Acta Biomaterialia 7 (2011) 3248–3266

Contents lists available at ScienceDirect

Acta Biomaterialia

journal homepage: www.elsevier.com/locate/actabiomat

Review

Biomaterials and implants for orbital floor repair ☆

Francesco Baino *

Materials Science and Chemical Engineering Department, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy

ARTICLE INFO

Article history:
Received 19 January 2011
Received in revised form 19 April 2011
Accepted 16 May 2011
Available online 20 May 2011

Keywords:
Orbital floor surgery
Biocompatibility
Autograft
Alloplastic
Tissue regeneration

ABSTRACT

Treatment of orbital floor fractures and defects is often a complex issue. Repair of these injuries essentially aims to restore the continuity of the orbital floor and to provide an adequate support to the orbital content. Several materials and implants have been proposed over the years for orbital floor reconstruction, in the hope of achieving the best clinical outcome for the patient. Autografts have been traditionally considered as the "gold standard" choice due to the absence of an adverse immunological response, but they are available in limited amounts and carry the need for extra surgery. In order to overcome the drawbacks related to autografts, researchers' and surgeons' attention has been progressively attracted by alloplastic materials, which can be commercially produced and easily tailored to fit a wide range of specific clinical needs. In this review the advantages and limitations of the various biomaterials proposed and tested for orbital floor repair are critically examined and discussed. Criteria and guidelines for optimal material/implant choice, as well as future research directions, are also presented, in an attempt to understand whether an ideal biomaterial already exists or a truly functional implant will eventually materialise in the next few years.

1. Introduction

Orbital floor fractures, alone or in conjunction with other facial skeletal damage, are the most commonly encountered midfacial fractures, second only to nasal ones. According to Ng et al. [1] and Chang and Manolidis [2], orbital floor fractures were first described by MacKenzie in 1844 in Paris. More than a century later, in 1957, Smith and Regan [3] described inferior rectus muscle entrapment with decreased ocular motility in the setting of an orbital fracture and coined the term "blow-out fracture". Since the 1960s different surgical routes have been proposed for the effective management of orbital floor fractures [4–11].

It should be taken into account that the management of orbital floor injuries is complicated not only by their technical difficulty per se, but also by the required extensive medical competencies, ranging from the maxillofacial to otolarygological to ophthalmic fields, and by the multitude of factors necessary to make a correct decision as to the proper timing of the repair.

In addition to timing- and surgery-related issues, another key factor in the treatment of orbital fractures is the choice of the material used for tissue(s) reconstruction. A wide number of studies describing orbital fracture repair with a considerable variety of autogenous, allogenic and alloplastic materials are available in the literature. However, direct comparison between different materials are rather rare and, therefore, it is not trivial to draw definite conclusions as to which material is best suited to repair these injuries. The present review addresses this issue: specifically, the advantages and limitations of currently adopted biomaterials and implants are critically examined and possible new research directions towards a truly ideal device are described and discussed.

The article can be divided into three parts, devoted to presenting an essential medical background, a comprehensive materials/implants review and some indications/remarks for material choice/prospective research, respectively. The first part, Section 2, gives the reader a concise overview of the features, treatment and complications of orbital floor fractures. In this context Table 1 provides a short glossary of the medical terms that are not explained directly in the text or that may be unclear or unknown to non-specialist readers. The second part, Sections 3–8, gives the different classes of biomaterials and implants used to treat orbital floor fractures are extensively reviewed. The third part, Sections 9–11, critically compares and discusses the performances of the different materials and implants in current use and forecasts about future challenges are presented.

2. Orbital floor fractures: a short overview

2.1. Aetiology and features

Damage to the facial skeleton is usually the result of low, medium or high velocity trauma due, for instance, to a motor

☆ This article is dedicated to Prof. Giuseppe Heer, a great ophthalmologist and Head Emeritus of the Ophthalmology Ward at Maria Vittoria Hospital, Turin, Italy, on occasion of his 60 years of clinical activity and 85th birthday.

* Tel.: +39 011 564 4668; fax: +39 011 564 4699.
E-mail address: francesco.baino@polito.it

1742-7061/$ - see front matter © 2011 Acta Materialia Inc. Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.actbio.2011.05.016

Table 1
Medical glossary (terms listed alphabetically).

Term	Explanation
Blepharoptosis	Drooping of the upper eyelid.
Bone morphogenetic protein (BMP)	A group of growth factors, also known as cytokines, able to induce and regulate the formation of bone and cartilage. Dysregulation in BMP signalling may involve a multitude of diseases and pathological processes, including cancer
Conjunctiva	Clear mucous membrane constituted of stratified columnar epithelium that covers the sclera and lines the inside of the eyelids. It contributes to eye lubrication by producing mucus and tears, although in a smaller amount with respect to lachrymal glands. In addition it prevents the entrance of pathogenic agents and foreign bodies into the eye
Diplopia	Commonly referred to as "double vision", it can occur when patient's eyes are not correctly aligned while aiming at an object and, therefore, two non-matching images are simultaneously sent to the viewer's brain. It is often the first manifestation of many systemic disorders, especially concerning muscular or neurological processes. An accurate and clear description of the symptoms, e.g. constant or intermittent, variable or unchanging, near or far, monocular or binocular, horizontal, vertical or oblique, is critical to appropriate diagnosis and management
Dysesthesia	Unpleasant, abnormal sensation produced by normal stimuli, with particular reference to touch; this altered sensation may be considered as a kind of pain
Ectropion	Turning out of the eyelid (usually the lower eyelid) so that its inner surface is exposed
Entropion	Folding inwards of the eyelid (usually the lower eyelid) so that the eyelashes constantly rub against the cornea
Enophthalmos	Recession of the eyeball within the orbit. It may be a congenital anomaly or be acquired as a result of trauma, such as blow-out fracture of the orbit. It is also referred to as endopthalmos
Epistaxis	haemorrhage from the nose. It is commonly referred to as a nose bleed
Exophthalmos	Also referred to as proptosis, it results in bulging of the eye anteriorly out of the orbit. It can be either bilateral or unilateral, and is usually due to orbital tumour, trauma or swelling of the surrounding tissue(s) resulting from trauma. Trauma to the orbit can cause bleeding behind the eye, a condition called retrobulbar haemorrhage. The resulting increased pressure pushes the eye out of the socket, thereby leading to exopthalmos
Extra-ocular muscles	Group of six muscles, attaching to the sclera, that control the movements of the eye
Hyperalgesia	Abnormally increased sensitivity to pain. It is usually due to damage to nociceptors or peripheral nerves
Hypoesthesia	Abnormally reduced sensitivity to sensory stimuli, particularly to touch
Hypoglobus	Downward displacement of the ocular globe. Its causes and symptoms are quite similar to those observed for enophthlamos
Infra-orbital nerve	Name of the maxillary nerve after entering the infraorbital canal. It innervates the lower eyelid, the upper lip and part of the nasal vestibule
Intra-ocular pressure (IOP)	Measure of the fluid pressure inside the eye (mean value in a normal population $\sim$15.5 mmHg). A IOP above 21 mm Hg indicates ocular hypertension, which may eventually develop into glaucoma and involve damage to the optic nerve
Maxillary sinus	Located in the body of the maxilla, it is the largest of the paranasal sinuses and is characterised by a pyramidal shape. This sinus, often termed the maxillary antrum, has three recesses: an alveolar recess (inferior region, bounded by the alveolar process of the maxilla), a zygomatic recess (lateral region, bounded by the zygomatic bone), and an infraorbital recess (superior region, bounded by the inferior orbital surface of the maxilla (orbital floor)).
Retina	Light-sensitive tissue of the eye. It lines the inner surface of the ocular globe and can be viewed as a highly specialised multilayered neural structure. The neurons that are directly sensitive to light are the photoreceptor cells, i.e. rods, which function mainly in dim light and provide black and white vision, and cones, which support daytime vision and the perception of colours
Sclera	Opaque, fibrous, protective, outer layer of the eye. Primarily constituted by collagen, it maintains the shape of the eye, offers resistance to internal and external forces and provides an attachment for the extra-ocular muscle insertions. The thickness of the sclera varies from 1 mm at the posterior pole to 0.3 mm just behind the rectus muscle insertions. It is commonly referred to as the "white of the eye"

vehicle or traffic accident. A fracture in the orbital floor commonly causes herniation of the orbital fat and other orbital content into the maxillary sinus(es), which results in an increase in the orbital volume (Fig. 1). Orbital floor fractures can occur as isolated injuries or in combination with extensive facial bony disruption. The orbital floor is most vulnerable to fracture because of the thinness of the roof of the maxillary sinuses, the existence of the infra-orbital canal and the curvature of the floor. Immediately behind the orbital rim the floor is concave, whereas further back it becomes convex, forming the so-called posterior ledge, in which the bony structure appears thicker and less prone to deformation in the case of fracture.

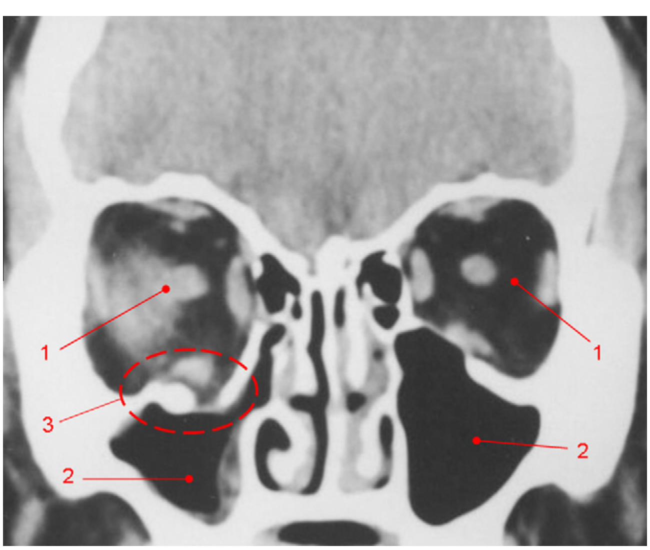

Fig. 1. Tomographical image (coronal plane) showing the patient's right orbital floor fracture, vertical elongation of the right orbit and, accordingly, a reduction in size of the right maxillary sinus. 1, Orbital cavities; 2, maxillary sinuses; 3, fracture area.

Pure orbital floor fractures, often referred to as isolated orbital fractures, commonly result from an impact injury to the ocular globe and upper eyelid. In most cases the object is large enough not to perforate the eyeball and small enough not to cause fracture of the orbital rim. Two possible mechanisms have been proposed to explain orbital floor fractures: (i) hydraulic theory (HT) and (ii) bone conduction theory (BCT) [12]. HT involves the direct transmission of pressure from the ocular globe and intra-orbital content to the peri-ocular structures, which eventually leads to blowing out of the orbital floor. In fact, most fractures occur in the posterior medial region, which is the thinnest bony orbital area. The second mechanism (BCT), which is generally less favoured, involves indirect transmission of pressure from the orbital rim along the bone to the floor.

Although most pure orbital fractures affect the medial region of the infra-orbital floor, any fracture type, size or geometry is, at least virtually, possible.