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Technical Note

Ballistics for neurosurgeons: Effects of firearms of customized cranioplasty implants

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Abstract

Introduction: There are about 33,000 deaths caused by gunshot wounds in the USA each year. Probably half of these deaths result from head wounds. Among US Army soldiers, 17% of all ballistic injuries are head wounds. This means that, even in those protected by ballistic helmets, gunshot injuries to the head represent a danger. The aim of this study was to examine the effects of shelling of computer-aided designed (CAD) cranioplasty implants made of two different materials.

Methods: An experimental model was developed in an indoor gun range. CAD cranioplasties with a material thickness of 2-6 mm, made of titanium or PEEK-OPTIMA® were fixed in a watermelon and shot at with a .222 Remington rifle at a distance of 30 m distance, a .30-06 Springfield rifle at a distance of 30 m, a Luger 9 mm pistol at a distance of 8 m, or a .375 Magnum revolver at a distance of 8 m. The CAD cranioplasties were subsequently inspected for ballistic effects by a neurosurgeon.

Results: Titanium CAD cranioplasty implants resisted shots from the 9 mm Luger pistol and were penetrated by both the .222 Remington and the .30-06 Springfield rifle. Shooting with the .357 Magnum revolver resulted in the titanium implant bursting. PEEK-OPTIMA® implants did not resist bullets shot from any weapon. The implants burst on shooting with the 9 mm Luger pistol, the .222 Remington, the .30-06 Springfield rifle, and the .357 Magnum revolver.

Conclusions: Titanium CAD cranioplasty implants may offer protection from ballistic injuries caused by small caliber weapons fired at short distances. This could provide a life-saving advantage in civilian as well as military combat situations.

Key Words: Ballistic injuries, bullet resistance, computer-aided designed customized cranioplasty implants

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INTRODUCTION

Even though decompressive craniectomy (DC) is viewed increasingly critically in contemporary literature, it still retains its status as a major surgical technique in neurosurgery.[1,6-8] Accordingly, cranial vault reconstruction remains an everyday procedure for most neurosurgeons. Reimplantation of the autologous bone flap may be preferable but, in cases of initially discarded bone flaps or secondary removal due to bone graft infection, customized computer-aided designed (CAD) cranioplasty implants are necessary.[3] Since firearms cause 35% of traumatic brain injury (TBI)-related deaths among US civilians and more than 50% of combat casualties in modern warfare among US service personnel result from head injuries, the resistance of cranioplasty implants to firearms is an issue of importance.[2,12]

To address this question, we carried out the experiment described here.

METHODS

The present study was a technical experiment without any involvement of patients. For this reason, in accordance with European Law, the study protocol did not require institutional review board approval.

The aim of the study was to evaluate the effect of projectiles discharged from four different fire arms on CAD cranioplasty implants (3di, Jena, Germany) made of different materials, under controlled conditions.

Four experimental runs were conducted in an indoor hunting training center. During each experimental run, a different firearm was used. We conducted two series with long arms: With (a) 222 Remington rifle at a distance of 30 m and (b) .30-06 rifle at a distance of 30 m. Another two series were conducted with handguns: With (c) a Luger 9 mm pistol at a distance of 8 m and (d) a .375 Magnum revolver at a distance of 8 m. All projectiles used had full metal jackets.

In each experimental run, four different CAD cranioplasty implants were used: (1) titanium 2-3 mm, (2) titanium 4-6 mm, (3) PEEK-Optima® synthetic material 2-3 mm, or (4) PEEK-Optima® 4-6 mm. All CAD implants were mounted in a watermelon [Figure 1] on a semi-rigid rack, to simulate the functional restraint of an implanted CAD cranioplasty.

Figure 1: CAD cranioplasty mounted in a water melon on a semi-rigid rack

All shots were fired by an experienced firearms specialist, to ensure an accurate, central strike on the convexity of the CAD implants and to allow comparison of experimental runs.

Analysis of the results involved macroscopic assessment and interpretation of the CAD implants after impact.

RESULTS

Sixteen cranioplasty implants were examined in the technical experiment. In the first experimental run, the .222 Remington rifle achieved full penetration in both titanium implants [Figure 2]. The thinner PEEK-Optima® implant burst into very small parts, which, to some extent, could not be found despite a green paint coating applied to improve identification [Table 1].

In the second run, the .30-06 Springfield rifle was fired at four different implants. The titanium implants were fully penetrated, the PEEK implants burst into fragments.

The 9 mm Luger (8 m distance) caused a deformation without penetration in both titanium implants [Figure 3]. The PEEK implants burst into more than 10 parts, which were hard to find, due to this breaking up into pieces. In contrast to all other experimental runs, the Luger caused the PEEK plastic to burst into a multitude of sharp splinters [Figure 4].

Shooting with the .375 Magnum at a distance of 8 m resulted in bursting of all implants, with both titanium as well as PEEK.

DISCUSSION

Ballistics, the science of motion of a projectile, also refers to terminal ballistics, that is, the projectile's motion and its effect after striking the target. Since the head consists of bony skull and soft tissue, terminal ballistics is more unpredictable in relation to traumatic brain injuries than injuries of other parts of the body.[9,10]

The aim of our experiment was to obtain data regarding

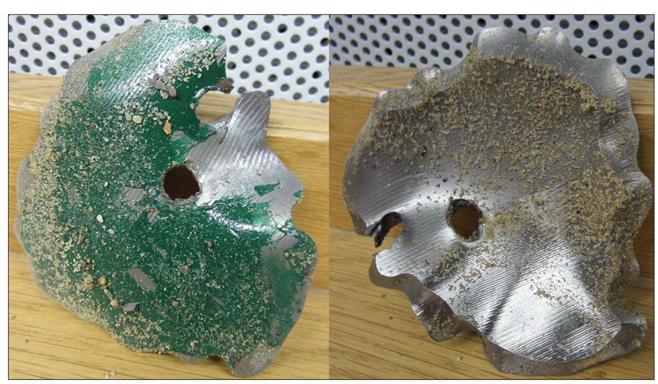

Figure 2: Titanium plastic 4-6 mm with a full penetration caused by the .222 Remington rifle

Table 1: Four experimental runs with different firearms were conducted on four different CAD cranioplasty implants

	0.222 Remington	0.30-06 Springfield rifle	9 mm Luger pistol	0.375 Magnum revolver
Ballistic performace	V_0=980 m/s E_0=1556 J	V_0=825 m/s E_0=3982 J	V_0=390 m/s E_0=570 J	V_0=385 m/s E_0=760 J
Bullet weight	3.24 g	11.66 g	7.45 g	10.24 g
Distance	30 m	30 m	8 m	8 m
Titanum 2-3 mm	Full penetration	Full penetration	Deformation, no penetration	Burst, >2 parts
Titanum 4-6 mm	Full penetration	Full penetration	Deformation, no penetration	Burst, >2 parts
PEEK® 2-3 mm	Burst, >10 parts	Burst, >2 parts	Burst, >10 parts	Burst, >10 parts
PEEK® 4-6 mm	Burst, 2 big parts	Burst, >2 parts	Burst, >10 parts	Burst, >10 parts

CAD: Computer-aided designed

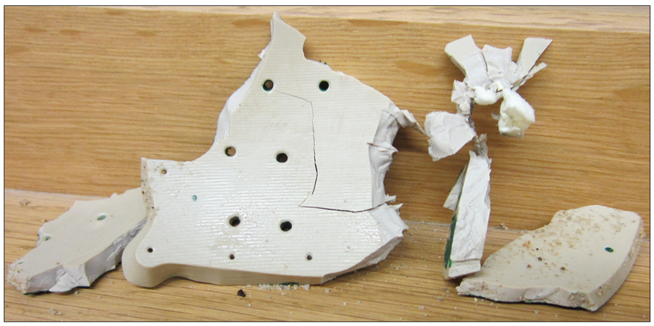

Figure 3: PEEK-Optima® implant after shooting with the 9 mm Luger pistol

a special cranial situation; namely, terminal ballistics in customized CAD cranioplasty implants. Because of limited resources, we were unable to conduct experimental series with different types of projectiles.

It is known that the severity of a wound and consequently the severity of an impact on a CAD implant may be limited when full metal jacket projectiles (which are intended to stay intact after impact) are used compared with partly metal-jacketed projectiles, even if they have the same kinetic energy.[5] Since, under the Geneva Conventions,[11] full-metal jacket projectiles are the only projectiles permitted for military use and since we intended to obtain information about the characteristics of CAD cranioplasty implants under military conditions, we decided to conduct the experiment with these projectiles. However, penetrating, high energy injuries of the head are associated with a poor prognosis, regardless of the penetrating object.[4]

Even though the small number of events evaluated precluded statistical analysis, we are confident that the results allow us to draw important conclusions, particularly bearing in mind the extremely simple configuration of the experiment and the controlled conditions under which it was carried out.

Since projectile contact resulted in bursting in all experimental runs using PEEK cranioplasties, these cranioplasties should not be used in patients who are likely to find themselves in another combat situation or run the risk of being shot at again. It is probable that shrapnel from the bursting PEEK cranioplasty would cause secondary traumatic brain injuries in such patients and in such situations.

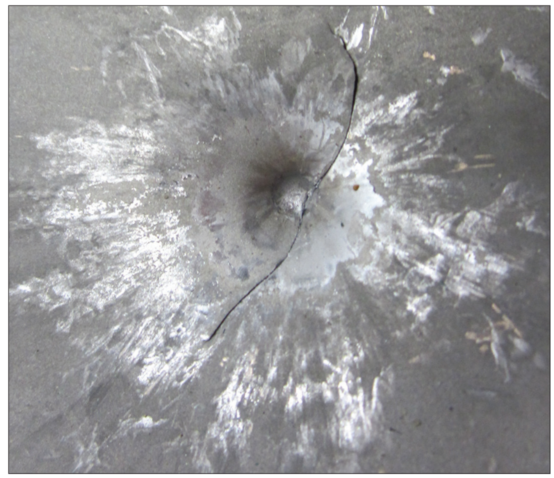

Figure 4: Titanium implant without penetration after shooting with the 9 mm Luger pistol

Titanium CAD cranioplasties offered resistance to the 9 mm Luger pistol. This could constitute an advantage for a patient with such an implant. Although direct strikes were not stopped by the titanium implants when other weapons were used, in our experiment, it may be possible that a grazing shot could be impeded by a titanium implant, whereas a PEEK implant could cause amplified trauma by bursting.

Thus, titanium implants may protect a patient from some ballistic injuries and may also be advantageous in providing a defence.

CONCLUSION

In a unique technical experiment, CAD cranioplasty implants were subjected to four different firearms. We found that PEEK-Optima® material did not provide any resistance to any ballistic action and that titanium is more resistant and so may, theoretically, avoid secondary injuries caused by shrapnel fragments from the implant.

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Commentary

This is specialized, and dismaying, but useful information, which deserves a place in the literature. Velocity and energy information for ballistics are available at http://www.remington.com/en/pages/news-and-resources/ballistics.aspx

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