AN EXAMPLE OF CRANIOPLASTY WITH THE ASSISTANCE OF 3D PRINTING TECHNOLOGY: A CASE REPORT

PRIMJER KRANIOPLASTIKE UZ ASISTENCIJU TEHNOLOGIJE 3D PRINTANJA: PRIKAZ SLUČAJA

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REZIME

Kranioplastika je hirurška popravka koštanog defekta lobanje koji je ostao nakon ozbiljne povrede ili prethodne operacije. Uobičajna svrha ove intervencije je zaštita moždanog tkiva, smanjenje lokalnog bola i poboljšanje estetike kranijalnog svoda. Kranijalne proteze mogu biti napravljenje od različitih materijala: autologne kosti, titanijuma, keramike i polimera. Njihova proizvodnja je skupa i često zahtijeva kompleksne intraoperativne procese, što ponekad rezultira slabim estetskim rezultatima kod velikih i kompleksnih defekata. Ovaj rad, na konkretnom primjeru, predstavlja metod za izradu implanta po mjeri pacijenta od polimetil metakrilata, uključujući trodimenzionalnu rekonstrukciju baziranu na CT snimcima, tehnologiju 3D printanja i izradu kalupa od zubarskog gipsa.

Professional paper

SUMMARY

Cranioplasty is the surgical repair of a bone defect in the skull that is left behind after a severe injury or previous operation. It is usually done to protect underlying brain tissue, reduce local pain and to improve the cranial vault aesthetics. Cranial prostheses can be made from different types of materials: autologous bone, titanium, ceramics and polymers. Their production is costly and often requires complex intraoperative processes which sometimes cause poor aesthetic results in large and complex defects. Using a real case, this paper presents a customised polymethyl methacrylate implant production method which involves three dimensional reconstruction based on CT scans, technology of 3D printing and mold-making from dental plaster.

1. UVOD

Nekoliko mogućih razloga za gubitak kontinuiteta kostiju kranijalnog svoda su: ozbiljna povreda glave, dekompresivna kraniotomija ili recidiv tumora. Ova vrsta defekta je zaista teška za pacijenta jer često uzrokuje fizičke (glavobolju, konfuziju, epilepsiju), ali i mentalne probleme (razdražljivost, depresija) [1]. Estetske abnormalnosti uzrokovane defektom lobanje također su jedan od glavnih problema, posebno kod mlađih pacijenata. Ljudsko tijelo nije u stanju regenerisati izgubljeni dio lobanje, ali se on može rekonstruisati kroz multidisciplinarni pristup i postavljanje proteze. Medicinski termin za ovu neurohiruršku proceduru je kranioplastika i prakticira se od 3000. godine p.n.e.

Postoji nekoliko materijala koji se koriste za izradu kranijalnih proteza: koštani transplantati, metali, biosintetički materijali kao što su keramika i smola. Metil metakrilat je reaktivna smola čija je formula $CH_2 = C(CH_3) COOCH3$, a

1. INTRODUCTION

Severe head injury, decompressive craniotomy or tumor recesion, are all possible reasons for lack of continuity of the cranial vault bones. This kind of defect is really hard for a patient since they often cause physical (headache, confusion, epilepsy) as well as mental problems (irritability, depression) [1]. Aesthetic abnormalities caused by skull defects are also one of the major problems, especially among young patients.

It is not possible for human body to regenerate a lost part of a skull, but, it can be reconstructed through a multidisciplinary approach and the placement of a prosthesis. The medical term for this neurosurgical procedure is cranioplasty and it has been practiced since 3000 BC.

There are several materials which are used for cranial prostheses: bone grafts, metals, biosynthetic materials such as ceramics and resin. Methyl methacrylate is a reactive resin with the formula $CH_2=C(CH_3)COOCH_3$ which was used for the first time in 1941; since then

prvi put je korištena 1941. godine; od tog vremena u operacionoj sali korišteni su i mnogi drugi derivati [2].

Proteze od polimetil metakrilata (PMMA) se prave intraoperativno i zahtijevaju pripremu dvokomponentne smjese, kao i podešavanja implantata - oblikovanje za vrijeme operacije što rezultira produženjem trajanja operacije. Kod velikih i složenih defekata, intraoperativna podešavanja implantata, naročito oblikovanje nepravilne krivine rukama, mogu rezultirati lošim estetskim rezultatima. PMMA ima mnoge prednosti: ne postoji potreba za donorom, nije previše skup, lagan je, otporan, inertan, radiolucentan, ne-feromagnetski i stabilan. Nedostaci su u tome što ima nizak stepen prijanjanja za okolno tkivo i može izazvati reakcije tkiva.

Da bi se napravila kranijalna proteza koja savršeno odgovara nedostajućem dijelu lobanje, koriste se tehnike računarske slike (kompjuterska tomografija ili magnetna rezonanca) u kombinaciji sa 3D modeliranjem zasnovanim na slikama i 3D printanjem [3]

2. PRIKAZ SLUČAJA

Nakon teške kraniocerebralne povrede, dvadesettrogodišnjem pacijentu zaostao je veliki koštani defekt koji je obuhvatao cijelu desnu polovinu lobanje i protezao se na krov očne šupljine (Slika 1).

many other derivatives have been used in the operating room [2].

Polymethyl methacrylate (PMMA) prostheses are produced intraoperatively and require preparation of the binary mixture as well as implant adjustments - molding at the time of surgery that causes an increase in operating time. In large and complex defects, intraoperative implant adjustments, especially molding irregular-shaped curvature by hands, may cause poor aesthetic results. PMMA has many advantages: no donor is required, it is not too expensive, it is lightweight, strong, inert, radiolucent, non-ferromagnetic and stable. The disadvantages are that it has low adherence to the surrounding tissue and it may cause tissue reactions.

In order to make a cranial prosthesis which perfectly fis to missing part of the skull, computer imaging techniques (Computed Tomography or Magnetic Resonance Imaging) in combination with image based 3D modeling, and 3D printing are used [3]

2. CASE REPORT

After a severe craniocerebral injury, a twenty-three-year-old patient was left with a large bone defect that covered the entire right half of the skull and stretched to the roof of the eye cavity (Figure. 1)

Slika 1. *Izgled lobanje pacijenta nakon teške kraniocerebralne povrede*
Figure 1*. The skull of the patient after severe craniocerebral injury*

Pacijent je imao kako estetske tako i funkcionalne poteškoće. S obzirom na veličinu defekta, nije bilo moguće načiniti adekvatnu rekonstrukciju nedostajućeg dijela lobanje primjenom standardnih neurohirurških metoda.

Trodimenzionalni model lobanje napravljen je koristeći CT snimke u DICOM formatu i softver za obradu medicinskih slika – Materialise Mimics 10.01 (Slika 2). Koristeći digitalne tehnike isijecanja i preslikavanja sa lijeve strane lobanje, konstruisan je 3D model implanta kojim se uspješno zatvorio defekt na desnoj strani modela lobanje (Slika 3). Digitalni model implanta izvezen je u STL formatu za potrebe 3D printanja.

Izrada prototipa proteze od PLA (polilaktička kiselina) plastike iz STL fajla izvršena je na 3D printeru Ultimaker 2+ korištenjem FDM (modeliranje spajanjem nanošenih slojeva) tehnologije (Slika 4). Nakon što je proces 3D printanja, koji je trajao oko 20 sati, završen, izrađen je kalup za izradu implanta od zubarskog gipsa (Slika 5).

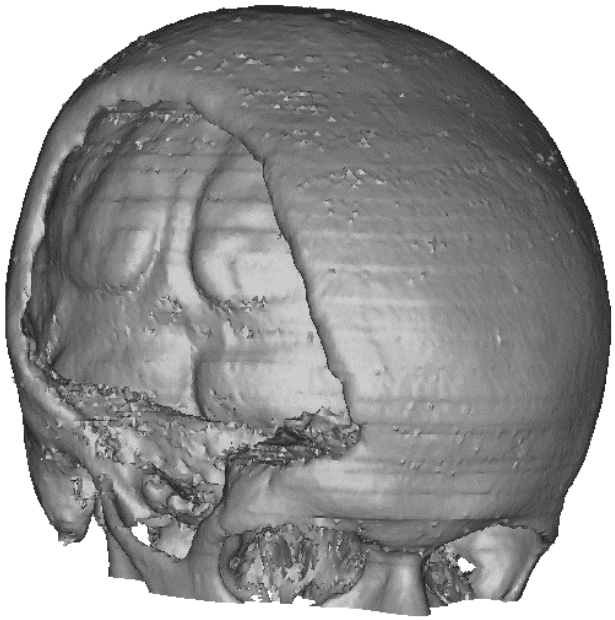
Tokom dvosatne hirurške intervencije, PMMA implantat, koji je napravljen intraoperativno koristeći pripremljeni kalup, uspješno je postavljen na mjesto defekta.

The patient had both aesthetic and functional difficulties. Given the size of the defect, it was not possible to make an adequate reconstruction of the missing skull part using standard neurosurgical methods.

Three-dimensional skull model was done using CT images in DICOM format and medical image processing software – Materialise Mimics 10.01 (Figure 2). Using digital cutting and mirroring techniques on the left side of the skull, a 3D model of the implant was constructed, which successfully closed the defect on the right side of the skull model (Figure 3). The digital implant model was exported to the STL format for 3D printing purposes.

Ultimaker 2+ 3D printer was used to print out a prototype PLA (Polylactic acid) implant from the STL file using FDM (Fused Deposition Modeling) technology (Figure 4). After the 3D printing process, which lasted about 20 hours, was completed, a mold for the implant was created using the dental plaster (Figure 5).

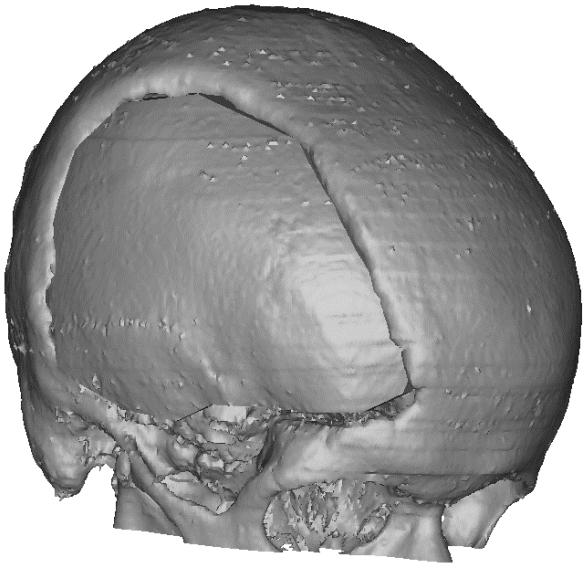
During a two-hour surgical intervention, the PMMA implant, which was made intraoperatively using the preformed mold, was successfully placed at the defect site.



Slika 2. *Digitalna 3D rekonstrukcija lobanje pacijenta*
Figure 2*. Digital 3D reconstruction of the patient's skull*

Nakon osam dana oporavka pacijent je otpušten kući potpuno zadovoljan postignutim rezultatima (Slika 6). Osim obnovljene estetike kranijalnog svoda pacijent je prestao imati glavobolje uzrokovane djelovanjem atmosferskog pritiska na moždano tkivo.
Stanje pacijenta se prati već sedam mjeseci – dobro se osjeća i vratio se svojim svakodnevnim aktivnostima.

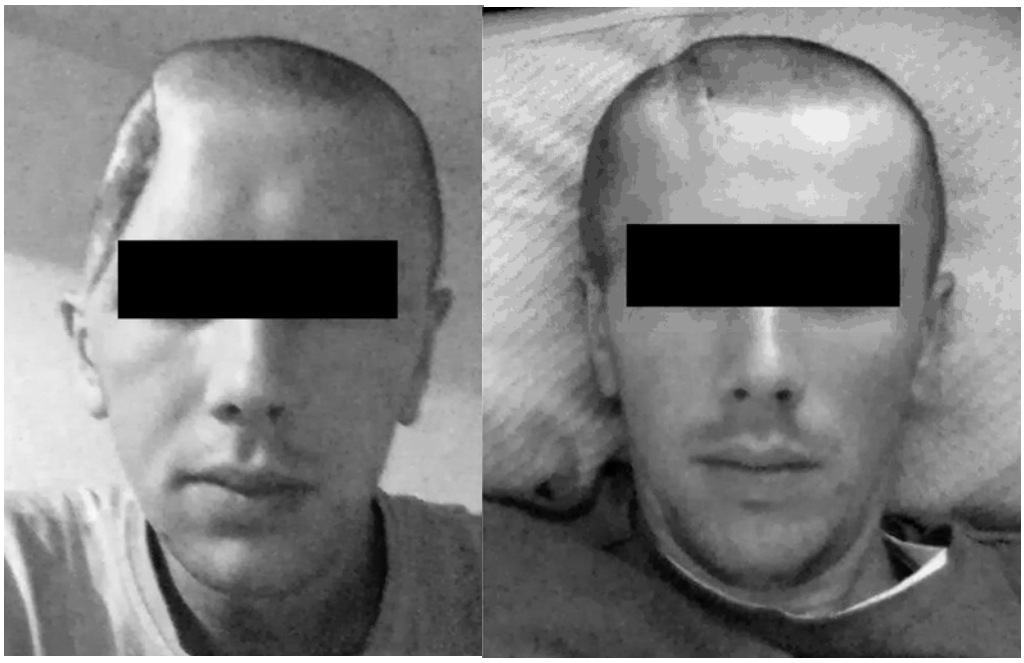
After eight days of the recovery, the patient was released home fully satisfied with the achieved results (Figure 6). In addition to the restored aesthetics of the cranial vault, the patient did not have headaches caused by atmospheric pressure on the brain tissue.
The patient's condition has been monitored for seven months - he feels well and returned to his everyday activities.



Slika 3. *Zatvaranje koštanog defekta lobanje implantom*
Figure 3*. Closing the skull bone defect with the implant*

Slika 4. *3D isprintani model implanta*
Figure 4*. 3D printed implant model*

Slika 5. *Kalup za implant napravljen od zubarskog gipsa*
Figure 5*.Mold for the implant made from dental plaster*



Slika 6. *Uporedni prikaz izgleda pacijenta prije i nakon rekonstrukcije koštanog defekta lobanje*
Figure 6*. Comparative presentation of the patient's appearance before and after the reconstruction of the skull bone defect*

3. ZAKLJUČAK

Da bi se postigli odgovarajući estetski rezultati i izbjegle moguće komplikacije kod saniranja većih koštanih defekata lobanje, izrada proteze/implanta po mjeri pacijenta je od izuzetne važnosti.

Na konkretnom primjeru, pokazano je da se, kombinirajući CT snimke, digitalnu rekonstrukciju modela, tehnologiju 3D printanja i zubarski gips kao materijal za izradu kalupa, mogu postići odlični rezultati kranioplastike.

3. CONCLUSION

In order to achieve appropriate aesthetic results and avoid possible complications in the repair of the severe bone skull defects, customised prosthesis/implant production is of the great importance.

In the case report, it was shown that, by combining CT scans, digital model reconstruction, 3D printing technology and dental plaster as a mold fabrication material, excellent cranioplastic results can be achieved.

4. REFERENCES

[1] Dumbrigue HB, Arcuri MR, LaVelle WE, Ceynar KJ: *Fabrication procedure for cranial prostheses*. J Prosthet Dent. 1998

[2] Van Gool A.: *Preformed polymethylmethacrilate cranioplasties. Report of 45 cases.* J Maxillofac Surg. 1985

[3] Spahić D., Karač A.: *Using magnetic resonance images tp create 3D models of bones for subsequent numerical analysis.* Trends in the Development of Machinery and Associated Technology, 2009

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