Deformation of a Titanium Calvarial Implant following Trauma: A Case Report

Valerie R. De Water, BSc¹ Ellianne J. dos Santos Rubio, MD² Joost W. Schouten, MD²
Maarten J. Koudstaal, MD, DDS¹

¹Department of Oral and Maxillofacial Surgery, Erasmus University Medical Center, Rotterdam, The Netherlands

²Department of Neurosurgery, Erasmus University Medical Center, Rotterdam, The Netherlands

Address for correspondence Valerie R. De Water, BSc, Department of Oral and Maxillofacial Surgery, Erasmus University Medical Center, Postbus 2040, 3000 CA, Rotterdam, Netherlands (e-mail: v.dewater@erasmusmc.nl).

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Abstract

Alloplastic material is widely used for the reconstruction of calvarial defects. The objective of this article is to describe the effect of mechanical impact on a titanium calvarial implant and to discuss mechanical properties of alternative implant materials. The patient is a 19-year-old man who was involved in a traffic accident and underwent decompressive craniectomy for an extensive subdural hematoma. Reimplantation of the skull flap was complicated by infection and the flap had to be removed. The remaining cranial defect was closed with a titanium plate. The recovery was without complications. One year later, the patient was hit on the titanium plate, during a soccer match, by the elbow of a fellow player. The implant deflected inward, leaving a visible indentation of the cranial vault. Fortunately, there were no significant neurological symptoms and radiography did not show any signs of damage or pressure on the brain parenchyma. The patient had no aesthetic complaints regarding the shape. Thus, there was no indication to remove the plate. This case illustrates the limits of the protection offered by titanium cranioplasty.

Keywords

- cranioplasty
- implant failure
- alloplastic material
- calvarial defect

Calvarial defects may result from trauma, infection, or surgery such as tumor resection and decompressive craniectomy. The defect is often aesthetically disturbing and may lead to insecurity about physical appearance and mental depression. Obviously, the unprotected brain is vulnerable to external forces that may lead to secondary brain injury. Large defects may also cause complications such as hydrocephalus, cortical herniation, and subdural effusion, with subsequent neurological deficits.^{1,2} Furthermore, patients often suffer from a set of symptoms often referred to as the “syndrome of the trephined” or “syndrome of the sinking scalp flap.” These symptoms include headache, dizziness, irritability, seizures, fatigue, and behavioral changes.^{3–5} Symptoms such as hemiplegia and visual defect have been reported as well.^{6,7}

Reconstruction of the defect can relieve these symptoms and protects the brain from external influences.⁸ If recon-

struction with autologous bone is not possible, an alloplastic material can be used. Several materials are available for reconstruction, and titanium is one of the most widely used.⁹ To our knowledge, there have been no reports considering damage to titanium implants *in vivo*.

This present report focuses on the behavior of titanium implants when exposed to mechanical forces. The mechanical characteristics of other available implant materials will be discussed.

Case Report

A 19-year-old male was involved in a traffic accident in April 2012. He was found unconscious when the ambulance arrived. He entered the hospital intubated and with signs of brain herniation. The computed tomography (CT) scan

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Fig. 1 Subdural hematoma over the left convexity: (a) midline shift; (b) effacement of basal cisterns.

showed a subdural hematoma over the left convexity of the brain with substantial midline deviation and effacement of the basal cisterns, indicating high intracranial pressure (► **Fig. 1**). The subdural hematoma was evacuated and because of the persistent brain swelling the bone flap was stored in a subcutaneous pocket in the abdominal wall and was replaced 25 days after the craniectomy. Three weeks following implantation, the patient returned to the hospital with low-grade fever and hydrocephalus. Despite repeated pressure-relieving lumbar punctures, the hydrocephalus and fever peaks recurred. Infection of the bone flap was suspected and in June 2012 the flap was removed. This resulted in an extensive defect of the frontal, temporal, and parietal bone (► **Fig. 2**). In November 2012, the patient received a titanium cranioplasty. The implanted plate had a thickness of 0.7 mm with a size of 150 × 170 mm. Recovery was uneventful.

Fig. 2 3D reconstruction of CT image: calvarial defect of the left frontal, temporal and parietal bone following craniectomy.

In November 2013, while playing soccer, the patient was hit by a fellow player's elbow. The elbow impacted the skull at the location of the implant, at the level of the former temporal bone, and left a deformity in the titanium (► **Figs. 3 and 4**). There were no clinical symptoms following this trauma. CT showed that the deflection did not cause compression of the brain parenchyma and there were no signs of trauma of the underlying brain tissue. The surrounding bony structures were intact and the screws by which the implant was placed were securely located within the bone. The patient was not bothered by the altered shape of the implant. Thus, there was no reason to remove or replace the implant. The patient was informed about the possible destructive effects of a second impact on the plate and the preventive use of a helmet during impact activities was advised.

Discussion

Cranial defects expose the brain to external forces and are often cosmetically disturbing. To prevent mechanical damage of the brain and to restore the natural shape of the skull, the calvarial defect can be closed depending on size, location, and neurological status. Ideally, the skull is reconstructed with autologous bone, which has the least postoperative complications.¹⁰ However, resorption of the autograft may occur and for large defects it may be difficult to obtain enough bone without causing complications at the donor site.¹¹ Another drawback of autologous bone is the difficulty to exactly shape the bone graft to reconstruct the convexity of the skull. Alloplastic reconstruction is often the treatment of choice for extensive defects.¹²

Various materials are available for alloplastic reconstruction. These include ceramics, titanium, the acrylic polymethyl-methacrylate (PMMA), and the plastic polyether-etherketone (PEEK). Titanium is used for cranioplasty in an alloy with aluminum and vanadium, to optimize the implant's strength, weight, and biocompatibility. The most widely used materials are titanium and PMMA, which give a relatively low

Fig. 3 CT image showing titanium implant: (a) before impact and (b) after impact causing inward deflection.

rate of infection and a good cosmetic result, and are available at reasonable cost.^{13–15}

Exposure to large mechanical forces may cause dislocation, deflection, or fracture of a calvarial implant, depending on the implant material. The magnitude of the force at which fracture occurs seems to depend on the specific material used. Fracture of a ceramic implant (Bioverit) after a fall out of the bed has been reported. As a consequence of this fracture, the implant had to be removed.¹⁶

Hydroxyapatite, another ceramic, is usually molded into a titanium mesh when used for calvarial reconstruction. The hydroxyapatite itself tends to fracture when high loads are applied.^{17,18} Posttraumatic fracture of the implant occurred in 27 of the 1,549 patients with a hydroxyapatite cranioplasty reported by Stefani et al.¹⁹ Staffa et al also reported hydroxyapatite implant fracture in their study. However, severe complications of these fractures did not occur, probably because of the hydroxyapatite.²⁰

Fig. 4 3D reconstruction image of CT after impact.

PMMA fractures after applying a sufficient load in in vitro settings.²¹ In vivo fracture of a PMMA implant has been reported as well: the implant of a 14-year-old boy was comminuted during an unhelmeted impact during a bicycle accident. Some of its scattered fragments caused dural lacerations, subarachnoid hemorrhage, and brain contusions. Removal of the implant was required and a new implant was placed, but the patient remained hemiparetic as a result of the trauma.²²

Compared with PMMA, titanium can absorb higher loads and thus gives a better protection to the surrounding bone tissue. In a study comparing PMMA and titanium implants by using a FEM-assisted model, the maximum developed stress after an applied force of 100 N was higher in the titanium than in the PMMA. Consequently, the maximum stress in the surrounding “cranium” in a skull model was lower for the model with the titanium implant. The highest stresses were measured at the impact region and at the borders of the implant surface, near the contact region with the skull.²³

In vivo fracture of PEEK has not been reported. However, titanium seems to be more resistant to high pressures. Lethaus et al simulated the clinical situation of a calvarial implant by fixing a titanium plate to a polyamide skull model. The titanium did not show any deformation up to the highest applied forces of ~50 kN, at which the screws and acrylic skull model were obviously deformed. This differs from the mechanical reaction of the PEEK implant, which fragmented into multiple pieces at a lower pressure than the maximum pressure applied to the titanium implant.²⁴ This shows that a titanium plate is more resistant to mechanical forces than PEEK is, when using implants of the same thickness.

There are no reported cases in which damage to a titanium skull implant caused complications in the patient. Deflection of a titanium plate caused by mechanical impact has been mentioned by Wiggins et al, in the context of a study on outcomes of custom-made titanium cranioplasty. They did not report any complications.²⁵

Theoretically, a titanium cranioplasty can offer optimal protection of the brain. However, there are numerous factors that influence the results of mechanical impact in daily

practice. Not only the thickness, shape, and size of the implant but also the direction of the impacting force and the mechanical properties of the impacting material contribute to the actual damage.²⁶

One should keep in mind that the mechanical resistance of the human skull itself is limited as well. The primary aim of calvarial reconstruction should not only be to improve but to equal the protectiveness of the natural calvarial bone. Extreme strength of alloplastic materials is not necessarily effective in protecting the brain. Mechanical impact on highly resistant cranioplasty material may result in fracture of the surrounding bone or damage or displacement of the fixation screws.²⁴

In this reported case, there are several factors that most likely contributed to the deformation of the implant: the high impact of an elbow—a relatively rigid body with a small radius—and an implant covering a large defect. Furthermore, the calvarial bones of a young male are relatively elastic, and in this case the bony tissue surrounding the implant probably absorbed some of the impact energy without being damaged.

Conclusion

Titanium cranioplasty offers protection of the brain tissue in patients with a calvarial defect, but the mechanical forces it can withstand are not unlimited. However, the widely used materials PMMA and PEEK have their own mechanical limitations. Their reaction to external forces is different—fracture instead of deflection—but does not seem to be less harmful. The inward deflection of the titanium implant in our patient did not cause tissue damage or signs of neurological impairment. Clinicians and patients should be aware of the possible consequences of mechanical impact on any calvarial reconstruction material.

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