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# Mechanical properties of collagen membranes: Are they sufficient for orbital floor reconstructions?

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ABSTRACT

*Introduction:* The most common reconstruction materials for orbital floor fractures are PDS (polydioxanone) foil and titanium meshes. These materials have advantages and disadvantages. Therefore, new materials are needed to improve surgical outcomes.

*Materials and methods:* Three resorbable collagen membranes (Smartbrane®, BioGide®, Creos®) were tested for their mechanical properties (puncture strength) in mint and artificially aged (3, 6, 8 weeks) conditions and were compared to PDS foil, titanium meshes (0.25 mm, 0.5 mm) and human orbital floors ($n = 7$).

*Results:* The following puncture strengths were evaluated: human orbital floor, 0.81 ± 0.49 N/mm$^2$; 0.25 mm titanium mesh, 5.36 ± 0.25 N/mm$^2$; 0.5 mm titanium mesh, 16.08 ± 5.17 N/mm$^2$; Smartbrane, 0.74 ± 0.31 N/mm$^2$; BioGide, 1.65 ± 0.45 N/mm$^2$; and Creos, 2.81 ± 0.27 N/mm$^2$.

After artificial aging, the puncture strengths were significantly reduced ($p \leq 0.05$) at 3, 6 and 8 weeks as follows: Smartbrane, 0.05 ± 0.03 N/mm$^2$, 0.03 ± 0.02 N/mm$^2$, and 0.01 ± 0.01 N/mm$^2$, respectively; BioGide, 0.42 ± 0.06 N/mm$^2$, 0.41 ± 0.12 N/mm$^2$, and 0.32 ± 0.08 N/mm$^2$, respectively; and Creos, 2.02 ± 0.37 N/mm$^2$, 1.49 ± 0.42 N/mm$^2$, and 1.36 ± 0.42 N/mm$^2$, respectively.

*Conclusion:* The tested materials showed sufficient puncture strength for orbital floor reconstruction in mint condition. Moreover, after artificial aging, the Creos and BioGide membranes showed sufficient resistance, while Smartbrane showed equivocal data after eight weeks. Therefore, collagen membranes have adequate properties for further in vivo investigations for orbital floor reconstructions.



## 1. Introduction

Orbital floor fractures are a common challenge in maxillofacial surgery (Polligkeit et al., 2013, Salentijn et al., 2013). The symptoms of orbital floor fractures are hematoma, hyposphagma, hypesthesia of the infraorbital nerve, reduced globe motility, and enophthalmos (Arangio et al., 2014, Carinci et al., 2006). The reduced globe motility follows swelling and herniation of the orbital contents into the maxillary sinus. Orbital rehabilitation is appropriate to remedy the enophthalmos, to relieve the infraorbital nerve, and to prevent scarred malformation of the orbital content by averting reduced globe motility.

The orbital floor measures approximately 600 mm$^2$, with a convex and concave profile. The orbital content weighs approximately 30 g (0.3 N), resulting in 0.0005 N/mm$^2$ of static mechanical stress. Orbital floor fractures measure approximately 30–350 mm$^2$, resulting in 0.01–0.0008 N/mm$^2$ of static mechanical stress on reconstruction materials (Czerwinski et al., 2008, Tabrizi et al., 2013).

Currently, two different common materials are used for orbital floor reconstruction, PDS (polydioxanone) foils and titanium meshes (Dietz et al., 2001, Essig et al., 2013). PDS foils are completely resorbable within approximately 30 weeks and are replaced with scar tissue without any adherence to the orbital content (Merten and Luhr, 1994). However, due to the rigidity of these materials, it is challenging to repair a convex orbital floor, but there is no need for surgical removal. Titanium meshes might

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require surgery for removal, and orbital adherence syndrome has been described (Lee and Nunery, 2009), but the meshes can be adapted to the orbital floor in three dimensions (Metzger et al., 2006). There has been controversy regarding both materials in the literature; however, thus far, there is no evidence demonstrating the superiority of either of these materials. Moreover, there is little available information regarding the demand for reconstruction materials. Recently published studies have investigated the demand for reconstruction materials (Birkenfeld et al., 2011, Birkenfeld et al., 2012a,b,c). However, there is also little available information regarding the mechanical properties of the human orbital floor.

This study had two objectives: (1) to investigate the puncture strength of human orbital floor bone specimens and (2) to compare this strength with the puncture strengths of titanium meshes, PDS foils, and three resorbable collagen membranes in mint condition and after artificial aging for 3, 6, and 8 weeks to determine their potential for orbital floor reconstruction.

## 2. Materials and methods

A Zwick Z010 TN1 universal testing machine (Zwick GmbH, Ulm, Germany) was used for the puncture strength investigations (Fig. 1). The materials were positioned under a height-adjustable horizontal traverse with a high-definition force transducer and a punch (diameter of 5.5 mm [23.758 $mm^2$]). The start position (approximately 20.0 cm above the materials) and end position (approximately 1.0 cm behind the materials) were set before the measurement was performed, and the same conditions were used for all tested materials. The measurement process began, and the punch was lowered approximately 2.0 mm toward the material. From this position, the feed speed was 0.2 $mm^*s^{-1}$ until the end position was reached. Puncture strength and punch height were recorded. Seven specimens were tested for each material, as summarized in Table 1.

Three resorbable porcine collagen membranes (Smartbrane®, BioGide®, Creos®) were tested for their initial puncture strengths and their strengths after simulated aging. For simulated aging, the membranes were stored in fetal calf serum (GIBCO, FBS South American, Ref. 41F3496K, Catalog No. 10270-106, Invitrogen, Darmstadt, Germany) in an incubator at 37 °C for 3, 6, and 8 weeks.

The titanium meshes (0.25 mm and 0.5 mm), PDS foil (0.15 mm), and human orbital floors were tested only for their initial puncture strengths.

The human orbital floor bones were harvested from body donors to the anatomical course at the Institute of Anatomy of the Christian-Albrechts University at Kiel. Unfortunately, personal identifications of sex and age were not possible due to the anonymity of the donors. After harvesting the specimens, the under surface (rims of the maxillary sinus, zygomatic bone) were carefully shaped with a bone pliers for balanced position. To prevent slip away, the specimens stood on sandpaper and were partially supported with small rubber rips from the side. The specimens were positioned under the punch 10 mm behind the orbital rim and beneath the bony canal of the infraorbital nerve (Fig. 1D).

### 2.1. Ethical approval

All cadavers were available from the Institute of Anatomy at the first author's institution and were used according to the institutional and national ethical and legislative frameworks. The human skulls were obtained from bequeathed body donations to the Institute of Anatomy of the Christian-Albrechts University at Kiel.

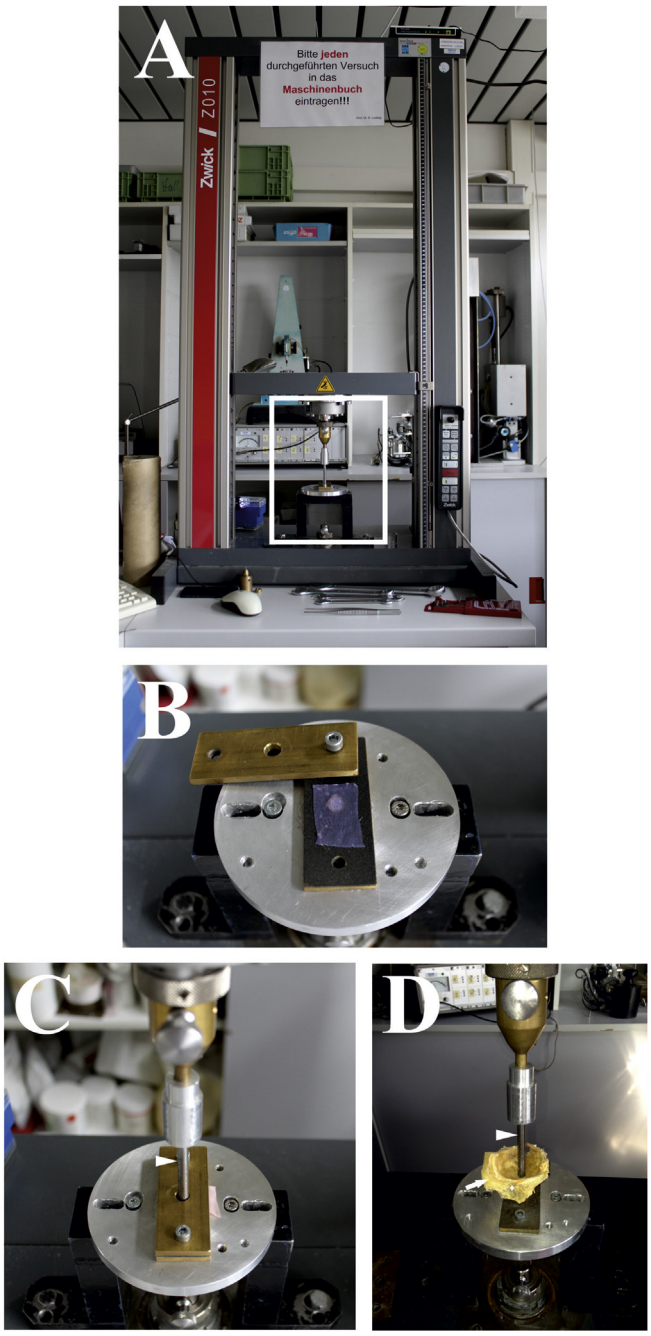


**Fig. 1.** A Zwick Z010 universal testing machine. (A) An overview of the machine (white frame close-up in B, C, and D). (B) Before the testing procedure, a collagen membrane is positioned over the aperture. (C) Punch while testing the membrane. (D) A human orbital floor positioned under the punch. The arrowhead indicates the testing punch (5.5 mm in diameter). The arrow indicates the zygomatic bone. The star indicates the infraorbital nerve foramen.

**Table 1**
An overview of the tested materials.

| | Thickness (mm) | Material/source | Manufacturer |
|---|---|---|---|
| Orbital floor | 0.1–0.5 | Bone/human | x |
| Smartbrane | 0.1 | Collagen/porcine | Regedent, Zurich, Switzerland |
| Creos | 0.2 | Collagen/porcine | Nobel Biocare, Köln, Germany |
| BioGide | 0.4 | Collagen/porcine | Geistlich, Wolhusen, Switzerland |
| Titanium | 0.25 | Titanium | Stryker, Duisburg, Germany |
| Titanium | 0.5 | Titanium | Stryker, Duisburg, Germany |
| PDS | 0.15 | Polydioxanone | Ethicon, Norderstedt, Germany |