Controversies in orbital reconstruction—III. Biomaterials for orbital reconstruction: a review with clinical recommendations


Abstract. The goal of orbital reconstruction is to repair trauma defects, to correct the position of the eye anatomically, avoiding enophthalmos, and to restore ocular function. For the reconstruction of (trauma) defects, many surgeons recommend materials that can be bent into an anatomical shape and that possess the properties of radiopacity and long-term stability. However, apart from these desired properties, the ideal material for orbital reconstruction remains controversial. Autologous bone is often mentioned as the ‘gold standard,’ likely because of its mechanical properties, revascularization potential, and its adaptation to the orbital tissue with minimal acute and chronic immune reactivity. However, autologous bone can show unpredictable resorption rates and suboptimal volume correction. In recent years, an increasing interest in the use of alloplasts for orbital reconstruction has become apparent in the literature. Modern technological advantages, such as preoperative planning, navigation, and perioperative imaging, can be beneficial in the decision to choose a certain implant. The aim of this review is to give a comprehensive overview of the advantages and disadvantages of materials used to reconstruct traumatic orbital defects and to provide a practical, evidence-based, complexity-driven set of guidelines.

Key words: orbit; trauma; blowout fractures; classification of facial fractures; orbital fractures; orbital reconstruction; biomaterials.

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In the reconstruction of orbital fractures, the purpose of an implant in orbital wall reconstruction is to restore function and aesthetic appearance by repairing the traumatic defect and bringing the globe into its correct position, thereby avoiding enophthalmos. In addition to the timing and methods of reconstruction, as described in previous reviews, a third pivotal factor in orbital fracture surgery is the choice of reconstruction material. Numerous studies describing orbital...
fracture repair with a variety of materials that offer various advantages and disadvantages have been reported in the literature.\(^1,2\) For many decades, biological transplants derived from human or animal tissues, polymers, and metals have been used. With the development of biocompatible alloplastic implants, new options (polymers, biological ceramics, and composites) have been added to the surgeon’s armamentarium (Table 1). Within this context, controversy exists regarding the best material features, which can be defined broadly by the following parameters: (1) autogenous versus allogeneic, (2) non-resorbable versus resorbable material, (3) malleable versus preformed anatomical plates, and (4) pre-fabricated versus custom-made implants.

The indication for repair of orbital wall fractures is based on a combination of clinical findings and radiological information.\(^3\) However, among 55 studies performed on orbital reconstruction, it was found that the indication for surgery was based on diplopia in only 18.3% of cases and on preoperative enophthalmos in only 29.8% of cases.\(^4\) The other two most frequently reported indications for orbital reconstruction are defect size (<50% of surface) and incarcerated tissue, with both identified on computed tomography (CT) scans. If an indication for surgery is present, the next dilemma is the selection of the correct implant. This choice could be based on an algorithm for the defect size, the anatomical location, or the remaining structural support.\(^5\) Small defects may heal solely by the formation of scar tissue, whereas larger defects, especially those associated with enophthalmos and hypoglobus, need material of a sufficient strength to support the orbital contents and restore the contour of the orbit.\(^6\)

In defining the ideal characteristics of an orbital implant, many surgeons prefer materials that (1) allow bending to an anatomical shape, (2) are radiopaque, and (3) remain stable over time. The key question is what specific characteristics orbital implants should have to be beneficial for the different types of orbital fractures. While an increasing body of evidence is pointing to the importance of differentiated and complexity-based treatment models in general trauma surgery, this approach seems to fail for orbital fractures. For smaller defects (types I and II), the strength of the reconstruction material holds limited relevance for a successful outcome.\(^6\) Rather, the choice of material is more dependent on biocompatibility.\(^7\) In larger fractures (types III and IV), mechanical properties and the contour or form factor needs special consideration, as well as biocompatibility. The orbit remains a controversial entity in the human body with respect to the appropriate material for fracture repair. Today, the search for a material with ideal characteristics is ongoing (Table 2).

The aims of this study were (1) to provide a comprehensive overview of the advantages and disadvantages of both traditional and new materials for the reconstruction of traumatic orbital defects, (2) to define the ideal characteristics of implant materials for future research, and (3) to offer evidence-based clinical recommendations regarding the best suitable material available.

<table>
<thead>
<tr>
<th>Biological materials</th>
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<tbody>
<tr>
<td>Autografts/autogenous materials</td>
</tr>
<tr>
<td>Allografts (polymers)</td>
</tr>
<tr>
<td>Polymeric (plastics)</td>
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<tr>
<td>Synthetic materials</td>
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<tr>
<td>Composites</td>
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</table>

**Table 1. Types of materials used for orbital reconstruction.**

### Materials

- **Biological materials**
  - Autografts/autogenous materials
  - Allografts (polymers)
  - Synthetic materials
  - Composites

- **Polymers (plastics)**
  - Polymeric (plastics)
  - Synthetic materials
  - Composites

- **Natural materials**
  - Natural polymers

- **Synthetic materials**
  - Synthetic polymers
  - Natural materials

- **Composites**
  - Composites

**Advantages and disadvantages of currently available reconstruction materials**

### Biological materials

Biological materials are defined as grafts harvested from the same or another human or animal and include autografts, allografts, and xenografts. Autologous grafts are characterized by cost-effectiveness but limited availability, variable resorption rates leading to unpredictable (orbital) volume, associated donor site morbidity (pain, scarring, infection, haematoma), and an increased surgical time. In the past, viral infections and other diseases (e.g., bovine spongiform encephalopathy and Creutzfeldt–Jakob disease) originating from the donor tissue have been reported for allografts and xenografts.

Since the 18th century, autologous bone has been the ‘gold standard’ biomaterial for the reconstruction of bony defects in
Table 2. Ideal orbital reconstruction material characteristics.

<table>
<thead>
<tr>
<th>1. Stability and fixation</th>
<th>Strong enough to support the orbital content and related forces</th>
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<tbody>
<tr>
<td>Ability to be stable and retain its shape once manipulated</td>
<td>No deformation (sagging of material into maxillary sinus) under pressure load</td>
</tr>
<tr>
<td>Stable over time</td>
<td>Possibility of being fixed to surrounding structures</td>
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<tr>
<th>2. Contouring and handling</th>
<th>Restores adequate volume to treat enophthalmos, diplopia, and motility disorders</th>
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<tbody>
<tr>
<td>Easy to shape to fit the orbital defect and regional anatomy/malleability</td>
<td>Adequate in three-wall fractures</td>
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<td>No sharp edges and smooth surface</td>
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<tr>
<th>3. Biological behaviour</th>
<th>Biocompatibility: no infection/extrusion/migration/foreign body reaction</th>
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<tbody>
<tr>
<td>Chemically inert, non-allergenic, non-carcinogenic</td>
<td>Durable with minimal resorption</td>
</tr>
<tr>
<td>Osteoinductive/osteogenic</td>
<td>High tissue incorporation but readily dissected in implant removal during secondary reconstruction</td>
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<th>4. Drainage</th>
<th>Spaces within the implant to allow drainage of orbital fluids</th>
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<tr>
<td>5. Donor site morbidity</td>
<td>Does not increase surgical complication rate/donor site morbidity (pain, swelling, etc.)</td>
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<tr>
<td>6. Radiopacity</td>
<td>Radiopaque to enable radiographic evaluation without artefacts</td>
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<tr>
<th>7. Availability and cost-effectiveness</th>
<th>Readily available in sufficient quantities</th>
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<tbody>
<tr>
<td>Acceptable costs</td>
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</table>

the craniofacial area. Autologous bone grafts are used in orbital surgery because of their strength, rigidity, vascularization potential, and incorporation into the orbital tissues with minimal acute and chronic immune reactivity (i.e. infection, extrusion, collagenous capsule formation, and ocular tethering). Calvarial bone appears to be a superior option in orbital reconstruction because of its accessibility, the various graft sizes that can be harvested, the hidden nature of the scar as a result of its location in a hair-bearing area, and the occurrence of little or no postoperative pain. Donor site morbidity remains a general drawback for autologous bone harvesting. In full-thickness calvarial harvesting, care has to be taken not to tear the dura, since this injury carries the risk of iatrogenic subarachnoid haemorrhage or even intracerebral haemorrhage and might require reconstruction itself. Iliac crest grafting carries an associated risk of peritonitis, haemorrhage, pain, anterior spine fracture, lateral femoral cutaneous nerve damage, increased hospitalization time, and possibly thrombo-embolism. Additional disadvantages of autologous bone are the difficulty that can occur in contouring the bone to the perfect shape (e.g. because of fracturing of the graft with bending). In addition, autologous bone grafting is associated with unpredictable resorption, especially rib and iliac bone, which are of endochondral origin. The latter is in contrast to calvarial bone, which is intramembranous in origin and is more stable. Resorption rates of 80% have been observed in iliac crest bone grafting. Resorption may be decreased by fixating the graft, which promotes revascularization and osteoconduction. Despite the popularity of autologous bone, cartilage is easier to harvest and much more malleable, and the relative avascularity of this tissue allows survival with minimal oxygen perfusion and less resorption. The nasal septum is particularly advantageous because of the rapid harvest time and the minimal cosmetic and functional morbidity. Bayat et al. performed a randomized clinical trial (RCT) and found a superior effect for nasal cartilage versus conchal cartilage with respect to the occurrence of enophthalmos at the 3–6-month follow-up. A second RCT found no significant differences in the clinical outcomes of orbital fractures repaired with either a cartilage graft or an absorbable polyacid co-polymer. In cartilage grafting, limited donor site morbidity is involved. The major drawback of cartilage use is acquiring sufficient tissue for large orbital defects.

Allografts (syn. homografts) are transplanted tissues (e.g. lyophilized dura mater or banked (demineralized) bone) from another human being. Their advantages include a decreased surgical time, preoperative customizability, absence of donor site morbidity (only in cadavers), and abundant availability of banked (demineralized) bone. Lyophilized dura (Lyodura) was a standard in the past for the reconstruction of smaller orbital defects because of its strength and absence of tissue reactions. However, it became controversial following a case of Creutzfeldt–Jakob prion disease in a patient who received dura originating from a cadaver. Consequent to this report, lyophilized dura sterilization was no longer performed with gamma irradiation but with sodium hydroxide. The disadvantages of allografts include a resorption rate substantially higher than that of autologous tissue, the need for immunosuppressive pharmacotherapy, and the alleged risk of viral transmission, such as hepatitis C virus and HIV. Demineralized bone sheets of 100–300-μm thickness have been shown to be too weak to support orbital prolapse in cases with enophthalmos.

The use of xenografts in bone reconstruction is generally not encouraged because it is associated with disease transmission, immunological transplant rejection, and unpredictable and high resorption rates. In contrast to biological materials, the use of manufactured implants saves operative time and avoids donor site morbidity.

Metals

Titanium has been used extensively in craniofacial surgery and dentistry in the form of implants, plates, and screws. With its high biocompatibility and physico-mechanical properties, it could be an ideal implant for covering large anatomical defects (categories III–V) and glove malposition if implant-stabilizing surrounding bone or a distal landmark (a ‘bony ledge’) is absent.

An attractive feature of titanium is its ability to be both incorporated into the surrounding tissues and to osseointegrate. Titanium mesh seems to be particularly suitable for reconstructing large orbital fractures. Computer-assisted designed and manufactured (CAD/CAM) titanium implants have enabled optimal reconstructive surgery, with the protection of vital structures such as the optic nerve. Titanium is strong, rigidly fixable, widely available, and is subject to osseointegration with minimal foreign body reaction. However, titanium is costly and may have irregular edges if not cut properly, which may impinge soft tissue. Furthermore, fibrous tissue will incorporate the mesh-holes, which can make implant
replacement technically complex.\textsuperscript{26} Late unwanted effects such as infection, corrosion, and toxic metal ion release have been reported with the use of titanium implants.\textsuperscript{24} One RCT has evaluated the effects of titanium implants as compared to perforated polydioxanone (PDS) foil for small orbital floor fracture reconstruction, and found no significant differences in the clinical outcomes.\textsuperscript{3} A pilot study without controls used a low-profile 0.25-mm titanium plate in large defects (categories II and III) and found successful clinical outcomes without complications in 93\% of the cases; at the 6-month follow-up, no functional or aesthetic concerns were observed.\textsuperscript{28}

Cobalt-based alloys such as vitallium are used widely in dentistry for their high resistance to corrosion. These alloys produce large artefacts on CT and magnetic resonance imaging (MRI) and have rarely been used in orbital surgery.\textsuperscript{29} These materials have been replaced by titanium in general prosthesisology.

**Polymers**

Polymers (or plastics) are large molecules comprising multiple repeated subunits and can be categorized into absorbable and non-absorbable (permanent) types.

**Non-absorbable permanent polymer implants**

Porous ultra-high density polyethylene (PE; Medpor) sheets of various sizes and thicknesses (0.4–1.5 mm) have been used widely to cover smaller floor defects since the 1990s. This widespread use is a product of the ability to easily cut the sheets into various shapes and the ability of orbital tissue to move freely over the smooth surface.\textsuperscript{30} Connective tissue and vascular components grow into the pores with minimal foreign body reaction.\textsuperscript{31} In a prospective cohort study of floor reconstructions, PE sheets showed satisfactory surgical outcomes and infection rates similar to autografts.\textsuperscript{5}

Silicone is flexible, easy to handle, chemically inert, and relatively cheap.\textsuperscript{3} Silicone implants are substantially less palpable than non-silicone implants (autografts, titanium, or resorbable plates).\textsuperscript{31} However, unacceptable high rates of implant extrusion, cyst formation, and infections have been found, especially in the early postoperative period.\textsuperscript{32} Indeed, 12\% of orbital silicone implants require removal within 1 month after placement.\textsuperscript{33}

Polytetrafluoroethylene (PTFE; Teflon) is biologically and chemically inert, non-antigenic with minimal foreign body reaction, sterilizable, and easily mouldable. However, this polymer has not yet been subject to comparative clinical studies.

Relatively new in orbital floor repair is the use of nylon foil, a non-porous polyamide. Nylon foil has provided favourable results in preliminary non-comparative studies.\textsuperscript{39} Hydrogels are a network of hydrophilic polymer chains in a watery gel, and possess flexibility similar to natural tissue. Hydrogels have shown promising results in animal research in delivering bone morphogenetic protein type 2 (BMP-2) locally, significantly stimulating local bone growth.\textsuperscript{36}

**Absorbable polymer implants**

These materials have been used widely for over 30 years in many fields of surgical practice,\textsuperscript{35} and are of interest because of their more predictable absorption rates than biological grafts, as well as their high level of customizability and control.\textsuperscript{38} Resorbable materials provide temporary support, leaving fibrous granulation tissue during their degradation.\textsuperscript{39} These materials do not necessarily require rigid fixation, can be applied in multiple layers in larger orbital volume displacement, and can be radiolucent on postoperative imaging.

In an RCT, the administration of an absorbable copolymer of poly(lactic acid) (PLA) and poly(glycolic acid) (PGA) had functional and aesthetic outcomes and complications similar to auricular cartilage implants in orbital blowout fractures with or without medial wall involvement.\textsuperscript{17} In addition, PLA 70/30 plates were studied in a controlled clinical trial and showed similar surgical outcomes and complications as compared to autografts in category II and III floor defects, without MRI evidence of foreign body reaction.\textsuperscript{30}

Polydioxanone (PDO, PDS) is used widely in surgery for resorbable sutures, which degrade completely in approximately 6 months. In a multi-centre RCT, perforated PDS foils of 0.15-mm thickness were found to have surgical outcomes similar to 0.3-mm titanium meshes in orbital floor reconstructions, although PDS foil was considered to be more convenient to handle.\textsuperscript{27} Another RCT compared the use of a porcine collagen membrane to a 0.15-mm PDS foil and observed that complications and clinical symptoms remained absent for 6 months after orbital floor surgery.\textsuperscript{41} In one prospective case series, PDS implants were suggested as inadvisable because of unsatisfactory orbital reconstructions and high complication rates.\textsuperscript{11}

In a retrospective cohort study, reconstructions with polyglactin 910/PDS (Ethisorb) flexible patches showed a similar postoperative orbital geometry as compared to 0.25-mm PDS foil in floor reconstructions.\textsuperscript{22} In contrast to reports that polyglactin 910/PDS implants have high infection rates,\textsuperscript{43} a retrospective study of 87 patients treated with this material found no postoperative infections during a 3-month follow-up.\textsuperscript{39}

**Biological ceramics**

Hydroxyapatite (HA), which is chemically and crystallographically similar to bone mineral, has been available for craniofacial surgery since the 1990s.\textsuperscript{24} However, in orbital surgery, it has been found to be inferior to porous PE sheets with regard to the postoperative outcomes of enophthalmos.\textsuperscript{45}

Bioactive glasses (BAGs) are synthetic blocks or granules that bond chemically to bone. The disadvantages of BAGs include their rather brittle nature and the lack of ease in moulding, shaping, and fixing them.\textsuperscript{46} Nonetheless, these materials have been demonstrated to be osteoinductive and osteoconductive as implants,\textsuperscript{47} and to cause minimal foreign body reaction, infection, extrusion, displacement, and resorption.\textsuperscript{46,47} The benefits of preformed bioglass implants need further research.

**Composites**

An interesting group of orbital implants is the composites because of the potential to utilize the advantages of a selected material while reducing its disadvantages through hybridization with a second material. A reciprocal process can allow the strengths of both materials to be used. A clinical example is titanium-reinforced PE. Titanium mesh offers the advantages of high strength and stability, easy contouring, and radiopacity in postoperative imaging, while PE implants have a smooth surface allowing the free movement of orbital tissue. In recent years, a composite material (titanium-reinforced porous PE) has become available for maintaining ocular function and facilitating a secondary surgery if necessary.\textsuperscript{49} A retrospective chart review found no significant differences in the clinical outcome measures between PE channel implants versus PE-reinforced titanium implants. Kim et al.\textsuperscript{50} suggested that reinforced titanium PE implants do not require screw fixation.
A promising addition to polymers may be an extra coating. Heparinized bone marrow-coated polycaprolactone (PCL) scaffolds have shown promising potential in animal research, showing significantly greater bone induction in comparison to non-coated PCL scaffolds.\(^5\)

To conclude, the predominant material investigated in the literature in the 1990s was autologous bone (45% bone versus 32% Medpor or titanium). A global trend towards the use of alloplastic material for orbital reconstruction can be identified. This trend is reflected in more recent publications, in which alloplastic materials have been chosen increasingly for orbital reconstruction (30% bone graft versus 46% alloplastic implants). This increasing preference for alloplastic materials is likely the result of their ease of use, technological advancements, absence of donor site morbidity, and an increasing level of evidence of the safety and efficacy of synthetic materials for this indication.\(^7\)

### The ideal implant material

#### Introduction

In the search for the best material for orbital reconstruction, the most convenient approach may involve searching for the optimal material with reference to the fracture characteristics (e.g. fracture complexity, medical history, experience of the surgeon, costs). This approach could support a decision-making process for selecting an implant type based on typical fracture patterns. Seven material characteristics that would necessarily influence this clinical decision-making process are discussed (Table 3): (1) stability and fixation, (2) contouring abilities, (3) biological behaviour, (4) drainage, (5) donor site morbidity, (6) radiopacity, and (7) availability and cost-effectiveness. Future developments and new technologies are discussed as well.

#### Stability and fixation

Restoring the original orbital volume is essential for recovering ocular function.\(^33,34\) To accomplish this, a reliable material that can reconstruct proper orbital volume and reposition the supporting tissues without significant resorption is required. Numerous materials have been used to achieve anatomical reconstruction and these differ with respect to their stability. Van Leeuwen et al.\(^6\) have developed a mathematical model to judge preoperatively whether a material is suitable based on four variables that influence deformation: (1) the size of the orbital defect, (2) the mechanical properties of the reconstruction material, (3) the thickness of the reconstruction material, and (4) the pressure load of the orbital content. Based on the properties of various biomaterials, the authors concluded that not all materials were suitable when varying defect sizes were considered.\(^6\) In particular, Jaquière category I and II defects can be treated safely with titanium, bone, PLA, and PE (see Table 4).\(^6\) For these defects, a flexible material may generally be sufficient, whereas for the reconstruction of larger defects (Jaquière III and IV), a more rigid material (e.g. titanium) is required. Gross soft tissue prolapse, orbital pressure, and the absence of a posterior bony ledge are decisive factors.\(^3,6\)

Autologous bone is prone to resorption, possibly leading to loss of stability and contour over time. Resorption rates of up to 80% have been observed in iliac crest bone grafting.\(^11\) Resorption may be decreased by fixation of the graft, facilitating subsequent revascularization and osteoconduction.\(^13\)

Resorbable implants are of interest because of their predictable resorption rates, high levels of customizability, and control.\(^38\) Resorbable materials provide temporary support, producing fibrous tissue during degradation.\(^39\) Van Leeuwen et al.\(^6\) showed that the material properties of some resorbables are stable enough to support the orbital content. In contrast, others have demonstrated an increase in orbital volume as a late complication.\(^11,55\)

For all orbital implants, fixation is required to prevent migration, which may lead to infections, fibrosis, and scarring, and may incidentally result in diplopia and even blindness.\(^36,46\) With the exception of bioglass, most orbital implant materials can be fixed easily to the surrounding tissue, mostly the bone. If the orbital rim is comminuted, fixation may be more complex. Titanium mesh may help to secure (or replace) the bony pieces.

#### Contouring

The size of the bony defect is important in choosing the alloplastic material for reconstruction. Larger fractures have more variability in the defect shape, and failure to place the implant in a correct position might lead to atrophy, contractions, and herniated tissue.\(^61\) In most situations, unless pre-bent plates are used, the restoration of the complex anatomy of the orbit requires a significant effort in contouring the implant. Bony orbital walls are often comminuted, and bone fragments are often displaced into the maxillary sinus. In this context, reconstruction of the absent pieces of bone is essential to support the globe and restore orbital shape. CT is the single best method for imaging in orbital fractures and planning orbital reconstruction.\(^62,63\) Intraoperative and postoperative CT scanning aids the surgeon in evaluating the result of reconstruction. Suboptimal alignment of the implant does not necessarily lead to clinically relevant enophthalmos or diplopia.\(^64\) Nevertheless, anatomical reconstruction of the bony orbit is an important prerequisite for predictable reconstruction.\(^2\)

Among the materials available, titanium mesh is the easiest material to shape anatomically, especially when an intraoperative skull model is used for adaptation of the implant. Ellis and Tan\(^64\) demonstrated that titanium mesh is architectonically more accurate in form than bone grafts. However, controversy exists in the use of preformed titanium mesh versus intraoperative bending of titanium meshes. A cadaver-based study found no significant differences in volume restoration between patient-specific implants (PSI) moulded on a pre-injury stereolithographic model, self-bent titanium meshes, and preformed titanium meshes.\(^65\) Preformed implants may be more advantageous because of versatility and costs.\(^65\) Andrades et al.\(^63\) concluded that pre-bent titanium implants are superior in terms of optimal reconstruction in comparison to other implants. In large defects (Jaquière III–VI), the implant contour becomes an increasingly important factor for repositioning the globe into a correct position.\(^65\)

#### Biological behaviour

In addition to being perfectly accepted by the acceptor area, autographs are both osteoconductive and osteoinductive if fixed properly, and elicit minimal foreign body reactions.\(^7\) However, autographs are associated with high resorption rates.\(^13\) Despite the popularity of autologous bone, cartilage is easier to harvest and much more malleable. Additionally, its hypovascularity allows survival with minimal oxygen perfusion, and this might explain why this tissue is less subject to resorption.\(^44\)

The role of resorbable materials is to provide temporary support, leaving fibrous tissue during and after their degradation.\(^39\) Late inflammation reactions may occur even up to 3 years after surgery.\(^67\) and incomplete degradation and thick scar formation have been described. In particular, animal studies found that poly-l-lactic acid
<table>
<thead>
<tr>
<th>Stability</th>
<th>Contouring</th>
<th>Biological behaviour</th>
<th>Drainage</th>
<th>Donor site morbidity</th>
<th>Radiopacity</th>
<th>Availability</th>
<th>Cost-effectiveness</th>
</tr>
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<tbody>
<tr>
<td>Titanium meshes (flat)</td>
<td>++ contouring</td>
<td>++ allows tissue ingrowth</td>
<td>+ permeable</td>
<td>+</td>
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<tr>
<td>Stability +++</td>
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<tr>
<td>Fixation ++</td>
<td>– possible sharp edges</td>
<td>– poor dissection of peri-orbita in secondary reconstruction</td>
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<tr>
<td>Bone graft</td>
<td>+ variability in thickness/smooth surface adequate in three-wall fractures</td>
<td>+++ maximal biocompatibility/peri-orbita readily dissects off bone in secondary reconstruction</td>
<td>–</td>
<td>– donor site needed: harvest time/pain/scarring/comlications</td>
<td>+</td>
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<td>+/-</td>
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<tr>
<td>Stability ++</td>
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<tr>
<td>Fixation +</td>
<td>– remodelling/difficult to shape</td>
<td>– readily dissects off bone in secondary reconstruction</td>
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<td>+/-</td>
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<td>Porous polyethylene sheets</td>
<td>+ eased by artificial sterile skull/smooth edges</td>
<td>++ allows tissue ingrowth</td>
<td>–</td>
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<td>+</td>
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<td>Lack of rigidity when thin</td>
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<td>Fixation +/-</td>
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<tr>
<td>Composite of porous polyethylene and titanium mesh</td>
<td>+ eased by artificial sterile skull, adequate in three-wall fractures</td>
<td>++ allows tissue ingrowth</td>
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<td>Stability ++</td>
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<td>Fixation ++</td>
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<td>+/-</td>
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<tr>
<td>Resorbable materials</td>
<td>+ smooth surface and edges/handling (thermoplastics)</td>
<td>+/- sterile infection/inflammatory response</td>
<td>– in case non-perforated: less drainage than uncovered titanium mesh</td>
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<td>+</td>
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<td>Stability +/-</td>
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<tr>
<td>Stable over time?</td>
<td>– non-thermoplastics</td>
<td>– degradation of material with risk of contour loss</td>
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<td>+/-</td>
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<tr>
<td>Fixation +/-</td>
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<tr>
<td>Preformed orbital implant</td>
<td>+++ minimal contouring necessary/smooth surface</td>
<td>++ allows tissue ingrowth</td>
<td>+ permeable</td>
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<td>Stability +++</td>
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</table>

**Table 3.** Advantages and disadvantages of commonly used biomaterials.
Table 4. Modified classification of orbital wall defect size.

<table>
<thead>
<tr>
<th>Category</th>
<th>Complexity</th>
<th>Description</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category I</td>
<td>Low</td>
<td>Isolated defect of the orbital floor or the medial wall, 1–2 cm², within zones 1 and 2</td>
<td>Bony ledge preserved at the medial margin of the infraorbital fissure</td>
</tr>
<tr>
<td>Category II</td>
<td>Medium</td>
<td>Defect of the orbital floor and/or of the medial wall, &gt;2 cm², within zones 1 and 2</td>
<td>Missing bony ledge medial to the infraorbital fissure</td>
</tr>
<tr>
<td>Category III</td>
<td>High</td>
<td>Defect of the orbital floor and/or of the medial wall, &gt;2 cm², within zones 1 and 2</td>
<td></td>
</tr>
<tr>
<td>Category IV</td>
<td>High</td>
<td>Defect of the entire orbital floor and the medial wall, extending into the posterior third (zone 3)</td>
<td></td>
</tr>
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</table>

(RLLA) had not fully degraded within 5 years, while PDS degradation was associated with thick scar formation. PDS is not approved for orbital reconstruction in the USA because of the significant postoperative sequelae, including sensory disturbances (59%), restriction of motility (38%), and enophthalmos (24%).

The stability of the position of non-resorbable implants is dependent on the degree of acute (e.g. sterile inflammation or infection) and chronic (capsulation, migration, extrusion) peri-orbital tissue reaction. Early integration in the acceptor area is advantageous for implant stability, but might decrease the possibility of removal in secondary reconstruction and replacement (e.g. if a fibrous capsule is present). Hence, the reconstruction may become increasingly technically complex.

Bioactive glasses exhibit both osteoinductive and osteoconductive properties with little overall resorption. Excessively large implants can alter the nutritional supply to the adjacent structures. The physical form of a material can increase the host response.

Titanium is highly biocompatible and the rate of postoperative infection is minimal. However, late unwanted effects such as corrosion and toxic metal ion release have been described. Currently, no allogeneic implant material exerts the ideal biological behaviour.

If the anterior iliac crest is selected, various complications can be encountered, including sensory disturbances, vascular injuries (e.g. bleeding or haematoma), seroma, fracture of the iliac crest, and accidental perforation of the lower abdomen. Postoperatively, gait disturbance together with pain at the donor site can occur. The pain experienced during mobilization can result in restricted activity and thereby lead to extra costs for both the patient and community.

Some surgeons prefer calvarial bone harvesting for orbital reconstructions because of the lower resorption rates and decreased postoperative pain. Complications encountered with calvarial bone grafts are alopecia along the incision line, bleeding from the incision site, and inner table perforations with or without dural tear. In the presence of damage to the dura, leakage of the cerebrospinal fluid will occur. In the worst case scenario, brain injury may occur.

Autologous cartilage grafts from the auricle are considered a relatively safe procedure with minor complication rates and favourable aesthetic outcomes. Complications can include the formation of haematoma and sensory impairment confined to the concha (donor site). In terms of anthropometric measurements, resultant differences in the length and width of the affected ear, in the tragus–lateral canthus distance, and in the protrusion angle of the involved ear may occur. Overall, these findings are minor and are not considered a contraindication to harvesting ear cartilage.

Radiopacity
The accuracy of an anatomical reconstruction can be evaluated by peri- or postoperative imaging. Visibility of the implant material (bone or titanium) on CT scans is of immense importance in challenging

Drainage
Retrobulbar haematoma is one of the most serious complications after orbital reconstruction. The reported incidence of retrobulbar haematoma in the literature is about 0.6%. If postoperative impairment of vision due to retrobulbar haematoma becomes evident, an immediate surgical intervention is essential. It is more likely to occur in heavily traumatized patients with comminuted fractures and in patients taking anticoagulant medication. Both anticoagulant and anti-platelet therapies are likely to increase the risk of traumatic haemorrhage. Maurer et al. found that anticoagulant therapy was associated with a significantly increased risk of retrobulbar haematoma. In this previous study, the incidence of retrobulbar haematoma in patients on anticoagulant therapy with orbital fractures was 2.4%; this percentage increased to 8.8% in the geriatric group. Anti-platelet therapy alone (e.g. aspirin) did not increase the risk.

Donor site morbidity
By choosing an autogenous graft for orbital reconstruction, the consequence is a second surgical site with its own specific after effects. There is the initial extra surgical time needed for the procedure, which can be reduced if the surgeons can work in two teams.

Fig. 1. The orbital implant (titanium mesh) is positioned below the ledge, resulting in an increased orbital volume.
injuries with severe dislocation of the orbital walls, e.g. in orbits with an absent posterior bony ledge. In these cases, limited visibility of the deep surgical field and the absence of a palpable ledge may cause the distal end of the plates to be placed too low (see Fig. 1). A good implant in a bad position will lead to a suboptimal result. To prevent poor implant positioning, accurate preoperative planning by mirroring a defined three-dimensional segment from the unaffected side onto the deformed/tramautized side with computer-assisted techniques is an important aid for precise and predictable results. Navigation can be beneficial, but imaging is the gold standard for peri- and postoperative evaluation of the position of the implant. Evaluation of the postoperative results is equally important for the learning curve of the surgeon and might help to predict postoperative enophthalmos.

**Availability and cost-effectiveness**

Availability is a relative parameter related to economic and local circumstances and hospital interest and availability. Stocks of alloplasts can be limited in some parts of the world. Under these circumstances, the harvesting of bone grafts may be preferable, and in the case of orbital reconstruction, several options are available for the donor site. However, alloplasts reduce both the operation time and hospitalization because of the lack of donor site morbidity.

Pre-bent or preformed alloplastic materials are even more advantageous and have shortened the operating time compared to other alloplasts.

**Technological advantages**

Computer-assisted surgery (CAS) may be beneficial to the outcome of orbital reconstruction. The use of three-dimensional reconstruction in CT imaging and virtual planning offers accurate and individualized assessment and planning for the restoration of orbital walls and orbital volume. Since more complex preoperative planning and intraoperative navigation have become available, it has been demonstrated repeatedly that CAS is helpful in achieving more predictability in orbital reconstruction. One of the greatest advantages of CAS is the possibility of checking the implant fit preoperatively in a digital environment. With stereolithographic files (stl) of pre-shaped implants, the best possible anatomical fit can be targeted. These digital stereolithographs may be pre-shaped or individually designed (PSI). This digital planning is not material-specific: the only prerequisite is that the material has rigidity such that the digitally formed shape is coherent with the actual shape of the implant, even after manipulation. To date, titanium mesh is most in concordance with this prerequisite. In the future, other modern materials such as bioglass, hydrogels, and poly-ether-ether cones and composites may be fabricated as custom implants or preformed scaffolds using new techniques for rapid prototyping.

**Clinical recommendations**

The debate on the clinical recommendations for orbital reconstruction material will likely continue because of the absence ofRCTs and best practice clinical studies. The predominant factor regarding the most suitable material characteristic may be the defect size and to a lesser extent the defect location. Availability is also an important variable and is dependent on geographic and economic backgrounds. Nonetheless, based on the literature and material characteristics of the different types of orbital implants, it is possible to derive clinical recommendations for materials in specific cases.

**Treatment algorithm for orbital wall fractures**

1. Small-sized, low-complexity defects (class I): Most materials are suitable; biological behaviour is most important and resorbables may be used in these cases.
2. Medium-sized, medium-complexity defects (class II): Apart from the biological behaviour of an implant, the experience of the surgeon with specific types of orbital implants will benefit the outcome. Various materials can be used, from autologous materials to alloplasts (e.g. PE or titanium).
3. Large-sized, high-complexity defects (classes III–VI): Stability and contour become more significant, and pre-bent or patient-specific titanium mesh is the preferred reconstruction material.

Further additional factors of influence are: (1) the chosen surgical approach (skin versus transconjunctival), (2) the need for simultaneous orbital rim reconstruction, which favours titanium, (3) costs, (4) operating time availability, with effective use of operating room time favouring the use of alloplasts, (5) patients on anticoagulant therapy will favour the use of mesh for drainage reasons, (6) experience of the surgeon in dealing with certain materials or in harvesting grafts, (7) the availability of modern planning tools (e.g. for PSI fabrication), (8) the availability of navigational surgery for stereolithographic virtual planning for .stl based on preformed titanium implants, and (9) the availability of intraoperative CT scanning.

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**Patient consent**

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**References**


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