanced age who have calvarial bone that is not amenable to osteotomy-based cranioplasty.

For this technique, a 19-year-old male patient with previously operated craniosynostosis, presenting with persistent cranial deformity, contour irregularity, and frontonasal displasia, was selected. He had undergone fronto-orbital advancement surgery in 2008 in another institution for the correction of unilateral anterior plagiocephaly (Fig. 1A). The patient's radiologic evaluation, including CT and MRI, demonstrated 2 distinct cranial defect areas in the frontal and parietal bones. No increase in intracranial pressure was observed (Fig. 1B, C).

As mentioned in the introduction, a 2-stage surgical approach was planned.

From the Department of Plastic, Reconstructive and Aesthetic Surgery, Bezmialem Vakıf University Hospital, Istanbul, Turkey.
Received May 2, 2026.
Accepted for publication May 11, 2026.
Address correspondence and reprint requests to Kemalettin Yildiz, MD, Bezmialem Vakıf University, İskender Paşa St. Adnan Menderes Blvd. 34093 Fatih/Istanbul, Turkey; E-mail: yildizkemalettin@gmail.com
The authors report no conflicts of interest.

ISSN: 1536-3732
DOI: 10.1097/SCS.0000000000013029

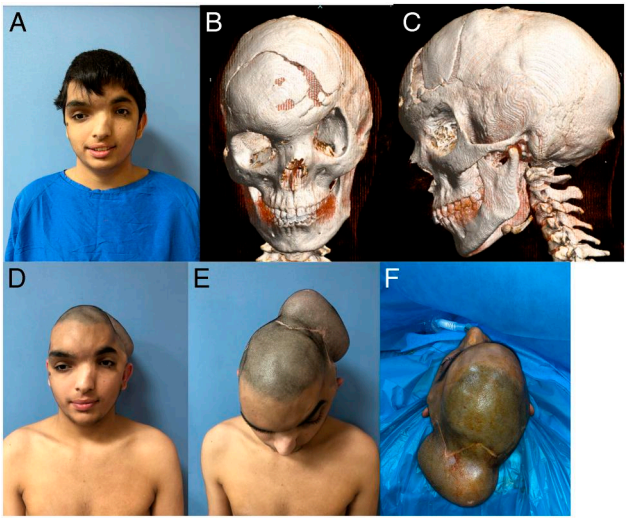

FIGURE 1. (A) Preoperative anterior view. (B) 3D CT anterior view. (C) 3D CT lateral view. (D) After tissue expander anterior view. (E) After tissue expander upper view. (F) Upper view before implant surgery.

During the first stage, a 550-mL rectangular tissue expander was placed in the left parietal region through the previous bicoronal incision scar. After 2 weeks of a healing period, the expander was gradually inflated with weekly saline injections, reaching a total volume of 570 mL during 8 weeks (Fig. 1D–F). Following completion of the expansion process, the second stage—cranial reconstruction—was scheduled 2 months later.

Although the contralateral side was used as a reference during virtual surgical planning, additional customized modifications were performed on the mirrored image. A patient-specific three-dimensional implant was designed with the aim of correcting the depressed areas in the frontal and parietal regions, addressing retrusion in the supraorbital area, and restoring contour irregularities. Furthermore, correction of the harlequin deformity was anticipated, with a consequent improvement in eyebrow position.

Using the patient's cranial CT images, a patient-specific 3D calvarial model was produced, and a custom-made implant design was performed according to the bone defect with a specific software (Mimics and 3-matics, Materialise Mimics Innovation Suite). In the initial phase, three-dimensional resin models of both the skull and the implant were printed to perform preoperative simulation (Fig. 2A). Cranial bone thickness was measured on the resin model, and the appropriate screw lengths were determined accordingly. Following approval and necessary refinements, the final implant design was established, and production of the definitive titanium implant—preoperatively tested on the printed model—was completed. The implant was designed to camouflage the existing cranial contour deformity and to restore symmetry. In addition, it was manufactured with a perforated structure to reduce overall weight.

During the second surgical session, a custom-made implant was positioned over the defect site and secured with 6 mini screws. Subsequently, a wide posterolaterally based galeocapsular flap was elevated from the capsule tissue that had developed around the removed tissue expander and was integrated with the galea (Fig. 2C).

This technique provided an additional soft-tissue layer, ensuring complete coverage of the implant (Fig. 2B, D). The edges of the large, protruding implant were covered with an additional galeocapsular flap beneath the thinned skin. The expanded scalp flap was then advanced over the implant, allowing for tension-free closure (Fig. 2E, F).

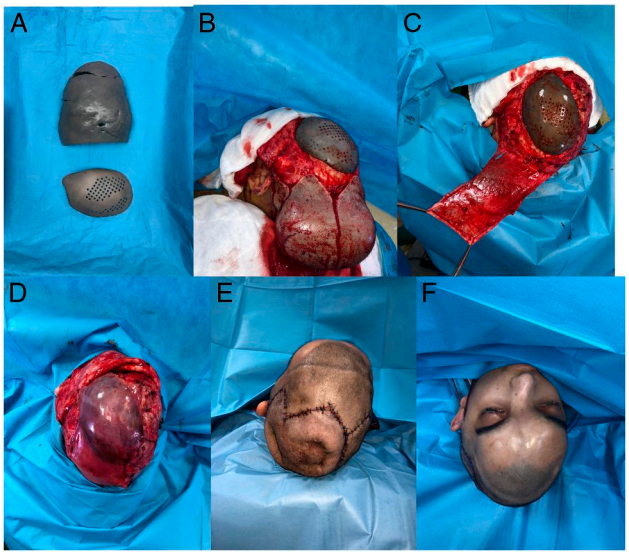

FIGURE 2. (A) 3D custom- made implant. (B) Intraoperative after implant insertion. (C) Preperation of galeocapsular flap. (D) Galeocapsular flap inset. (E) Intraoperative result upper view. (F) Intraoperative anterior view.

Postoperative recovery was uneventful. No infection, implant displacement, or wound-healing problem was observed. At 12-month follow-up, the patient remained free of complications, with satisfactory cranial contour and frontal projection (Fig. 3A–C). No development of heat or cold intolerance was observed during the follow-up period.

DISCUSSION

In the present study, the tissue expander was placed posterior to the bony defect, within healthy tissue, and without compromising the subcutaneous tissue of the previously scarred area (Fig. 2B). The galeocapsular flap obtained through tissue expansion consisted of well-vascularized autologous tissue that could be safely transposed.[3] Coverage of the implant with vascularized tissue not only provided mechanical support but also reduced the risk of complications such as infection, adhesion, and wound dehiscence. Furthermore, the additional soft-tissue layer helped to camouflage implant contour irregularities and functioned as a buffer between the implant and the skin, potentially preventing cold sensitivity during winter months.[3,4]

FIGURE 3. (A) Anterior view postoperative 6 months. (B) View from inferior postoperative 6 months. (C) Lateral view postoperative 6 months.

Secondary craniosynostosis surgeries present various technical challenges.[5] Although revision distraction procedures may be performed for cosmetic purposes in selected cases, they are not feasible in every patient due to the presence of secondary bone defects following the initial surgery, as well as thinning and reduced structural integrity of the frontal bone. Late-stage synostosis surgeries carry several risks, including increased intraoperative bleeding, a higher likelihood of bone defect development, an increased need for bone grafting, and the potential for suboptimal cosmetic outcomes.

Revision surgery for craniosynostosis has been performed in appropriately selected patients, with satisfactory cosmetic outcomes achieved in certain subgroups. However, the patient presented in this study had undergone surgery at another center at the age of 2 and was subsequently lost to follow-up; the primary complaint at presentation was cosmetic in nature. The patient was not considered a candidate for revision cranioplasty surgery due to the absence of clinical and radiological evidence of increased intracranial pressure. Given that the patient's clinical condition was not suitable for revision cranioplasty, and considering the patient's age, restoration of the fronto-orbital contour using a customized implant emerged as a viable alternative. This approach may represent a surgical option for patients who are not candidates for revision cranioplasty or who seek alternative solutions.

In such circumstances, and in other cases of late cranial defect reconstruction where restoration of symmetry and correction of deformity are required, the use of patient-specific three-dimensional implants may be considered. However, insufficient scalp surface area may increase the risk of complications, including wound dehiscence, cicatricial alopecia, and implant exposure.[6]

In late cranial defect reconstruction, adopting a 2-stage approach rather than a single-stage procedure may provide significant advantages. Expansion of the scalp skin and subcutaneous tissue increases both surface area and vascularity, thereby facilitating excision of previously scarred and alopecic regions and enabling tension-free closure over the implant. This strategy may help prevent complications such as wound necrosis, dehiscence, and perfusion-related problems.[7] Despite requiring 2 operative stages, this method may ultimately reduce the need for additional revision surgeries and the associated costs.

Reconstruction with alloplastic implants carries a risk of biofilm formation and infection due to their avascular structure and large surface area. However, recent meta-analyses have shown no significant difference in infection risk between calvarial reconstructions performed with autologous versus alloplastic materials.[8] In some studies, the infection rate for titanium mesh (2.6%) was found to be lower than that for autologous bone grafts (25.9%) and PMMA (13.8%).[9] In our approach, the implant is covered with an additional vascularized tissue, thereby forming a barrier against the development of infection, and no infections were encountered during the follow-up period.

In the study conducted by Heissler et al,[10] titanium implants were used for the reconstruction of frontal calvarial defects, and tissue expanders were placed in 5 of the 15 patients to increase soft tissue volume. In our study, the designed implant was intended not only for the reconstruction of the calvarial defect but also for the correction of the frontal contour and for achieving symmetry by matching the synostotic side to the contralateral side exhibiting frontal bossing. Therefore, the implant was designed to be more projected than the existing frontal contour. In addition to increasing soft tissue volume, the tissue expander used in our study enabled closure without hairline lowering by utilizing the preexpanded scalp flap and the surrounding galeocapsular flap.

Titanium is a biocompatible, durable, and easily moldable material.[11] Owing to its compatibility with computed tomography (CT) and magnetic resonance imaging (MRI), it also facilitates postoperative radiologic follow-up.[12] The perforated design of the implant aimed to reduce heat conduction and overall weight, thereby enhancing patient comfort.

With the use of a patient-specific three-dimensional titanium implant in combination with tissue expansion, a satisfactory cosmetic outcome was achieved despite the presence of contralateral frontal contour bossing. This approach not only reduced the risks of infection, wound dehiscence, and implant exposure but also provided aesthetically successful results.

In most published studies, frontal titanium implants have predominantly been used in patients with calvarial defects secondary to tumor resection or trauma, and they have not typically been designed with the primary aim of achieving marked projection enhancement, as in our case. One of the limitations of this technique is the unilateral design of the implant. Because the contralateral frontal bossing could not be reduced without performing an osteotomy-based cranioplasty, only unilateral advancement could be achieved from a cosmetic standpoint. Furthermore, the implant did not provide the same degree of projection to the supraorbital bar and lateral orbital rim as it did to the frontal bone, which represents an additional limitation of the method.

In the study by Chocron et al,[13] patient-specific PEEK implants and fat grafting techniques were used for frontal contour restoration following fronto-orbital advancement surgery. Although PEEK implants are more flexible and provide a smoother contour, they may not achieve the same rigidity and degree of projection as titanium implants in cases requiring significant augmentation, potentially leading to loss of shape stability; in addition, they are associated with higher costs.[14] In the present technique, titanium implants were preferred due to the requirement for substantial projection. To address the inherent drawback of titanium, namely contour palpability, an additional galeocapsular flap was utilized to improve soft tissue coverage.

Although similar implants have been described in older patients with cranial deformity seeking alternative reconstructive solutions, larger case series are needed to provide more comprehensive evidence regarding the safety, efficacy, and aesthetic outcomes of this approach.[15,16]

CONCLUSIONS

In our study, the combined use of a tissue expander–derived galeocapsular flap and a patient-specific three-dimensional titanium implant was found to be a safe and effective approach for complex late cranioplasty cases. This 2-stage technique enables correction of cranial defects, enhancement of frontal projection, and restoration of the frontoparietal contour. With careful preoperative planning and an experienced surgical team, it may serve as a viable option for a larger population of patients requiring late reconstructive cranial surgery.

REFERENCES

1. Hatamleh MM, Cartmill M, Watson J. Management of extensive frontal cranioplasty defects. *J Craniofac Surg* 2013;24:2018–2022
2. Park EK, Lim JY, Yun IS, et al. Cranioplasty enhanced by three-dimensional printing: custom-made three-dimensional-printed titanium implants for skull defects. *J Craniofac Surg* 2016;27:943–949

3. Çamli MF, Koç C, Canter HI, et al Two-staged three-layered cranial reconstruction: galeocapsular flaps through tissue expansion and slit-designed cad/cam titanium implants. *J Craniofac Surg*. 2025. doi:10.1097/scs.0000000000011752
4. Gordon CR, Fisher M, Liauw J, et al. Multidisciplinary approach for improved outcomes in secondary cranial reconstruction: introducing the pericranial-onlay cranioplasty technique. *Neurosurgery* 2014;10 (suppl 2):179–189; discussion 189-190
5. Panchal J, Uttchin V. Management of craniosynostosis. *Plast Reconstr Surg* 2003;111:2032–2048
6. Merlino G, Carlucci S. Role of systematic scalp expansion before cranioplasty in patients with craniectomy defects. *J Craniomaxillofac Surg* 2015;43:1416–1421
7. Mikami T, Suzuki H, Ukai R, et al. Flattening the curvature of synthetic materials to relieve scalp skin tension in cranioplasty. *J Clin Neurosci* 2019;61:196–200
8. Yadla S, Campbell PG, Chitale R, et al. Effect of early surgery, material, and method of flap preservation on cranioplasty infections: a systematic review. *Neurosurgery* 2011;68:1124–1129
9. Leão RS, Maior JRS, Lemos CAA, et al. Complications with PMMA compared with other materials used in cranioplasty: a systematic review and meta-analysis. *Braz Oral Res* 2018;32:e31
10. Heissler E, Fischer FS, Bolouri S, et al. Custom-made cast titanium implants produced with CAD/CAM for the reconstruction of cranium defects. *Int J Oral Maxillofac Surg* 1998; 27:334–338
11. Oliver JD, Banuelos J, Abu-Ghname A, et al. Alloplastic cranioplasty reconstruction: a systematic review comparing outcomes with titanium mesh, polymethyl methacrylate, polyether ether ketone, and norian implants in 3591 adult patients. *Ann Plast Surg* 2019;82(5S):S289–S294
12. Maqbool T, Binhammer A, Binhammer P, et al. Risk factors for titanium mesh implant exposure following cranioplasty. *J Craniofac Surg* 2018;29:1181–1186
13. Chocron Y, Alabdulkarim A, Gilardino MS. Patient-specific implants and fat grafting for contour deformities post craniosynostosis reconstruction: a therapeutic approach. *J Craniofac Surg* 2023;34:959–963
14. Shash YH. Cranial reconstruction utilizing polymeric implants in two different designs: finite element investigation. *BMC Musculoskelet Disord* 2024;25:935
15. Messerer M, Cottier R, Vandenbulcke A, et al. Aesthetic results in children with single suture craniosynostosis: proposal for a modified Whitaker classification. *Childs Nerv Syst* 2023;39:221–228
16. Park H, Choi JW, Jeong WS. Clinical application of three-dimensional printing of polycaprolactone/beta-tricalcium phosphate implants for cranial reconstruction. *J Craniofac Surg* 2022;33:1394–1399