CUSTOMIZED 3D-PRINTED BONE RESECTION GUIDE AND PMMA CRANIOPLASTY MOLD IN OSTEOLYTIC LESIONS – A CASE REPORT

PEROSNALIZOVANI TRODIMENZIONALLNI ŠTAMPANI VODIČ ZA RESEKCIJU KOSTI I KALUP ZA PMMA KRANIOPLASTIKU KOD OSTEOLITIČKIH LEZIJA – PRIKAZ SLUČAJA

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Case report
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Abstract
Introduction. Osteolytic skull lesions pose significant surgical challenges because of their destructive nature and potential involvement of adjacent soft tissues. Complete resection of the affected bone is essential to reduce the risk of recurrence and ensure cranial stability; however this frequently results in large defects that require precise and immediate reconstruction. Advances in three-dimensional printing have enabled patient-specific surgical planning and the creation of customized tools and implants, thereby improving surgical accuracy, operative efficiency, and cosmetic outcomes. **Case Report.** We present a case of a patient with an osteolytic skull lesion treated using a customized three-dimensional-printed bone resection guide and a polylactic acid mold for intraoperative polymethyl methacrylate cranioplasty. Preoperative computed tomography and magnetic resonance imaging data were used to generate a virtual three-dimensional model, allowing accurate definition of resection margins and precise implant design. This approach enabled controlled lesion excision and immediate reconstruction using a well-fitting polymethyl methacrylate implant. Postoperative imaging confirmed complete lesion resection and optimal implant positioning, with excellent cosmetic and functional outcomes observed at one-year follow-up. **Discussion.** The integration of three-dimensional printing into cranial reconstructive surgery enhances surgical precision, reduces operative time, and offers a cost-effective method for individualized reconstruction. This case highlights the practical applicability of three-dimensional-printed surgical guides and molds in managing complex osteolytic skull lesions. **Conclusion**. The use of three-dimensional-printed resection guides combined with intraoperative polymethyl methacrylate molding enables accurate bone resection and immediate cranial reconstruction, achieving high precision, reproducibility, and favorable clinical outcomes.
Key words: 3D printing; osteolytic skull lesion; cranioplasty; Bone resection; PMMA; personalized surgery

Sažetak
Uvod. Osteolitičke lezije lobanje predstavljaju značajan hirurški izazov zbog svog destruktivnog karaktera i potencijalnog zahvatanja i kosti i okolnih mekih tkiva. Postizanje potpune resekcije zahvaćene kosti od suštinskog je značaja za smanjenje rizika od recidiva i obezbeđivanje strukturne stabilnosti, ali takav pristup često dovodi do velikih kranijalnih defekata koji zahtevaju preciznu i trenutnu rekonstrukciju. Napredak u tehnologiji trodimenzionalne štampe omogućio je individualno planiranje operacije i izradu implantata, čime su poboljšani preciznost, efikasnost operativnog zahvata i estetski ishodi. **Prikaz slučaja.** Prikazujemo slučaj bolesnice sa osteolitičkom lezijom lobanje koja je lečena primenom prilagođenog trodimenzionalno štampanog vodiča za resekciju kosti i kalupa od polilaktične kiseline za intraoperativnu kranioplastiku polimetilmetakrilatom. Preoperativni podaci dobijeni kompjuterizovanom tomografijom i magnetnom rezonacom iskorišćeni su za izradu virtuelnog trodimenzionalnog modela, koji je omogućio precizno određivanje margina resekcije i dizajn implantata. Ovaj pristup omogućio je precizno uklanjanje lezije i trenutnu rekonstrukciju sa dobro prilagođenim polimetilmetakrilatnim implantatom. Postoperativno snimanje potvrdilo je potpunu resekciju i adekvatno pozicioniranje implantata, uz odlične estetske i funkcionalne rezultate tokom jednogodišnjeg praćenja. **Diskusija.** Integracija trodimenzionalne štampe u kranijalnu rekonstruktivnu hirurgiju donosi veću tačnost, kraće trajanje operacije i ekonomičnu prilagodljivost. Ovaj slučaj naglašava praktičnu i inovativnu vrednost trodimenzionalne tehnologije u lečenju osteolitičkih lezija lobanje i optimizaciji rezultata kranijalne rekonstrukcije. **Zaključak**. Primena trodimenzionalno štampanih vodiča za resekciju u kombinaciji sa intraoperativnim oblikovanjem polimetilmetakrilata omogućava precizno uklanjanje lezije i neposrednu rekonstrukciju kranijuma sa zadovoljavajućim funkcionalnim i estetskim ishodima.
Ključne reči: 3D štampa; Osteolitička lezija lobanje; Kranioplastika; Resekcija kosti; PMMA; Personalizovana hirurgija

Introduction

Osteolytic skull lesions comprise a heterogeneous group of pathological entities characterized by focal destruction of calvarial bone, often involving both cortical and cancellous layers. These lesions may result from primary bone tumors, metastatic disease, hematologic malignancies, infectious processes, or

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Abbreviations

PMMA	– polymethyl methacrylate
3D	– three-dimensional
PLA	– polylactic acid
CT	– computed tomography
MRI	– magnetic resonance imaging
PEEK	– polyetheretherketone/polyether ether ketone
CAD	– computer-aided design

inflammatory disorders [1,2]. Clinical presentation ranges from incidental asymptomatic findings to painful, palpable masses or neurological symptoms caused by intracranial extension. Regardless of etiology, osteolytic skull lesions pose sustainable surgical challenges owing to their often ill-defined margins, potential invasion of adjacent dura or soft tissues, and the cosmetic and functional consequences of bone resection [3,4]. Complete excision of the affected bone is essential to prevent recurrence or progressive osteolysis, however, such resections frequently result in large cranial defects that necessitate immediate and accurate reconstruction. Conventional reconstruction approaches – including autologous bone grafts, intraoperatively hand-molded polymethyl methacrylate (PMMA), and prefabricated alloplastic implants – are associated with several limitations, such as suboptimal anatomical fit, prolonged operative time, and variable cosmetic outcomes [5]. The integration of three-dimensional (3D) printing technology into cranial reconstructive surgery has significantly advanced both preoperative planning and intraoperative precision. Using high-resolution CT imaging, computer-aided design (CAD), and additive manufacturing, patient-specific surgical guides and reconstruction tools can now be fabricated with millimetric accuracy [6–8]. Customized bone resection guides enable precise delineation of resection margins while minimizing unnecessary bone loss, while intraoperative molds facilitate rapid fabrication of anatomically accurate PMMA implants. Together, these innovations improve surgical accuracy, reduce operative time, and enhance functional and aesthetic outcomes [8,9]. The availability of biocompatible printable materials such as polylactic acid (PLA) and polyetheretherketone (PEEK) has further expanded the scope of safe intraoperative customization [9,10]. This multidisciplinary strategy – combining neurosurgery, biomedical engineering, and materials science – represents a major advancement in patient-specific cranial reconstruction. In this report, we describe a case of an osteolytic skull lesion treated using a customized 3D-printed bone resection guide and an intraoperative PLA mold for PMMA cranioplasty, highlighting the precision and efficiency of this technique.

Case Report

Patient Information

A 55-year-old female presented with headache and a palpable skull mass over the right frontoparietal region. Neurological examination revealed no focal deficits, although mild scalp tenderness was noted over the lesion. Imaging studies, including CT (Figure 1) and contrast-enhanced MRI, demonstrated a hyperostotic lesion in the right frontoparietal region with an associated soft-tissue component.

Surgical Planning and 3D Printing Process

Given the extent of bone involvement, a multidisciplinary approach was adopted, integrating neurosurgical, radiological, and biomedical engineering expertise. High-resolution CT and MRI datasets were

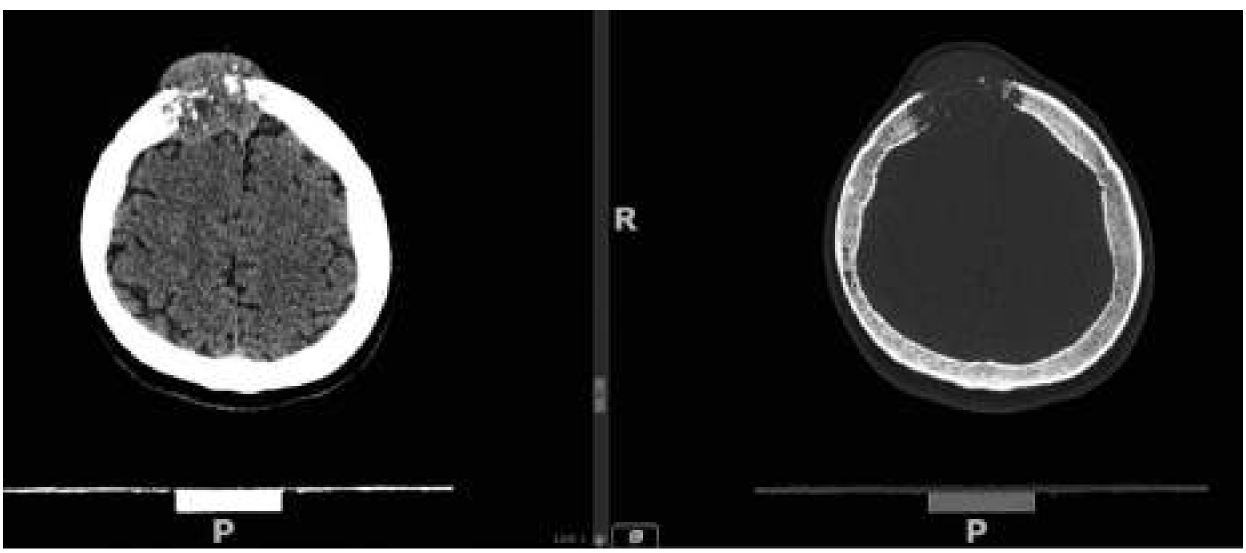

Figure 1. Preoperative endocranial CT – *osteolytic lesion*

processed using Fusion 360 CAD software to generate an accurate 3D model of the skull, lesion, and surrounding anatomical structures. This model enabled virtual surgical planning, including precise definition of resection margins while preserving critical neurovascular structures.

A patient-specific 3D-printed bone resection guide was designed to conform exactly to the cranial surface, ensuring accurate and reproducible bone removal. In addition, a PLA mold was created for intraoperative fabrication of a customized PMMA implant. Both the cutting guide and the mold were manufactured using polylactic acid and sterilized with ethylene oxide prior to surgery.

Surgical Procedure

A standard curved skin incision was performed to expose the hyperostotic bone. The PLA resection guide was positioned and secured, allowing for precise bone removal along the preplanned surgical margins. Guided resection facilitated complete excision of the involved bone, followed by microsurgical tumor removal while maintaining anatomical accuracy. After resection, the sterilized PLA mold was used intraoperatively to form a PMMA implant, which was contoured and polished to match the surrounding cranial anatomy. Fixation was achieved using stainless steel wires, providing stable reconstruction.

Postoperative Outcome

The postoperative course was uneventful. Follow-up CT imaging **(Figure 2)** confirmed complete lesion resection and accurate positioning of the PMMA implant. At one-year follow-up, the patient reported excellent cosmetic satisfaction and functional outcome, with no evidence of complications or recurrence.

Discussion

The application of 3D printing in cranial reconstructive surgery has substantially improved the management of osteolytic skull lesions. Traditional techniques based on intraoperative estimation and manual implant shaping are often associated with prolonged operative times and imprecise reconstruction, particularly in large or irregular cranial defects [6,7]. In contrast, patient-specific 3D-printed resection guides and molds enable highly accurate surgical planning and reconstruction that closely replicates native cranial anatomy. Preoperative 3D modeling allows precise visualization of lesion extent, facilitating controlled bone removal while protecting adjacent neurovascular structures [7]. In cases of metastatic or locally aggressive osteolytic disease, this approach improves oncological clearance by minimizing residual pathological bone [3]. Simultaneously, 3D-assisted reconstruction provides superior aesthetic results – an especially important consideration for anterior or frontotemporal defects, where cosmetic outcomes significantly influence postoperative quality of life [8,9].

The use of customized PLA molds for intraoperative PMMA cranioplasty eliminates labor-intensive manual shaping, reducing operative time and potential human error. PMMA remains a reliable and cost-effective cranioplasty material, offering excellent mechanical strength, contourability, and long-term biocompatibility [8]. The addition of 3D-printed molds further enhances implant precision, ensuring seamless integration with adjacent bone and reducing postoperative asymmetry [9]. Sterilization and biocompatibility remain important considerations.

Although PLA is unsuitable for permanent implantation, its application as a temporary intraoperative

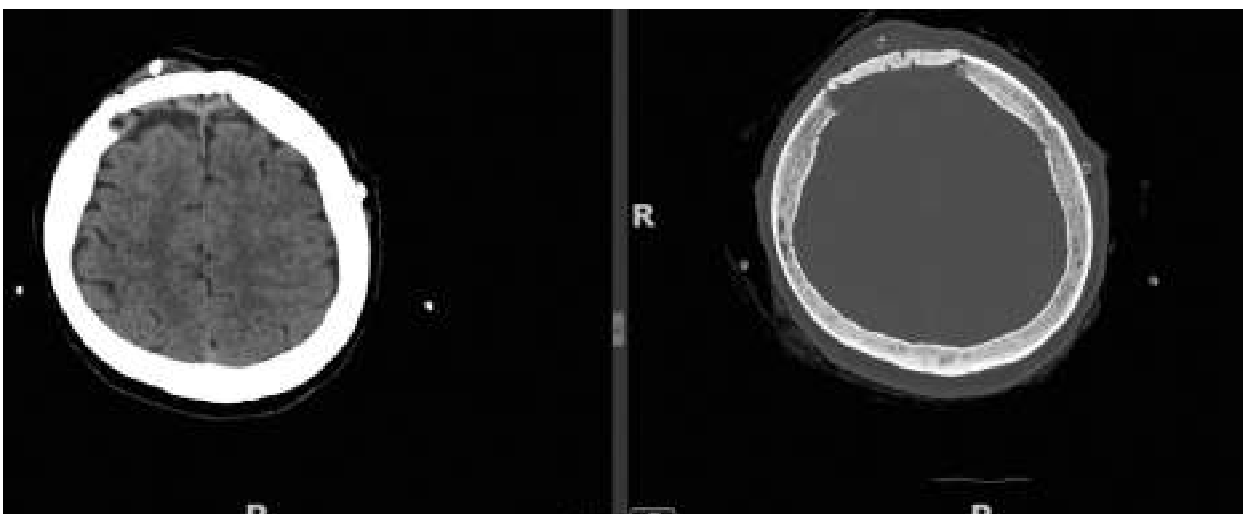

Figure 2. Postoperative endocranial CT – *PMMA implant*

guide or mold is safe when appropriately sterilized, most commonly using ethylene oxide [10]. Emerging printable biopolymers, including PEEK and composite resins with antibacterial coatings, may further improve long-term safety, sterility, and durability [9,10].

From an economic standpoint, in-house 3D printing represents a cost-effective alternative to commercially prefabricated implants, particularly in resource-limited healthcare settings [8]. The increasing availability of open-source software and affordable 3D printers has facilitated broader access to patient-specific cranial reconstruction, allowing neurosurgical teams to produce accurate surgical aids locally [9]. Nevertheless, successful implementation requires technical expertise in image segmentation, CAD modeling, and additive manufacturing [6]. Close collaboration among neurosurgeons, radiologists, and biomedical engineers is essential to ensure optimal outcomes. Establishing standardized protocols and training programs can promote wider adoption and consistency across institutions [10,11]. Future studies should focus on long-term outcomes of 3D-assisted reconstruction in osteolytic skull lesions, including implant stability, recurrence rates and patient satisfaction. Comparative analysis between conventional and 3D-guided cranioplasty techniques are also needed to further define clinical and cost-effectiveness [9–11]. As digital planning platforms continue to evolve, the integration of artificial intelligence for automated image segmentation and implant modeling may further streamline this process, enhancing both precision and accessibility. The combined use of 3D-printed resection guides and intraoperative PMMA molding represents a transformative advancement in the management of osteolytic skull lesions. This approach improves surgical accuracy, reduces operative time, and achieves superior cosmetic and structural outcomes. With ongoing developments in biocompatible materials and digital design technologies, patient-specific 3D printing is poised to become a cornerstone of contemporary cranial reconstructive surgery.

Conclusion

Three-dimensional printed bone resection guides combined with intraoperative polymethyl methacrylate molding enable precise lesion resection and immediate reconstruction in patients with extensive osteolytic skull lesions. This approach enhances surgical accuracy, improves workflow efficiency, and yields favorable functional and cosmetic outcomes. Further prospective studies are warranted to assess long-term durability and to define the role of this technique in standard neurosurgical practice.

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