Biomaterials for Reconstruction of the Internal Orbit

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INTRODUCTION

Orbital floor injuries, alone or combination with other facial fractures, are one of the most commonly encountered midface fractures. Significant complications can occur as a result of these injuries, including enophthalmos, persistent diplopia, vertical dystopia, and restriction of gaze. Appropriate repair is therefore critical. There is currently a greater understanding of the complex anatomy of the orbit and changes that occur within the orbit from disruption of its contents caused by trauma. The principal mechanism of posttraumatic enophthalmos has been shown to be displacement of the orbital soft tissues within an enlarged bony orbit.1,2 Practitioners generally agree that the optimal treatment is to restore the normal bony architecture and reduce the herniated orbital tissues. Despite advances made in understanding of the injury, wide variation still exists in the method of reconstruction.1–125

Of all the considerations in orbital reconstruction, probably no topic has more differing opinions than the selection of biomaterial with which to reconstruct the orbital walls. This paper reviews the biomaterials currently available for internal orbital reconstruction and provides insight into their selection and application.

CHARACTERISTICS OF MATERIALS

Biomaterials include both naturally occurring and synthetic substances. They can be classified as alloplasts, allografts, autografts, and xenografts. The ideal material has physical properties that most closely replicate those of the tissue it replaces.
Specific criteria for the ideal properties of a generic biomaterial have been established (Box 1). The material should be chemically inert, biocompatible, nonallergenic, and noncarcinogenic. If alloplastic, it should be cost-effective and capable of sterilization without deterioration of its chemical composition. The material should be easily cut and sized in the operating room, and be able to be shaped to fit orbital contours and retain its new form without memory. It should allow fixation to host bone using screws, wire, suture, or adhesive. It should not potentiate growth of microorganisms nor promote resorption of underlying bone or distortion of adjacent tissues. It should be radiopaque to allow radiographic evaluation. The material should be capable of removal without damage to surrounding tissues. The material should be permanently accepted and, if resorbable, completely resorb with replacement by host bone. Lastly, it should be readily available. To date, no single material has been universally successful in meeting every one of these criteria. However, as materials science continues to advance, materials come to possess increasingly more of these qualities (Fig. 1). The clinician is responsible for recognizing the diversity of the available materials and selectively applying them to the appropriate clinical setting.

All of the characteristics listed in Box 1 are important qualities of an implanted biomaterial; however, the interplay of the properties is what contributes to the most important aspect of an implanted material: its permanence. The long-term biocompatibility of a material is dependent on the dynamic relationship between host and implant and is influenced by many factors. Calnan reported that alloplastic implants may initiate 6 different biologic reactions (Box 2). The cellular reaction to an implanted material, as described by Coleman and colleagues, begins with an acute inflammatory reaction, with polymorphonuclear leukocytes being the predominant initial cell type. Lymphocytes and macrophages migrate into the area in an attempt to phagocytize the foreign material. Being unable to phagocytize the implant, a chronic inflammatory reaction ensues. This granulation tissue subsequently matures, and an encapsulating connective tissue sheath is formed, isolating the implant.

Once a fibrous capsule is established around the implant, it is generally well tolerated by the body; however, the relationship between host and implant can be altered by several factors. These include various chemical, mechanical,
geometric, and physical factors. Chemical factors are associated with alterations in the composition of the material from degradation. Before the current implantable alloys, this was most problematic with corrosion of implanted metals. Most implanted polymers are regarded as chemically inert.14

Chemical factors have become a concern again in regard to resorbable biomaterials. All resorbable biomaterials undergo a breakdown reaction and provide the potential for a host’s reaction to the breakdown products. Mechanical factors include chronic movement of the implant, discontinuity of the surrounding capsule, and chronic trauma to the implant site. In general, materials that are well tolerated (when implanted subcutaneously) show an increased host reaction if the implant is chronically mobile, subjected to repeated trauma, or insufficiently surrounded by host tissue (Fig. 2).7 Each of these factors may lead to exposure of the implant, and once exposed, implants in humans practically never heal over.7 Geometric and physical factors include size, shape, and form of the material. Studies have clearly shown that the physical form of a material can increase the host response to that material.7,14−17 Porous materials allow for variable degrees of soft tissue ingrowth, decreased capsular contracture, and long-term immobility.18 The acceptance of porous material is hypothesized to be through microscopic adherence of collagen fibrils and capillaries to the pores of the material.14 Fibrovascular permeation of the implant by host tissue allows locally active immune defense and implant fixation.19 The importance of maintaining local immune defense to prevent late rejection of an implant is probably underestimated. Isolation of an implant by a thick fibrous capsule creates an avascular interface between host and implant. Bacterial seeding of the periimplant space is not accessible by the host immune defenses and can lead to abscess formation,12 which ultimately will lead to failure of the implant. Optimal soft tissue compatibility is characterized by either a limited inflammatory reaction with thin fibrous encapsulation or mesenchymal ingrowth with minimal macrophage activity.19 Small increases in the amount of host reaction to a given material directly affect the permanence of an implant. Davila and colleagues16 observed that the encapsulating sheath can thicken and outstrip its blood supply, leading to inflammation, rupture of capillaries, and degeneration of the capsule. Realization of the important role of physical form and material biocompatibility have led to the development of the next generation of implantable materials that have the ultimate goal of incorporation into host tissue and not isolation from them.

CONSIDERATIONS FOR THE INTERNAL ORBIT

Several considerations unique to reconstruction of the internal orbit make the procedure particularly challenging for the development of an ideal biomaterial. Because of the diversity of problems that may present in orbital reconstruction, currently no single material is easily and successfully used in all situations. Clinicians must therefore be cognizant of the properties of the various biomaterials available and to which clinical situation each is best suited. Specific considerations in reconstruction of the internal orbit are presented in Box 3.

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**Box 3**

Factors influencing choice of biomaterial for use in the orbit

- Size of defect
- Involvement of multiple walls
- Adaptation to internal contours
- Restoration of proper volume
- Presence of adjacent sinus cavity
- Prevention of displacement
- Risk of further trauma
- Adhesions/restriction of ocular mobility
- Early versus late repair

Size of the bony defect is important in considering a biomaterial for several reasons. As the size of the defect increases, the variability in shape of the defect increases as the involvement of multiple walls increases (Fig. 3). Failure to restore continuity to the walls of the orbital cavity inevitably leads to atrophy and cicatricial contraction of herniated or incarcerated intraorbital contents. Therefore, materials to reconstruct larger defects ideally must be easy to size, shape, and contour to most accurately reconstruct the natural contours of the bony orbit. Dependence on the implant to support orbital soft tissues increases with increasing size of the defect. Consequently, more rigid materials are best suited for reconstruction of large defects to prevent sagging of the material or displacement into the maxillary antrum and/or ethmoid sinuses.

The size of the defect can also be a reflection of the degree of trauma sustained and evidence of the disruption of the orbital ligament system. Disruption of this system has been implicated in the development of enophthalmos from the reshaping of orbital soft tissues that occurs from loss of ligament support. Restoration of proper orbital volume and repositioning of orbital soft tissues are of fundamental importance in orbital reconstruction. Care must be taken to select a material that can reliably reconstruct orbital volume and reposition the soft tissues without significant resorption.

Displacement of the material is an unfortunate and preventable occurrence (Fig. 4). Converse and colleagues theorized that implants become displaced on active rotation of the globe. The severity of this event depends on the direction and degree of displacement of the material. Extrusion, recurrent enophthalmos, restriction of gaze, loss of vision, and lacrimal duct obstruction have all been reported in the literature as a result of displaced biomaterials in the orbit. Displacement of the implant occurring before fibrous tissue becomes established across the defect provides a mechanism for recurrent prolapse of orbital contents into the paranasal sinus. These adverse effects underscore the importance of stabilizing biomaterials within the orbit. Browning noted that large unfixed implants were more likely to become extruded than similar implants fixed in place with wire or suture. Many authors have advocated the routine use of fixation when placing biomaterials within the orbit. Fixation has been shown to reduce implant-associated complications; therefore, migration should be considered a preventable complication. In a review of long-term stability of Teflon implants, Aronowitz and colleagues reported no cases of migration or extrusion in 77 patients over a 16-year period when implants were stabilized. Several authors have reported that migration and displacement of an implant are directly related to the fixation modality. Methods of fixation reported in the literature include nonresorbable suture, wire, adhesives, and screws.

Preventing adhesions between orbital soft tissues and materials used for reconstruction is essential for restoring normal ocular function. Adhesions can lead to restriction of gaze and persistent diplopia. The primary function of the implant is to provide an inert nonadherent surface. Browning and Walker reported that interposition of a smooth inert floor plate between traumatized orbital soft tissues and the fragmented bony floor would prevent the development of motility-restricting adhesions. Concern about preventing adhesions has been most marked with metal implants, and several authors have recommended the placement of autogenous or alloplastic materials between the device and orbital tissues. Adhesion to metal or other materials has been shown to not be a problem characteristic of the material and is probably best prevented through meticulous handling of orbital soft tissues to prevent impingement by the implant.

Timing of the repair is a major consideration when selecting a material for reconstruction. Early repair of orbital fractures helps prevent long-term incarceration of orbital contents and more reliably restores proper orbital volume. Biomaterial selected for early repair should consist of the thinnest, least space-occupying material, because exophthalmos can result from overcorrection. Soft tissue volume loss needs to be compensated for less in the acute setting. Browning reported that small defects treated early may be adequately

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**Fig. 3.** CT scan showing a large internal orbital defect involving multiple walls.
reconstructed with thin (0.3–1 mm) materials because they need only provide a nonadherent surface. In contrast, late repair is much less predictable because atrophy and scar contracture often necessitate compensation for larger degrees of soft tissue loss and enlargement of orbital volumes (Fig. 5). Except for titanium mesh, thin materials will not adequately correct globe dystopia and reduce orbital volume to correct cases of established enophthalmos. Materials capable of occupying greater space and maintaining stability over time to maintain the appropriate orbital volume are usually necessary for late repair.

**SELECTION OF A MATERIAL: AUTOGRRAFT VERSUS ALLOPLASTIC MATERIALS**

Selection of the source of material has been and remains an ongoing debate. Autogenous bone remains the standard against which other materials are compared, although its use has become less common over the past 2 decades. However, generally the material selected for orbital reconstruction is largely determined by the experience of the surgeon. Many authors have outlined the relative advantages and disadvantages of each class of material. These characteristics are based on concerns for donor site morbidity, complication rates, availability of the material, operating room time, and stability of the material over time (Table 1).

**AUTOGENOUS MATERIALS**

Autogenous tissues were the first material used to reconstruct the internal orbit and are still frequently used. They require a second operative site, which increases patient morbidity; require increased operative time to harvest; are limited in quantity; and are plagued by variable amounts of resorption over time. The variable resorption and potential for late-occurring enophthalmos are the most critical arguments against autogenous materials.

**Autogenous Bone**

The advantages of autogenous bone are its inherent strength, rigidity, and vascularization potential. It also demonstrates a relative resistance to infection, incorporation by the host into new bone, lack of host response against the graft, and lack of concern for late extrusion. Foreign body reactions, such as infection, extrusion, collagenous capsule formation, and ocular tethering, are minimized. However, the use of autogenous bone is associated with several less favorable aspects, including donor site morbidity,
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Symbols indication: –, poor; +, Fair; ++, good; ++++, excellent. Abbreviations: NA, not applicable; PLA, polylactide; PGA, polyglactin; PDA, polydioxanone.

variable graft resorption, and limited ability to contour some types of bone (Fig. 6).

Endochondral and membranous bone sources are used in orbital reconstruction, with the major donor sites for each being iliac crest and calvarium, respectively. The technique of bone grafting in the internal orbit is most consistent with onlay grafting. All bone grafts undergo some degree of resorption and remodeling, although the degree to which each type of graft is affected remains unclear. Early studies showed that membranous bone maintained a greater volume of the original graft compared with endochondral bone when used as an onlay graft. Resorption rates of up to 75% have been reported for endochondral, and of 20% to 30% for membranous bone grafts. In contrast, Ozaki and Buchman showed that resorption is not a function of the embryonic origin of the graft, but instead depends on its microarchitecture. Separating the cortical and cancellous components of the grafts, these investigators found cortical grafts maintained their volume significantly better than cancellous grafts regardless of embryonic origin. Fixation of bone grafts has also been shown to reduce graft resorption when grafts are placed under mobile tissues (see Fig. 6).

Resorption of graft volume is obviously a concern for the long-term success of reconstructions using autogenous bone. For this reason, calvarial bone is the primary choice for autogenous bone. It has the advantage of being located in the same operative field and provides a high volume of cortical bone. It is available in quantities sufficient for multiple grafts in bilateral orbital reconstructions and can be easily used in conjunction with rigid fixation. It is also sufficiently available in children. Iliac crest and rib provide large quantities of bone, but show greater resorption because of the difference in microarchitecture, have potential for significant patient morbidity, and require a second operative field. Their primary advantage over cranial bone is the relative ease of shaping the graft.

Many alternative sources of autogenous bone have been anecdotally reported in the literature, including anterior maxillary wall, mandibular symphysis, ramus, lingual cortex, and coronoid process. The main advantages reported for these sources are the ease of access and reduced donor site morbidity. These sources are extremely limited in quantity, however, restricting their application to a narrow subset of internal orbital fractures.

**Autogenous Cartilage**

Autogenous cartilage grafts are the most frequently used material for nasal augmentation. Their use for reconstructing orbital fractures, however, is not as prevalent. Proponents of autogenous cartilage tout its ease of harvest, flexibility, and limited donor site morbidity as its main advantages. Infection and resorption of autogenous cartilage grafts are rare. Histologic studies have shown the survival of chondrocytes within normal matrix, and a general absence of fibrous ingrowth and resorption of the graft. Investigators have postulated that cartilage grafts will calcify with time.

The main sources of autogenous cartilage for orbital reconstruction are the cartilaginous nasal septum and conchal cartilage (Fig. 7). In general, both of these require contouring for accurate reconstruction of the internal orbit, which is problematic because cartilage possesses inherent

![Fig. 6. Calvarial bone graft positioned over orbital floor defect and stabilized with a miniplate. Note that plate does not cross the orbital rim to reduce risk for scar adherence of lower lid to plate.](image1)

![Fig. 7. Photograph of harvested conchal cartilage graft that can be used to reconstruct small internal orbital defects.](image2)
memory and a tendency to return to its previous shape.\textsuperscript{56,61–64} Motoki and Mulliken\textsuperscript{65} reported that cartilage will tend to return to its original shape unless maintained in the new shape for several months, which is difficult to accomplish within the confines of the internal orbit. Furthermore, carving necessary for contouring produces changes in the balance of intrinsic tensile and expansive forces, causing distortion of the cartilage shape.\textsuperscript{65} Progressive changes in the shape of the graft can alter support and volume within the orbit, causing increased likelihood of late complications.

Patient selection is important because patients must be free of nasal symptoms, have no previous history of nasal surgery, and have a septum that is not complicated with significant deviation or spurs.\textsuperscript{64} However, autogenous cartilage provides an easily harvested autogenous material for smaller defects in appropriately selected patients.

### ALLOPLASTIC MATERIALS

Alloplasts have been gaining popularity for reconstruction of the internal orbit because of their ease of use and reduced surgical morbidity. Other benefits of alloplasts include decreased operative time, multitude of sizes and shapes available, and seemingly endless supply. The disadvantages of alloplasts have previously been outlined and stem from the fact that they are foreign bodies and elicit some degree of host reaction to the material (see Box 2). Many more products are available on the market today than ever before, some without long-term clinical outcome data. This lack of evidence is an obvious concern, because the literature contains many reports of implant complications occurring up to 20 years\textsuperscript{27,30,55} after placement. The development of resorbable materials has renewed the interest in alloplastic materials. Resorbable materials are immune to many of the late-occurring complications; however, the literature reports several cases of inflammatory reactions to some of these products. The surgeon must bear in mind that alloplasts are not the panacea that some claim them to be, and that the risk for complications can be lifelong.

### ALLOGENEIC MATERIALS

Allogeneic materials (allografts, homografts) and xenografts contain no living cells but, depending on the material, may possess osteoinductive and/or osteoconductive properties. These materials become incorporated into host tissues through providing a structural framework for ingrowth of host tissues. They do not require a second operative site, therefore require less operative time, and are generally abundant in supply. Waite and Clantons\textsuperscript{5} reported that allografts seem to give equally successful results as autografts for reconstruction of the orbital floor. Use of allogeneic materials, however, is marked by concern for antigenicity of the material and transmission of infectious disease.\textsuperscript{68} Both xenograft and allogeneic materials are processed through various methods to reduce antigenicity. Xenografts possess more antigenic potential than homografts, and are therefore used less frequently and not recommended by the authors for internal orbital reconstruction. Before placement of xenografts, the surgeon should inquire about previous use of xenografts in the patient, because delayed hypersensitivity reactions have been reported.\textsuperscript{8} The 2 most common allografts used for orbital reconstruction, namely homologous bone and cartilage, are discussed in the following sections.

### Homologous Bone

Homologous bone provides a scaffold for new bone formation and has the same working properties of autogenous bone. In general, homologous bone is slower to become incorporated and vascularized than autogenous bone.\textsuperscript{73} Studies have shown it to be associated with few complications when used for reconstructing the maxillofacial skeleton.\textsuperscript{74} Homologous bone is uncommonly used in reconstructing the internal orbit because of reports that bone allografts have a greater tendency to resorb than autografts and are associated with more infections.\textsuperscript{55} In a review of their use of homologous bone in the maxillofacial skeleton, Ellis and Sinn\textsuperscript{74} reported few complications with its use and relative stability of volume with time. They also noted that, in several cases in which homologous bone was used to reconstruct the internal orbit, reexploration of those orbits showed that the material had undergone remodeling to form a normal-appearing bony orbit (Fig. 8). Abundant supply, rigidity, and incorporation into host tissue are characteristics of homologous bone that make it an acceptable material for reconstruction of the internal orbit.

### Homologous Cartilage

Homologous cartilage has not been widely reported in the literature for reconstruction of the internal orbit. Chen and colleagues\textsuperscript{70} reported their results with lyophilized fascia and cartilage over a 5-year period in 77 patients with isolated orbital floor fractures. Homologous fascia was used for minimally displaced fractures and defects smaller than 5 mm, and cartilage was used for moderately displaced fractures and defects larger
than 5 mm. Patients with severe displacement or other associated facial fractures were excluded. Only 11 patients were treated with homologous cartilage. Although the authors report a comparatively low complication rate for the overall study, how many complications were associated with the use of homologous cartilage is unclear.

Homologous cartilage has been shown to undergo ossification and calcification with time. However, homologous cartilage has a greater tendency to undergo resorption and replacement with fibrous tissue than autogenous cartilage. Preserved cartilage is reported to have significantly greater amounts of resorption and increased rates of infection.

**ALLOPLASTS**

Alloplasts have been gaining popularity for reconstruction of the internal orbit because of their ease of use and reduction in surgical morbidity. Other benefits of alloplasts include decreased operative time, multitude of sizes and shapes available, and seemingly endless supply. The disadvantages of alloplasts have been outlined previously and stem from the fact that they are foreign bodies and elicit some degree of host reaction to the material (see Box 2). Alloplasts may be classified as nonresorbable or resorbable. Nonresorbable materials confer a lifelong risk for complications. Resorbable materials are immune to many of the late-occurring complications; however, the literature reports several cases of inflammatory reactions to some of these products.

**NONRESORBABLE MATERIALS**

**Metallic Mesh**

Implantable metals and alloys have revolutionized the treatment of facial fractures through providing rigid internal fixation across fracture lines. As these systems have continued to evolve, the development of low-profile microplating systems has led to their acceptance in the treatment of orbital fractures. The earliest application of these materials in the orbit included rigid internal fixation of the fractured orbital skeleton and fixation of bone grafts within the orbit. Most recently, they have been adapted for reconstruction of the bony internal orbital walls and spanning large bony defects. Several different forms of these alloys are available for this purpose, including preformed orbital plating systems and mesh sheeting (Fig. 9). These materials are thin, easy to contour, easily stabilized, maintain their shape, and have the unique ability to compensate for volume when properly contoured, without the potential for resorption. They can easily span large defects to provide rigid support, are visible on radiographs, and are sterilizable. Titanium has the further advantage of producing fewer artifacts on CT than other metals.

Metallic mesh is used routinely to treat orbital fractures and has shown good success when used appropriately. Rubin and colleagues...
compared the use of custom orbital floor titanium plates or vitallium mesh versus autologous bone grafts retained with either screw fixation or microplating techniques. They reported no significant complications related to the orbital implants and relative ease of use when compared with placing autologous bone grafts. In a review of 54 patients who underwent internal orbital reconstruction with vitallium mesh without bone grafts, Sargent and Fulks reported excellent results, with no postoperative infections nor need for removal of the material in any case. Ellis and Tan showed better overall reconstruction of orbital blowout fractures with titanium mesh compared with autogenous bone. Rubin and Yaremchuck, in a comprehensive review of the implantable biomaterials literature, reported good results for both mesh and plate systems. Two studies with 69 total patients reported no complications, including infection or extrusion with titanium mesh. Range of follow-up was only 1 to 3 months. Four studies with 92 total patients reported an infection rate of 4.4% overall for metal plates, with 3.3% of implants requiring removal because of an implant-related complication. The range of follow-up was 6 months to 3 years.

Disadvantages of metal alloys include the risk of extrusion and infection, and the theoretical risk to the tissues of the orbital apex from another trauma. Removal of these materials when indicated may be extremely difficult because of fibrous ingrowth through holes machined into them, and also the possibility of osseous overgrowth/osseous integration of the material. Some investigators have also expressed concern that the presence of metal plates may lead to inflammation and adhesions, which contribute to ocular muscle restrictions (Paul Manson, MD, personal communication, 1998). Lee and Nunery reviewed 10 patients with orbital fractures repaired using titanium mesh covering an orbital wall or a plate along the orbital rim who presented with orbital adherence syndrome. Of the 10 patients, 6 presented with cicatricial eyelid retraction, and 9 of 10 presented with extraocular motility restriction resulting in diplopia. During surgical repair, an intense fibrotic adherence was noted between the titanium implant within the orbit or periorbital tissues. All surgical patients with diplopia had improvement in extraocular motility after the titanium was removed and replaced with 0.4-mm nylon implants. They concluded that titanium implants may lead to the adherence of orbital and periorbital structures, resulting in restrictive diplopia and eyelid retraction.

**High-density porous polyethylene**

Polyethylene has been used as an implanted material for more than 40 years. High-density porous polyethylene (HDPE) has been commercially available as Medpore (Porex Surgical, College Park, GA) since 1985. HDPE is a pure polyethylene implant that is highly biocompatible and processed specifically to include and control pore size. It is insoluble in tissue fluids, does not resorb or degenerate, incites minimal surrounding soft tissue reactions, and possesses high tensile strength. Pore size is engineered to range in size from 100 to 200 μm, with greater than 50% being larger than 150 μm. Pore size has been shown to directly influence the rate and amount of bony and fibrovascular ingrowth into the implant. Animal studies have shown that tissue ingrowth and formation of a mucosal lining occur even when the implant is placed over an open maxillary sinus. Fibrovascular ingrowth minimizes capsule formation; plays a vital role in maintaining the local host immune response within the implant, providing resistance to infection; and provides stability to the implant to prevent migration and exposure. Fibrovascular ingrowth has not been shown to cause extraocular muscle restriction through soft tissue adherence to the implant. HDPE is available in many different forms. Thin sheeting (0.85–3.0 mm) is most commonly used for internal orbit applications and is easily cut to

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**Fig. 9.** Example of orbital floor fracture repaired with titanium mesh. (A) Preoperative CT showing orbital floor blowout fracture. (B) Postoperative CT showing repair of defect with titanium mesh. (C) Examples of preformed titanium orbital implants.
form with scissors. The material should be soaked in an antibiotic solution before placement within the orbit. It is easily and reliably stabilized with screws.\textsuperscript{3}

HDPE is widely accepted for its role in correcting acute injuries and late enophthalmos. Romano and colleagues\textsuperscript{18} reviewed the use of HDPE in 140 patients with facial fractures, 128 of whom had implants placed within the orbit. They observed 1 instance of implant infection requiring removal and no cases of implant migration or extrusion. In a review of 21 patients who underwent late correction of enophthalmos using HDPE, Karesh and Horswell\textsuperscript{79} observed no cases of infection or extrusion. In a report of 37 orbital reconstructions using HDPE, Rubin and colleagues\textsuperscript{37} reported that 1 patient developed infection necessitating implant removal and a second patient had a palpable implant requiring revision 12 months later. Overall, their experience was favorable toward the use of HDPE within the orbit.

Lupi and colleagues\textsuperscript{116} used porous HDPE to reconstruct the orbit floor in patients with posttraumatic (27 cases) and postoncologic (5 cases) injuries. No cases of implant migration, extrusion, or enophthalmos were seen; diplopia persisted in 2 patients after 6-month follow-up. The implant was considered safe and represented a stable platform for orbital soft tissues growth.

In 2008, Wang and colleagues\textsuperscript{117} restored orbital floor fractures under the peristeme in 21 patients using shaped autogenous bone, titanium mesh, and porous polyethylene (Medpor). All patients had good results, including significant improvements in appearance and function after surgery, without exhibiting severe permanent complications. They suggested that porous polyethylene and titanium mesh may be preferable to autogenous bone because of decreased operative time and donor site morbidity.

Proponents of HDPE tout its technical ease of use for establishing precise 3-dimensional reconstructions and its biocompatibility, durability, and porous structure (allowing fibrovascular ingrowth).\textsuperscript{18,35} Aside from being an alloplast, its main disadvantage for use in reconstructing the internal orbit is that it is not radiodense and therefore its position cannot be easily visualized on immediate postoperative CT scans (\textbf{Fig. 10}).

**Medpor Titan**

The Medpor Titan implant is a sheet of titanium mesh embedded in porous polyethylene and has gained much attention in the literature recently (\textbf{Fig. 11}). It has the strength, memory, and radiopacity of titanium and the potential for fibrous ingrowth of polyethylene. The new design provides a smooth surface on both sides of the implant; sharp edges of cut titanium are covered by the polyethylene layer, eliminating the need to burr down or smooth the edges to avoid abrasion. Tabrizi and colleagues\textsuperscript{123} evaluated orbital floor reconstruction in 101 patients using different materials, including the Medpor Titan implant, concluding that Medpor Titan provided excellent structural support and stability within the orbit and in reconstruction of orbital volume. Both stability and orbital volume are important in resolving enophthalmos and diplopia. Garibaldi and colleagues\textsuperscript{124} studied 100 patients who received Medpor Titan implants, 70\% of which were fixated with a single screw. One case of orbital hemorrhage and overcorrection was
reported, which was attributed to the thickness of the implant. They reported no cases of extrusion or infection. The Medpor Titan implant allows the surgeon to avoid the considerable tissue ingrowth through the holes that is seen with titanium mesh, preventing the tissue from adhering to the surface of the implant. Medpor Titan possesses improved handling characteristics compared with traditional Medpor, allowing the surgeon to bend and contour a thin implant material to the desired shape while providing the strength usually associated with a much thicker traditional Medpor implant.

**Nylon SupraFoil**

Smooth nylon foil is a nonabsorbable clear sheeting material manufactured from standard nylon suture (Fig. 12). Formerly known as Supramid, nylon foil has been used to repair orbital fractures since 1965. In 2007, Majmundar and Hamilton examined 10 orbital floor fractures in 9 patients who were treated with smooth nylon foil from 2004 to 2006. They reported no incidences of implant extrusion, rejection, or infection, and concluded that SupraFoil was safe, easy to use, and reliable. In 2008, Numery and colleagues reported excellent clinical outcomes obtained after implanting a single 0.4-mm thick nylon foil in 102 patients. They showed that 101 patients displayed normal globe position and full ocular motility without diplopia. One patient had persistent enophthalmos requiring a second procedure. Park and colleagues reported a retrospective study of 181 patients having undergone repair of orbital fractures with nylon foil from 1995 to 2003. Repair of fractures consisted of nylon sheets of varying thickness using a transconjunctival approach with a single-screw fixation of the implant. They reported 1 case of orbital hemorrhage and 1 late infection. Results showed that smooth nylon foil implants are safe and effective in the repair of orbital fractures, and suggested that implant fixation may be instrumental in reducing the incidence of hemorrhage within the implant capsule in nonporous implants. Custer and colleagues investigated complications of 41 orbital floor fractures repaired with Supramid implants. They concluded that insertion of larger implants (>600 mm²) in late repair of orbital defects may predispose patients to hemorrhage or infection. Su and Harris showed no complications in 19 repairs of combined floor and medial wall fractures using an implant 0.3-mm thick with pre-punched holes to encourage fibrovascular ingrowth to aid in stabilization.

**Hydroxyapatite**

Hydroxyapatite \([\text{Ca}_{10} \ (\text{PO}_4)_6 \ (\text{OH})_2]\) is a calcium phosphate salt that is a major constituent of bone. Calcium phosphate ceramics can be produced through the fusion of calcium phosphate crystals. Several forms are available for reconstruction of the facial skeleton. Dense hydroxyapatite is produced synthetically through high-pressure compaction of calcium phosphate crystals, which are then sintered (fused) into a solid form. Porous hydroxyapatite can be produced synthetically or naturally. Various pore sizes may be engineered into the synthetically produced material. Porosity allows for bony and fibrovascular ingrowth.

Hydroxyapatite is highly biocompatible and causes minimal inflammatory response in the surrounding tissues. It produces a strong mechanical bond with host bone and allows ingrowth of host tissue, providing a scaffold for bone repair. It demonstrates limited resorption and obviates a second surgical site. Hydroxyapatite (all types) has a favorable infection rate of 2.7% for craniofacial reconstruction.

Block forms of hydroxyapatite are most commonly used within the internal orbital skeleton. Large blocks may be ground to the proper size for placement, or multiple small blocks may be placed. Ease of use and limited mechanical qualities are the main disadvantages of hydroxyapatite. Its low tensile strength and inflexibility make HA a poor bone substitute. It is brittle, and therefore challenging to contour for placement within the orbit. Hydroxyapatite is extremely
difficult to stabilize because overtightening a screw will lead to fracture of the implant. Because of its limited adaptability and relative incompatibility with rigid fixation, hydroxyapatite is rarely used for primary treatment of orbital fractures.

**Silicones and Polytetrafluoroethylene (Teflon)**

These materials are included for discussion sake, but the current use of these materials is limited because of numerous reports of late complications arising as many as 20 years postoperatively. Silicone rubber is a chemically inert material available in block and sheet (Silastic; Dow Corning, Midland, MI) forms (Fig. 13). Teflon is a long-chain halogenated carbon polymer produced by the polymerization of tetrafluoroethylene gas at high temperature and pressure. It is chemically inert with no known solvent, noncarcinogenic, and able to be sterilized. It is available in a felt-like sheet that is easily cut to size. Silicone and Teflon were the 2 earliest and most commonly used alloplasts for reconstruction of orbital defects. Both show excellent biocompatibility and ease of use. However, these materials histologically demonstrate fibrous encapsulation by the host, a mechanism that has been postulated to lead to failure.

An overall rate of extrusion of 3.1% is reported for smooth silicone implants. The infection rate reported in the literature for silicone implants in the orbit is 1.2%, and other complications include displacement (2%) and seroma (0.5%). Morrison and colleagues reported data on 302 patients treated over 20 years who had received silicone implants for treatment of orbital trauma. Of these patients, 41 (13%) required removal of the implant secondary to implant-related complications. Most complications associated with silicone implants can probably be attributed to their lack of stabilization that was characteristic of early techniques. Many reports have cited the lack of fixation as a cause for a potentially preventable complication.

Teflon implants have similarly been under scrutiny for potential late complications. Two reports have documented the long-term outcome with Teflon orbital implants. Aronowitz and colleagues reported data on 35 implants in 31 patients treated over 16 years. The short-term and long-term complication rates were 3.9% and 2.8%, respectively. Antral packing was a clinically significant factor associated with implant failure. No cases of implant migration were seen with proper fixation. Polley and Ringler reported data from a 20-year review of 230 Teflon implants, with a mean follow-up of 30 months. Only 10% of patients had fixation of the implant. No postoperative or long-term complications of extrusion, hemorrhage, or displacement of the implant were observed. One case of infection (0.4%) was reported. Despite these favorable reports, the literature is scattered, with case reports of Teflon implant complications resulting many years postoperatively. These reports, combined with the development of more recent materials, have lead to the disfavor of Teflon for orbital reconstruction.

**RESORBABLE ALLOPLASTS**

**Polylactide**

Biodegradable fixation systems have been available for more than 10 years, and are gaining acceptance in many areas of facial reconstructive surgery. Advocates believe these systems perform comparably to metal fixation systems and that the resorbable systems possess a distinct advantage over the lifelong risk of complications characteristic of nonresorbable alloplasts. The development of a resorbable fixation system with mechanical properties similar to metal fixation systems is particularly enticing for use within the orbital skeleton.
Early systems consisted of high-molecular-weight polymerized poly(L-lactide) (PLLA). Initial animal studies reported the use of PLLA plating and screw systems for repair of mandibular fractures.\(^{93}\) Another study showed the successful use of PLLA systems for the repair of zygomatic fractures in 10 patients.\(^{94}\) A follow-up report to this study published 6 years later\(^{95}\) reported that all of the patients developed swelling at the site of implantation approximately 3 years after placement. The cause of the late inflammatory reaction was attributed to the physical nature of the highly crystalline PLLA particles still present in large quantities in the tissues and the slow rate of PLLA degradation.

Animal studies investigating the use of PLLA within the orbit have been performed using a 0.4-mm thick PLLA implant in a goat model.\(^{96}\) Clinical and microscopic evaluation showed good healing of the orbital defects, with formation of a mature connective tissue capsule and new bone on both antral and orbital sides of the implant. On the antral side, normal sinus mucosa was present across the implant surface. No inflammatory reactions were noted at longest follow-up (78 weeks); however, the implants had not fully resorbed at this time. In a 5-year follow-up to this study,\(^{97}\) no complications related to the implants were seen in the remaining goats, and the implants were still present. The authors reported that the tissue reaction around the implants had not increased substantially, but the mass-loss seemed to be limited.

Lactosorb (Walter Lorenz Surgical, Jacksonville, FL) is a biodegradable copolymer of polylactic and polyglycolic acids that has been in use clinically for more than 10 years. Studies have shown that this copolymer formulation has a more rapid rate of degradation (9–15 months) compared with PLLA and therefore might be better suited for use as an orbital implant.\(^{98}\) Clinical studies have shown good results with Lactosorb throughout the craniofacial skeleton.\(^{99–101}\)

### Polyglactin

Polyglactin 910, most commonly known as the suture material Vicryl, is a resorbable synthetic material composed of lactide and glycolide acids. Both film and mesh forms of polyglactin 910 have been reported for repair of orbital fractures.\(^{101,102}\) In laboratory studies in a cat model, Morain and colleagues\(^{102}\) showed that polyglactin 910 elicits the same tissue reaction adjacent to a paranasal sinus as the same control defect without an implant.\(^{24}\) Mesh forms of the material elicit the same reaction, but the process of resorption may take longer compared with the film.\(^{102}\)

Vicryl mesh is currently the most commonly used form of polyglactin 910 for repair of orbital fractures. Mauriello and colleagues\(^{102}\) reported the use of Vicryl mesh for repair of orbital floor fractures in 28 patients over a 5-year period (median follow-up of 13 months). The mesh was folded in on itself to achieve the desired thickness (6–56 layers) and then cut to size. The most common complication reported was transient low-grade inflammation of the eyelid lasting up to 11 months. Mauriello and colleagues\(^{102}\) believe Vicryl mesh has many advantages over other implants for use in the orbit, such as the fact that it is resorbable, it is layered and may be cut to the appropriate thickness at the time of surgery, it is soft and pliable, and therefore easily fits within the orbit and presents no risk to the tissues of the orbital apex; and it does not require fixation.

Vicryl mesh is too flimsy to function effectively as a material for orbital repair; this is best shown in the report by Mauriello and colleagues,\(^{102}\) in which up to 56 layers of material were required to obtain the desired result. The bulk of material necessary for successful outcome may be the underlying cause of the low-grade inflammatory reactions seen; however, no mention is made of an association between the patients who developed inflammatory reactions and the amount of material used.

### Polydioxanone Plates

Polydioxanone is a resorbable aliphatic polyester polymer. Degradation reportedly occurs through hydrolysis in 10 to 12 weeks, although animal models have demonstrated its persistence over 12 months. The use of polydioxanone plates for orbital fractures has been recommended for orbital defects of 1 to 2 cm.\(^{103}\) Polydioxanone is available in preformed bowl-shaped plates that are easily cut to fit. It can be easily stabilized to adjacent host bone with screws, wires, or suture. Histologic studies have shown a wide range of host responses to the material, from minimal inflammatory reactions in the surrounding tissues\(^{104}\) to fragmentation and dislocation of the material, causing significant tissue reaction.\(^{105}\)

Early reports of use of polydioxanone within the orbit seemed favorable. Iizuka and colleagues\(^{103}\) reported the use of polydioxanone plates for orbital floor reconstruction in 20 patients. All patients had a defect of 1 to 2 cm with communication into the maxillary sinus. Larger defects were reconstructed with homologous bone. They reported the material to be well tolerated, with no clinically apparent inflammatory reactions. The most common complication was inferior migration.
of globe position over time, for which the authors recommend routine overcorrection of globe position at surgery. Of the 20 patients in the study, 10 (50%) showed overcorrection postoperatively, 9 of which had transitory diplopia related to the degree of overcorrection. It resolved in all but 2 cases over an average of 29 days.

Other studies have shown a less favorable outcome. Kontio and colleagues \(^{106}\) prospectively followed 16 patients treated with polydioxanone implants for internal orbital wall reconstruction. Postoperative evaluation consisted of clinical, CT, and MRI examination. Reconstructed orbital shape was unsatisfactory and proper orbital volume was not restored. MRI showed thick scar formation (37.5%). The investigators concluded that use of polydioxanone implants for internal orbital reconstruction is not advisable. de Roche and colleagues \(^{105}\) compared the use of polydioxanone with polylactide in a sheep model. Histologic and radiologic findings at 4 and 12 months were reported for each material. The polydioxanone membranes showed fragmentation leading to severe fibrous tissue reaction, and demonstrated a greater tissue reaction than did polylactide membranes. Tissue reactions associated with polydioxanone led to significant postoperative sequelae, including sensory disturbances (59%), restriction of globe motility (38%), and enophthalmos (24%). \(^{99}\) Currently, polydioxanone implants are not approved for internal orbital reconstruction in the United States.

**DISCUSSION**

Treatment of traumatic orbital injuries will continue to be a topic of considerable and evolving debate. The authors have witnessed significant change as techniques for orbital reconstruction have migrated away from autogenous bone grafts to well-tolerated alloplastics, such as titanium and Medpor. The ideal technique is influenced by many factors, including specific characteristics of the injury and the experience of the surgeon. The purpose of this paper was not to determine the ideal material for reconstruction of the internal orbit, but rather to outline the important factors of the most commonly used materials and a few of historical interest. Material for reconstructing the orbit can then be selected based on requirements of the defect matched to the mechanical properties of the material.

Autologous bone has persisted as a reliable, safe, and lifelong material for reconstruction of the orbit. Its use seems to depend on the experience of the surgeon. A wide variety of specialties, and therefore training backgrounds, are involved in the primary treatment of traumatic orbital injuries, which has significant impact on the selection of biomaterials for orbital reconstruction. Dr Anthony Wolfe stated at a symposium on biomaterials that alloplastic materials have been overused, because surgeons have not had adequate training to reach a level of comfort with the effective use of bone grafts. \(^{109}\) The authors can echo this experience with residents in both oral and maxillofacial surgery and plastic surgery at their institution; few are comfortable with or have had any experience in harvesting cranial bone grafts during their training. In appropriate hands, harvesting autologous tissue results in minimal added morbidity to the patient, especially when it may be obtained within the same operative field, and is reasonably easy to mold and adapt for use within the orbit. No alloplastic material to date has been shown to be superior to fresh autogenous bone grafts. Autologous bone will remain the gold standard for reconstructing the bony defects characteristic of orbital injuries.

Resorbable materials may evolve into reliable materials for reconstruction of the orbit. However, biodegradable materials used in the orbital floor currently manifest an 8.3% incidence of inflammatory reactions. \(^{4}\) This complication is the second most common when comparing all classes of orbital implants, \(^{4}\) and therefore these materials should be used with appropriate caution.

After reviewing the literature, selection of biomaterial for reconstruction of the orbit becomes a topic mostly for academic discussion, because the literature shows that several easily available and user-friendly materials provide reliable outcomes for repair of most injuries. Knowledge of biomaterials prevents inappropriate application of materials and, it is hoped, will lower rates of complication. The literature also teaches one to be cautious when selecting from the ever-increasing number of alloplastic materials available. It may be many years before the newer en vogue materials begin to show possible complications. All materials should undergo thorough laboratory and clinical research, which should include clinical outcome data, before becoming a major constituent of one’s surgical armamentarium.

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