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Case Report

Single-staged resections and 3D reconstructions of the nasion, glabella, medial orbital wall, and frontal sinus and bone: Long-term outcome and review of the literature

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Abstract

Background: Aesthetic facial appearance following neurosurgical ablation of frontal fossa tumors is a primary concern for patients and neurosurgeons alike. Craniofacial reconstruction procedures have drastically evolved since the development of three-dimensional computed tomography imaging and computer-assisted programming. Traditionally, two-stage approaches for resection and reconstruction were used; however, these two-stage approaches have many complications including cerebrospinal fluid leaks, necrosis, and pneumocephalus.

Case Description: We present two successful cases of single-stage osteoma resection and craniofacial reconstruction in a 26-year-old female and 65-year-old male. The biopolymer implants were preselected and contoured based on imaging prior to surgery. The ideal selection of appropriate flaps for reconstruction was imperative. The flaps were well vascularized and included a pedicle for easy translocation. Using a titanium mesh biopolymer implant for reconstruction in conjunction with a forehead flap proved advantageous, and the benefits of single-stage approaches were apparent. The patients recovered quickly after the surgery with complete resection of the osteoma and good aesthetic appearance. The flap adhered to the biopolymer implant, and the cosmetic appearance years after surgery remained decent. The gap between the bone and implant was less than 2 mm. The patients are highly satisfied with the symmetrical appearance of the reconstruction.

Conclusions: Advances in technology are allowing neurosurgeons unprecedented opportunities to design complex yet feasible single-stage craniofacial reconstructions that improve a patient's quality of life by enhancing facial contours, aesthetics, and symmetry.

Key Words: Biopolymers, craniofacial reconstruction, implants, osteoma, single-stage approach

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INTRODUCTION

Neurosurgical treatment for anterior cranial fossa tumors often requires extensive alteration to the surrounding bony anatomy.[6] Craniotomy with complementary osteotomy is commonly used for various neurosurgical approaches.[21] The patient's quality of life is highly dependent on cosmetic and functional reconstruction post-surgery.[12] Recent approaches have incorporated the use of computed tomography scans to accurately configure implants for osseous three-dimensional (3D) reconstruction.[9] The use of autogenous bone is preferred, however, the underlying tumor may cause osteolysis limiting the neurosurgeon's ability to use removed bone flaps for reconstruction.[11] The most common approach is a two-stage procedure involving osteotomy with surgical resection of the tumor followed by multiflap-based reconstruction in a follow-up procedure.[27] The ability to perform a single-stage orbital-cranial reconstruction at the time of tumor resection has recently been shown to offer distinct advantages.[14] The two-stage approach increases the risk for cerebrospinal fluid leakage, pneumocephalus, and necrosis.[13] The single-stage approach mitigates these complications while increasing soft-tissue flap adherence around plastic or titanium-mesh implants.[5]

Utilizing the criteria established by Yano *et al*. for skull-based defects, it may be possible for the neurosurgeon to determine when it is safe and efficient to use a one-stage vs. two-stage approach.[25] In this series, we highlight successful 3D craniofacial reconstructions of the nasion, glabella, medial orbital wall, and frontal sinus using the single-stage approach. We collected long-term follow-up data for several years after reconstruction. We provide a detailed review of the literature looking at the different types of implants used in reconstruction, the benefits of single-stage approaches, and novel developments in craniofacial reconstruction using biopolymers.

CASE SERIES

Case 1

A 26-year-old female florist presented with a craniofacial defect in the area of the nasion and glabella. She was concerned about the cosmetic appearance of the bony growth. A computed tomography (CT) scan revealed an enlarged osteoma in the area of the nasion and glabella and medial orbital wall. A surgical plan was developed for osteoma resection and craniofacial reconstruction. Preoperative planning in real time web meetings was utilized to design the plan for resection as well as 3D implant for reconstruction. An intraoperative view of the osteoma can be appreciated in Figure 1. A polymethylmethacrylate (PMMA) patient matched implant was decided upon for the reconstruction. Using 3D imaging, computer-aided design, and a skull cast [Figure 2], a detailed approach for reconstruction was formalized. First, the extent of resection was determined. Second, the optimal cosmetic outcome based on the symmetry and restoration of normal skull and skin contour was assessed. A "masquerade mask" distribution was envisioned as the best reconstruction design and created intraoperatively from the PMMA implant [Figure 3]. Third, live Webex sessions with the company were used to help define the resection margins, view the defect, and use volume averaging software to recreate the normal contour and anatomy of the nasion, glabella, frontal bone, and medial orbital wall. Intraoperatively, bony landmarks of the skull were used to define the resection and minor drilling of the implant was done to sculpt the implant. The accuracy of intraoperative bone juxtaposition, aesthetic results, complications and overall long-term outcomes were assessed.

Good cosmetic outcomes and restoration of normal skull and skin contour was achieved. The patient had an intraoperative lumbar drain placed for brain relaxation that was done to avoid frontal lobe retraction during tumor resection. The patient required a blood patch for low-pressure headache after lumbar drain removal. No cerebrospinal fluid (CSF) rhinorrhea occurred. The patient and her family stated that they were highly satisfied with the outcome [Figure 4]. An implant graft with less than 2 mm gap from the bone was achieved. She has been followed-up for 4 years after the surgery with no complications.

Case 2

A 65-year-old male presented with diplopia secondary to medial rectus displacement by the large osteoma. A CT scan revealed a large osteoma invading the medial orbital wall, glabella, nasion, and frontal sinus [Figure 5]. It was decided that a single-stage combined endoscopic, endonasal, and open bifrontal craniotomy would be performed. Gross total tumor resection was achieved, and the orbital wall, glabella, and nasion were reconstructed [Figure 6]. In the same manner as documented for the previous patient, preoperative and intraoperative planning of the resection and reconstruction was done with real time web ex meetings

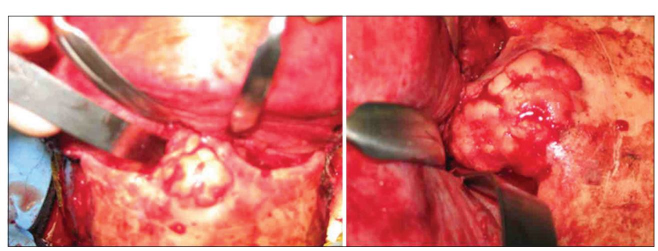

Figure 1: Osteoma involving the frontal sinus, nasion, glabella, and medial orbital wall in a 26-year-old female

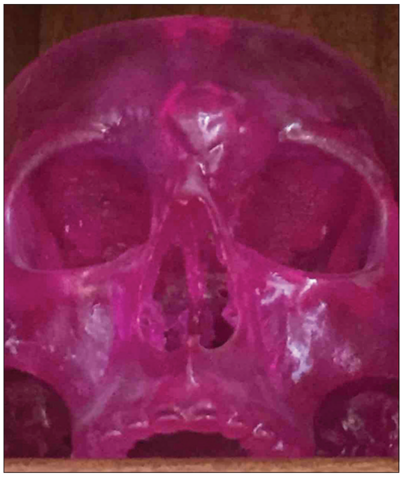

Figure 2: Three-dimensional skull model to aid in surgical planning

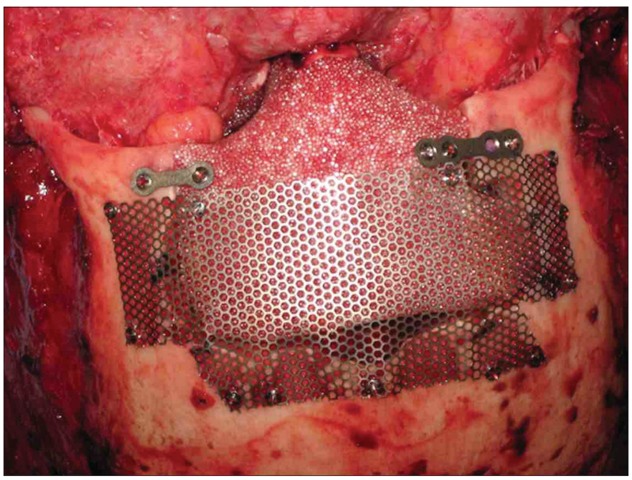

Figure 3: Single staged resection and three-dimensional reconstruction: Osteoma involving the frontal sinus, nasion, glabella, and medial orbital wall in a 26-year-old female

Figure 4: Postoperative picture showing good cosmetic outcome

based on the 3D CT scan and intraoperative images that had been obtained. The active approach to designing the resection and reconstruction affords the surgeon a very detailed understanding of the patient's surface anatomy. Contour margins of 2 cm were made around the defect in order to design a custom 3D reconstruction [Figure 7]. The high tensile strength of the PMMA implant allowed successful configuration around the orbit. The porous implant with pre-plating allowed successful adhesion to the remaining bone with less than a 2 mm gap. The skin flap was placed and the incision site closed.

Post-surgical recovery was uneventful. Objective outcomes were considered good with the implant resting passively on the surrounding bone. The "masquerade mask" 3D reconstruction was performed to ensure a great fit with contoured symmetry. The patient reports high satisfaction with good aesthetic appearance [Figure 8] post reconstruction. The stability of the reconstruction has been maintained for the past 3 years.

DISCUSSION

Complex bony deformities in the craniofacial region are common following surgical tumor resection.[15] Approximately 28000 new patients each year require craniofacial reconstruction following tumor ablation.[23] Orbital deformities, in particular, warrant carefully designed reconstruction. Neurosurgeons performing these reconstructions have benefited from the recent development of 3D imaging and computer-aided design and manufacturing.[27] The 3D imaging allows for careful reconstruction not only of the bony abnormality but also overall facial contour with the use of soft tissue buttress flaps.[2] To perform a single-stage procedure for tumor resection and craniofacial reconstruction, it is often necessary to customize a computer-assisted planning and execution workstation.[8] The workstation can be employed with cone beam CT to give an accurate 3D image that can be used to plan reconstruction prior to surgery.[16] By evaluating the magnitude of the resection via the 3D image, the neurosurgeon can determine the necessity of an autologous skin flap or a specific implant type [Table 1] prior to surgical intervention.[24]

Depending on case complexity, the neurosurgeon must decide if a single-stage or two-stage approach is best for resection and reconstruction. A two-stage approach has clear limitations. By re-exposing the patient to a second surgery, the likelihood of flap-associated infection drastically increases.[4] In the past, two-stage approaches were almost universally necessary for implants because two-dimensional (2D) printing workstations limited the ability of the neurosurgeon to produce adequate 3D contours at the bedside.[3] This has been solved by 3D printing, which facilitates better preoperative planning and implant preparation. Two-stage approaches are still recommended when using multiple flaps for reconstruction. Often the two-stage procedure is complicated by wound contracture, however, it lengthens operation time.[10] Double-layer fascial grafts

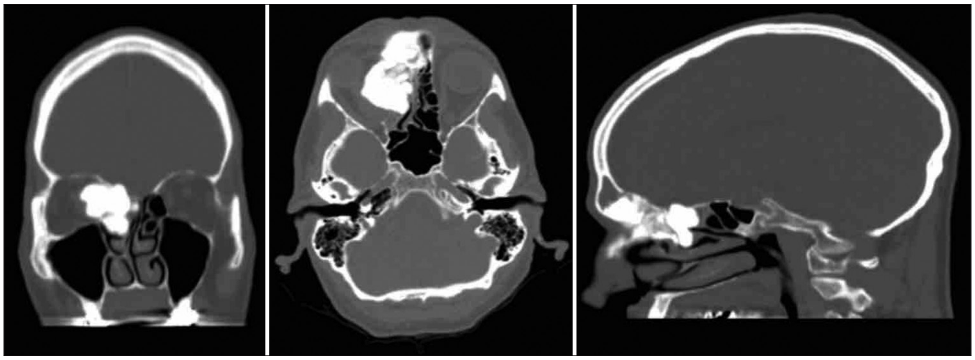

Figure 5: Osteoma involving the medial orbital wall, nasion, glabella, frontal bone and sinus, ethmoids, cribriform with displacement of the medial rectus and optic nerve

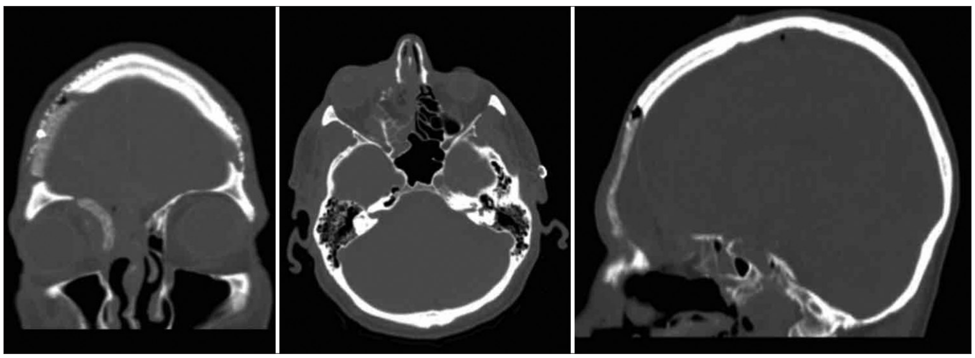

Figure 6: Complete total resection of the osteoma using a combined endonasal endoscopic approach with bifrontal craniotomy

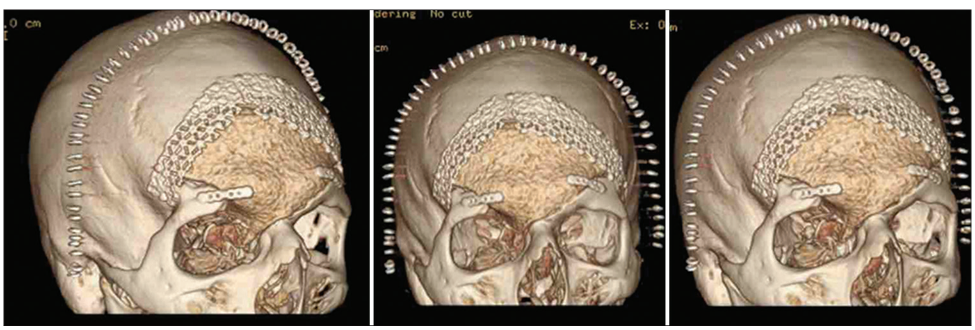

Figure 7: Combined endoscopic endonasal and bifrontal craniotomy with preoperative custom three-dimensional reconstruction

Table 1: Implant type, benefits, and uses

Implant Type	Benefits	Primary Use
Titanium	Good retention, not affected by environment	Dental implants
PMMA, polymethyl-methacrylate	Good biocompatibility	Temporal skull defects
PEEK, poly-ether-ether-ketone	Strong tensile strength	Craniofacial skull defects
PEEK poly-ether-ether-ketone w/ titanium mesh	Combines contours of porous implant with strengthened mesh	Orbital reconstructions
UHMWPE ultra-high-molecular-weight polyethylene	Oxidation resistant	Spine implants

are frequently required to prevent CSF leakage in these two-stage approaches.[7] One-stage approaches should be employed when the bony defect can be adequately appreciated with preoperative 3D imaging and an implant can be readily designed for the reconstruction.[20] Table 2 highlights the differences between one-stage and two-stage approaches. A single-staged resection and reconstruction technique is more cost effective than

Table 2: One-stage vs. two-stage approach

	One-Stage	Two-Stage
Use When	Bony defect can be seen with 3D imaging and computer-assisted planning is available	Long surgery expected with multiple flaps for reconstruction
Primary Reconstruction Technique	Implants	Flaps
Complications	Infection of implant and immune activation	Cerebral spinal fluid leak, meningitis, pneumocephalus
Surgical Challenges	Contouring implant in real time in the operating room	Contracture at initial surgical site
Special Considerations	Ideal for Yano Classification Stage IA-C tumors	May require double-layer fascial grafts

Figure 8: Combined endoscopic endonasal and bifrontal craniotomy with single staged custom three-dimensional reconstruction at 2 weeks postoperatively

a two-staged approach to perform. The single-staged approach obviates the period of time the patient is faced with an acquired cranial defect, and reduces the need to wear a helmet. It also mitigates the emotional and cosmetic self-esteem issues that can result.

Autologous bone grafts are the gold-standard for reconstruction, but due to a lack of sufficient donor sites, implants are more commonly used.[19] Recent advances in bioengineering and stem cell biology have shown promise for the use of biopolymers in conjunction with implants to limit infection risk and immune activation.[1] These biologic approaches have the potential to improve cosmetic appearance for 3D reconstructions.[22] Mesenchymal stem cells may be used to repopulate tissue that was resected during tumor ablation.[18] This new development in craniofacial reconstruction will allow aesthetics to advance to a point where geodesic networks can be used to classify reconstruction success.[26] Geodesic networks evaluate the accuracy of facial appearance based on ideal contours of the patient's reconstructed skull. In order to enhance reconstruction accuracy, the use of specialized biosurgery approaches to recruit mesenchymal stem cells to areas of deformity will be required.[17]

The nasion-glabellar region is a very challenging region to reconstruct. The goal is to return a patient to an appearance that is consistent with their normal anatomy. Both of these patients had significant and noticeable preoperative deformities involving the regions of the nasion, glabella, and medial orbital wall. Preoperative real time online web-based 3D planning of the resection was essential in understanding the extent of the defect. This approach also allowed the surgeon to actively plan a tailored reconstruction. During the planning of the osteoma resections, it was determined that a larger area of frontal bone was to be removed laterally to create a more uniform appearance of the frontal bone. As such, we have coined the phrase "masquerade mask" reconstruction to describe the technique.

CONCLUSION

Craniofacial reconstruction following ablative neurosurgery is necessary to improve patient's quality of life. Historically, two-stage approaches have been used for resection and reconstruction. With the advent of 3D imaging, computer-assisted programming, and preoperative planning, it is now feasible to conduct single-stage approaches. Single-stage 3D preoperative planning provides the patient and healthcare system with multiple potential benefits. These benefits would be cost savings, avoiding multiple hospitalizations, decreased complications, good long-term cosmetic results, and high patient satisfaction.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Conflicts of interest

There are no conflicts of interest.

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