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Transverse shear simulations on bioactive glass implants for orbital floor reconstruction

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Abstract

With the development of vitreous implants for orbital floor reconstruction, a question arises whether their high fragility and very small thickness are capable of withstanding loads imposed by inflammation and tissue growth during convalescence. Since glass fracture surfaces are sharp blades, an eventual failure could cause serious damage to the local tissue. To assess the risk of fracture by transverse shear, a computational model of an orbital floor implant was created and shear loads were simulated, from 20 to 100 N, on a transverse plane. Using the Finite Elements Method, the software plotted the stress distribution in an implant made of three vitreous materials: amorphous Bioglass 45S5, 40% crystalline Bioglass 45S5 and apatite-wollastonite glass ceramic. The partially crystallized Bioglass showed the best mechanical resistance to shear, with a safety factor of at least 1.7 at the simulated load levels.
Keywords: Bioglass; glass ceramics; facial bones reconstruction; numerical simulations; Finite Elements Method.

Introduction

Facial traumas can lead to severe fractures of the orbital floor and surrounding structures (Fig. 1), which may need reconstruction if there is a clear herniation of the adipose tissue or the inferior rectus muscle in the maxillary sinus. As the floor is very thin, orbital wall defects cannot be restored, so the injured area must be reconstructed using an implant [1].

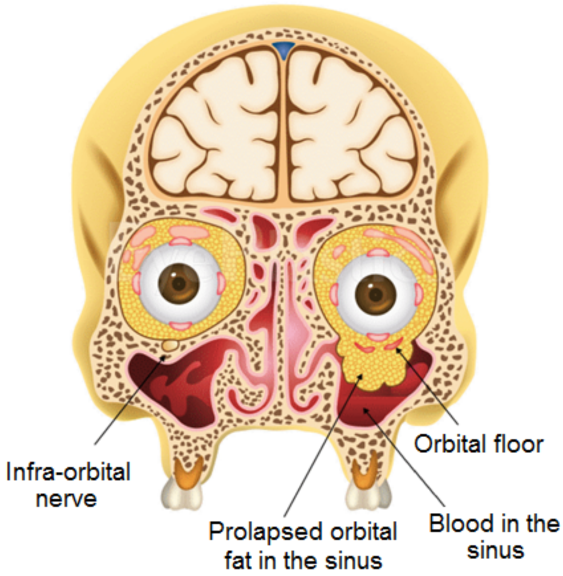
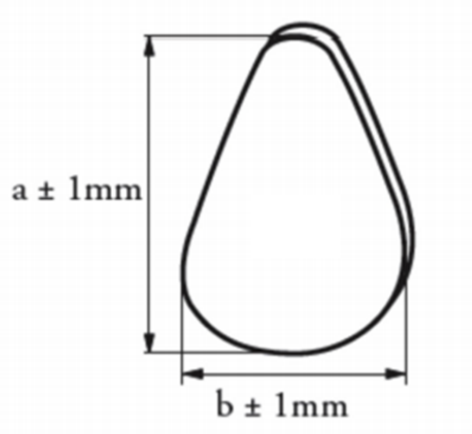


Figure 1 – Fracture of the orbital floor [2].

The aim of the reconstruction is to restore the distorted floor shape and recover the original orbit volume. Many implants, both autogenous and alloplastic, have been used to reconstruct such defects [1]. Autogenous grafts made from bone, cartilage, and fascia have been used [3,4], but it was only in 2015 that Stoor et al. [1] developed an implant with satisfactory long-term results. Made of a 1.5 mm thick bioactive glass sheet, the implant has an anatomical shape (Fig. 2), but without the natural concavity of the orbital floor in the sagittal plane, to compensate for the adipose tissue atrophy that occurs during trauma and surgery:



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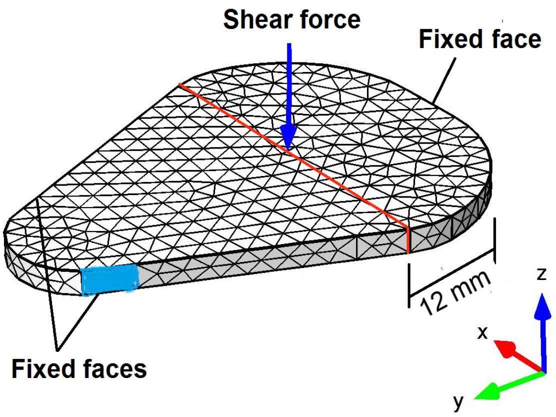


Figure 3 – Computational model of the orbital floor implant.

Three materials were evaluated: totally amorphous Bioglass 45S5, 40% crystallized Bioglass 45S5 and apatite-wollastonite (A/W) glass ceramic. The elastic properties of these materials are shown in Table 1:

Table 1 – Young's Modulus (E), Tensile Strength (TS), density (ρ) and Poisson's Ratio (ν) of the evaluated glasses [5]

Property	45S5 Bioglass	40% crystalline 45S5 Bioglass	A/W glass ceramic
E (GPa)	35	68	118
TS (MPa)	42	210	215
ρ (g/cm³)	2.7	2.7	3.1
ν	0.26	0.27	0.28

Using the Finite Elements Method, the software plotted the distribution of stresses and strains using tetrahedral elements with edges of at most 0.5 mm and linear interpolation. Since glasses are brittle materials, the safety factors were calculated by the Maximum Normal Stress Failure Theory:

$$SF = \frac{TS}{\sigma_I \text{ or } \sigma_{II}} \quad SF = \frac{TS}{\sigma_I \text{ or } \sigma_{II}} \quad SF = \frac{TS}{\sigma_I \text{ or } \sigma_{II}} \tag{1}$$

where TS is the tensile strength and σ_I and σ_{II} are the maximum principal stresses [6].

Results and Discussion

The stress distribution has the same spectrum (Fig. 4) for all materials and loading levels, changing only its intensities:

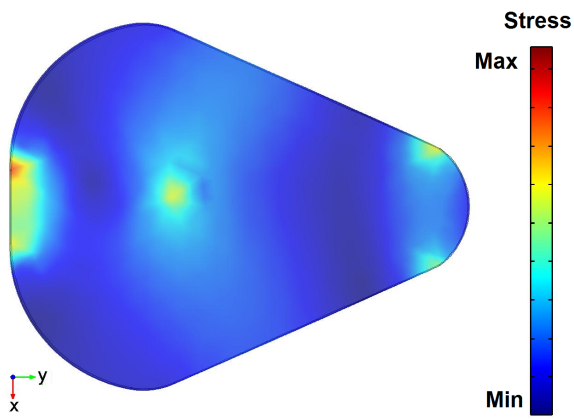
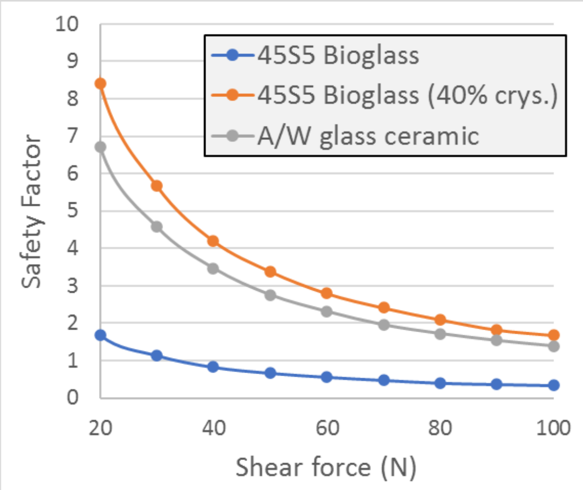


Figure 4 – Stress spectrum of the implant under shear load

Figure 4 shows that stresses are maximum at the fixed faces and at the shear plane. The safety factor calculated for each material and load level is shown in Figure 5:



Conclusions

The simulations showed that, for transverse shear loads, the maximum stresses occur on the fixed faces of the implant and on the plane of application of the shear force. Of the three simulated materials, Bioglass 45S5 with 40% crystallized volume fraction has the best elastic properties to support shears. For a more complete finite element analysis, it is necessary to simulate other types of loads, such as torsion, bending, compression and traction, so that it is possible to select the material on a more reliably way, suggest design modifications and validate the computational model with experimental tests.

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