Chapter 3
Materials Used Intraoperatively During Oral and Maxillofacial Surgery Procedures

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1 Introduction

The methods that currently exist for treating maxillofacial defects are not as robust as they could be. Moreover, large contributors to success are the surgeon's skill and the patient's own bodily reactions to materials used intraoperatively [1]. Often, patients are left with oral and maxillofacial defects or fractures, which range in size due to such things as congenital anomalies, acquired pathologies, and trauma. For instance, complete or partial resection in the midface or mandible due to oncologic surgery or following trauma requires the use of grafting materials, whether natural or synthetic, to resolve the void created. Further, bone graft materials are applied to congenital defects such as cleft palate, facial clefts, and facial asymmetries [2]. To enhance the effectiveness of such grafts, growth factors are used. Growth factors are steroid hormones or proteins that aid in cellular differentiation, proliferation, growth, and maturation. Growth factors may also have both inhibitory and stimulatory effects and have been shown to aid in the regeneration of bodily hard and soft tissues. Growth factors are also involved in a multitude of processes including mitogenesis, angiogenesis, metabolism, and wound healing [3]. In this chapter, we place

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emphasis on BMP, TGF, FGF, and PDGF. Within the realm of oral and maxillofacial surgery, oral implantology is becoming more popular among patients hoping to bridge gaps within their dentition for improvement in form, function, and esthetics. As will be discussed later in the chapter, there are a multitude of different implant systems and numerous types of implant materials, shapes, and coatings that are used at the surgeon's preference and skill level [4]. This chapter will also explore different options concerning inter-maxillary and mandible fractures and how to fixate with plates, and screws, either biodegradable or permanent, in an effort to speed healing and recovery.

2 Grafting and Growth Factors

2.1 Grafting

Recovery and maintenance of natural structures has been a great challenge within the realm of oral and maxillofacial surgery. For a number of years, autogenous bone has been the gold standard for grafting due to its osteogenic, osteoinductive, and osteoconductive properties. However, there are several drawbacks to using autogenous bone including morbidity, availability, and inability to customize shape and potential resorption [5–8]. To date, the perfect grafting material has not been identified, as this may be very patient specific. This section focuses on autografts; however, properties of various bone grafts and bone substitutes will be discussed later in this chapter.

Autogenous grafts may include cortical, cancellous, or cortico-cancellous bone with multiple factors determining successful incorporation. The healing process of these grafts requires both osteoconduction and osteoinduction. Embryonic origin, extent of revascularization, biomechanical features, type of fixation, and availability of growth factors are all factors of significant importance for incorporation of autogenous bone grafts [9]. Albrektsson and colleagues used a rabbit model to investigate the survivability of both cortical and cancellous bone grafts. It was found that trauma to the graft compromised cell viability in addition to a lag in the revascularization time, whereas the carefully handled graft revascularized and remodeled faster [10]. Furthermore, it was found that the cancellous bone grafts demonstrated a faster rate of revascularization than the cortical grafts [11–13]. More regarding grafting techniques will be discussed later in this chapter.

With regard to healing, it has been suggested that soft tissue pressure applied by the periosteum and/or the flap covering the graft may in fact increase the osteoclastic activity [14, 15]. As will be discussed in more detail later in the chapter, rigid fixation, a technique often used in the operating room, is important for healing. Several studies have concluded that rigid fixation (Figs. 3.1 and 3.2) increases the survival rate of the graft [16, 17].

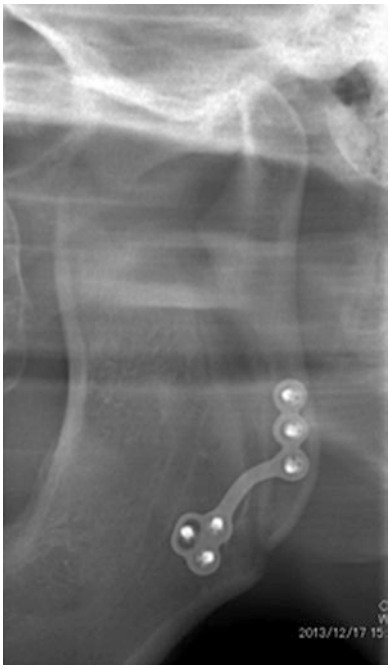

Fig. 3.1 Mandibular angle fracture with rigid fixation [18]

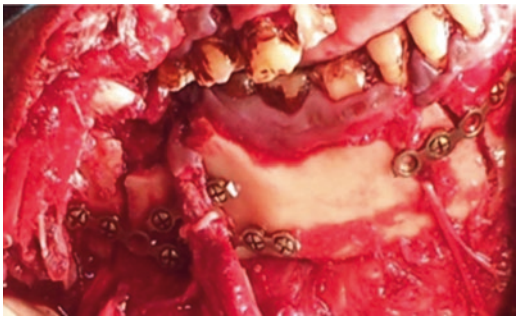

Fig. 3.2 Rigid fixation of mandibular fracture using plates and screws [19]

2.2 Growth Factors Relevant to Surgery

Currently, researchers are investigating proteins and carriers for the delivery of growth factors (GFs): however, there are questions that exist with regard to the efficacy of these materials [20]. GFs are present in bone matrix and plasma, albeit in low concentrations [21]. GFs are biological mediators that have been shown to help in the regeneration of the natural periodontium. They are key factors in cellular differentiation, proliferation, and maturation. In addition, these GFs have been shown to have both stimulatory and inhibitory effects [3].

2.2.1 Bone Morphogenetic Protein

In 1971, it was shown that protein extracted from demineralized bone matrix induced the formation of the bone. This extracted protein was named BMP [22]. BMPs can provoke local immediate action, bind to extracellular antagonists, or interact with the extracellular matrix proteins and, subsequently, target cells. Interestingly, BMPs can regulate morphogenesis during development while also inducing bone and cartilage formation [23]. In their work, Karsenty and Kingsley describe how BMPs form a large group of proteins, which affect migration, differentiation, and cell growth. This protein group is the TGF-β superfamily [24, 25]. The TGF-β superfamily includes a number of proteins such as BMPs, osteogenic proteins, cartilage-derived morphogenic proteins, and growth differentiation factors [26]. Mesenchymal stem cells exhibit several BMP receptors [27] while also synthesizing the BMP antagonists noggin, gremlin, follistatin, and sclerostin. The osteoconductive biomaterial BMP/hydroxyapatite has been used in oral and maxillofacial surgery for contour augmentation by means of a macroporous delivery system [28].

2.2.2 Transforming Growth Factor

TGF-β increases the chemotaxis as well as the mitogenesis of the osteoblast precursors while also acting to stimulate osteoblast deposition of collagen matrix for wound healing and the regeneration of the bone [29]. TGF-β is produced by osteoblasts and is found at the highest concentration in platelets [30]. This growth factor stimulates the expression of bone matrix proteins [31] and moderates the breakdown activity of matrix metalloproteinases, among others [32]. The differentiation and proliferation of osteoblastic cells, along with the inhibition of osteoclast precursor formation, may be attributed to TGF-β [33]. Unlike BMP, TGF-β does not have the capacity to induce ectopic bone formation [34]. During the healing of bone fractures, the release of TGF-β, BMP 1–8, and growth differentiation factors (GDFs) 1, 5, 8, and 10 are plentiful [35]. Signaling molecules that are released after a bone fracture and during the progression of healing include pro-inflammatory cytokines, TGF-β superfamily, and other growth factors like PDGF, fibroblast growth factor, and insulin-like growth factors, as well as angiogenic factors such as vascular endothelial growth factor, angiopoietins 1 and 2, and matrix metalloproteinases [36]. TGF-β is found in high amounts in PRP which will be discussed in a later section.

2.2.3 Platelet-Derived Growth Factor

PDGF has the important biological activity of initiating connective tissue healing while also increasing mitogenesis and macrophage activation [29]. PDGF is produced by monocytes, macrophages, osteoblasts, endothelial cells, and platelets [37]. There are three types of PDGF, including PDGF AB, AA, and BB, with PDGF BB

being the most biologically potent. In the early stages of fracture healing, PDGF plays a key role in acting as a chemotactic agent for inflammatory cells and as an inducer for osteoblasts and macrophages [34]. Hock and Canalis proposed that PDGF acts as a stimulant for osteoblasts, as well as osteoclast lineages, which may allow for decreased healing time [38]. As mentioned previously, PRP, which on its own will be discussed in a following section, is an autologous source of PDGF and TGF-β. Moreover, both of these growth factors play a primary role in the creation of platelet gels that, unlike fibrin glue, have a high concentration of platelets that release bioactive proteins necessary for tissue repair and regeneration .

2.2.4 Fibroblast Growth Factor

FGF may be produced by macrophages, mesenchymal cells, monocytes, chondrocytes, and osteoblasts. FGF is essential in the process of bone resorption and chondrogenesis [39]. Of the two isoforms that exist, α-FGF plays a key role in chondrocyte proliferation, while β-FGF is significant in the maturation of chondrocytes and bone resorption during the process of fracture healing, which often occurs after oral and maxillofacial surgery. Basic fibroblast growth factor (bFGF) is a growth factor that may be isolated from the pituitary glands of bovine [40]. bFGFs have also been isolated from a number of cells and tissues in tumors [3]. FGF-2 is considered a mitogen that has an effect on angiogenesis, thereby inducing a differentiation stimulus for mesodermal cells. In the short term, FGFs prevent the mineralization of the bone; however, in the long term, they act to speed and support bone development [41]. This was shown in a study by Takayama and colleagues where topical application of FGF-2 had a healing effect on bone fractures [42].

3 Growth Factor Enhancements

At the foundation of any surgical discipline is the science of wound healing. The oral and maxillofacial surgeon is usually blessed to work in an environment with rich vasculature; surgical and traumatic wounds tend to heal. But there will be compromised patients and ambitious reconstructive goals, and the surgeon will take any advantage given to assist his patient's natural healing process.

As discussed previously, growth factors with cytokine-mediated healing have been shown to assist in the biological healing process. Many of these growth factors can be resultant from platelets, including PDGF, TGF, VEGF, and EGF [43]. Platelet-derived products have been used as early as the 1970s, starting with fibrin glue [44]. Fibrin adhesives are still commercially available today (e.g., Tisseel from Baxter Healthcare) and are primarily used for hemostasis of diffuse microvascular bleeding. Its use is well documented in multiple surgical specialties, including oral and maxillofacial surgery [45]. Fibrin glue evolved into other autologous platelet concentrates including PRP [46], platelet gel, and platelet-rich fibrin (PRF) [47].

The literature reveals multiple studies with favorable treatment effects, not only in dentistry but also in orthopedics, dermatology, and ophthalmology [48]. Unfortunately, the literature has not come up with any consensus in terminology for platelet derivatives [49], and even less uniformity in their preparations, which likely accounts for inconsistencies in reported therapeutic effects.

3.1 The Biology of Wound Healing

Injury to tissue, whether surgical or traumatic, starts a cascade of events to allow wound healing. There are overlapping phases of inflammation, proliferation, and remodeling. The initial priority is to prevent hemorrhage, then prevent infection, and ultimately, restore the injured tissue [50]. The immediate reaction to injured tissue is vasoconstriction to limit bleeding. Coagulation factors are activated and multiple cascades are set into motion. A fibrin matrix is formed at the injured vasculature, and circulating platelets aggregate at the exposed subendothelium, creating a platelet plug. This plug functions not only for hemostasis but also orchestrates subsequent healing [51]. Activated platelets in the plug degranulate and create cellular signals through cytokines and growth factors.

Entire chapters can be devoted to each individual component of the wound healing process. We will limit and simplify our discussion to the roles of fibrin and platelets.

Platelets are anuclear structures arising from bone marrow precursors. The platelet membrane contains receptors for many molecules, including thrombin, and the cytoplasm contains granules that are released on activation [52]. Fibrin is a fibrous protein, which is activated by thrombin. Activated platelets and resulting thrombin allow fibrin to form a cross-linked mesh with the platelet plug to finalize a blood clot.

3.2 Collection and Preparation of Platelet Derivatives

Platelet derivatives have few contraindications, specifically in patients with platelet counts less than 10^5/microliter, hemoglobin level less than 10 g/dL, or presence of active infections [53]. PRP has shown great variability in centrifugation protocol. Current PRP procedures start with the collection of whole blood in acid/citrate/dextrose, which are then centrifuged. The red blood cells are removed, and the PRP then undergoes a second centrifugation step to obtain a supernatant of platelet-poor plasma (PPP) and the pellet of platelets. Growth factor release of the PRP happens with platelet activation from thrombin, either bovine thrombin or autologous thrombin obtained by adding calcium gluconate to the PPP. Thrombin is combined to the PRP and allows handling as a gel [48].

PRF is considered a second-generation platelet concentrate, notably with a simplified preparation in comparison to PRP. Whole blood is collected without

anticoagulants and centrifuged to form a fibrin clot, which contains the platelets. As opposed to PRP where the activation of the platelets is due to thrombin, the PRF activation is a result of the centrifugation process itself. The PRF clot is homogenous and is interpreted to have the cytokines incorporated into the fibrin mesh, allowing for an increased lifespan of these intrinsic growth factors and cell signaling molecules [52]. The inflammatory markers present also indicate degranulation of the leucocytes, which may play a role in the reduction of infection [54].

3.3 Applications in Oral and Maxillofacial Surgery

Both PRP and PRF continue to be used and reviewed in the literature. The therapeutic effects are not validated with multi-center randomized trials, and there still exists discrepancies in overall benefits. In the literature, benefits have been documented when platelet concentrates are used in multiple maxillofacial applications. In post-extraction sites, including third molars, healing times have been improved, with reduction of complications including alveolar osteitis [55–61]. However there are studies that show no significant benefit using scintigraphic evaluation [62]. Many studies discuss platelet concentrates used in combination with bone grafting for both reconstruction and for site preparations for dental implants. Studies showed accelerated healing, particularly of the soft tissue [63]. Reviews of the literature in regard to sinus augmentation show increased bone density [64] but no significant improvement in bone formation or implant survivability [65, 66]. In the setting of poor wound healing, we see applications of platelet derivatives in the setting of medication-related osteonecrosis of the jaws (MRONJ) and other oral mucosal lesions, with cautious interpretation of results suggesting benefits of their use [67–70]. Successful treatment of alveolar cleft bone grafting has been shown by multiple teams [71–73].

In the temporomandibular joint (TMJ), platelet concentrates have been hypothesized to help, given that the cartilage is avascular and has difficulty with self-repair. Bone growth was significantly improved in osteoarthritis in the rabbit model, with improved, but not significant, regeneration of the cartilage [74]. Injections of platelet concentrates into the TMJ have been shown to be effective for treatment of temporomandibular osteoarthritis [75–77] and better than arthrocentesis alone [78]. However, it has been pointed out that growth factors associated with PRP, including VEGF, may be detrimental to cartilaginous healing [79].

3.4 Future Applications

The common complaint in the systematic reviews of PRP and PRF therapy continues to be a large discrepancy in preparation and use of platelet concentrates. Good evidence is available that there is a quantifiable increase in growth factors

when using platelet-rich products [80–83]. However, large multi-center trials need to be conducted to prove the efficacy of these treatments reliably and reproducibly.

4 Implantable Devices

4.1 Replacement of Teeth

Oral implants have become the sought-after method of treatment, which is scientifically accepted and well documented in the literature [84–86]. Oral implants were introduced some 30–40 years ago [87–89]. Since then, implants have revolutionized the concept of replacing missing teeth and improved the quality of life for patients [90, 91]. Today, there are over 1300 different implant systems worldwide. They vary in shape, dimension, bulk, surface material, topography, surface chemistry, wettability, and surface modification [92]. Titanium is the material most commonly used for oral endosseous implants, due to its mechanical strength, excellent biocompatibility, and osseointegration [93]. Some studies have reported regarding the clinical disadvantages of titanium, such as host sensitivity to titanium, electrical conductivity, corrosive properties, and esthetic concerns as a result of their dark-grayish coloring [94–96]. Furthermore, elevated titanium concentrations have been found in close proximity to oral implants [97] and in regional lymph nodes [98]. However, the clinical relevance of these facts is still unclear [99]. Ceramic materials have been suggested as a substitute to titanium for oral implants because of their esthetic benefits and excellent biocompatibility in vitro and in vivo [100–102], great tissue integration, low affinity to plaque, and favorable biomechanical properties [103]. These ceramic materials have already been investigated and clinically used since approximately 30–40 years ago. The first ceramic material utilized was aluminum oxide [104, 105], and later, the Cerasand ceramic and the ceramic anchor implant were introduced [106, 107]. The physical and mechanical properties of alumina ceramics are high hardness and modulus of elasticity, which make the material brittle. In combination with the relatively low bending strength and fracture toughness, alumina ceramics are vulnerable to fractures. Based on these drawbacks, there are no alumina implant systems remaining on the market [86, 108]. Currently, the material of choice for ceramic oral implants is zirconia (ZrO2), containing tetragonal polycrystalline yttria (Y2O3) (Y-TZP). In comparison to alumina, Y-TZP has a higher bending strength, a lower modulus of elasticity, and a higher fracture toughness [86, 109, 110]. Through in vitro and in vivo studies, zirconia has become an attractive alternative to titanium for the fabrication of oral implants [103]. However, animal studies have indicated a better bone-to-implant contact with titanium implants than with Y-TZP implants [101, 111]. In addition, early failures were significantly higher for zirconia implants than for titanium implants [103].

Surface topography is one of the important parameters for the achievement of osseointegration and can be classified into macro-, micro-, and nanoscale [112]. The three major modifications of macrotopography are screw threads (tapped or self-tapping), solid body press-fit designs, and sintered bead technologies. Recently, studies were mainly focused on micro- and nanogeometry. The osteoblast activity is significantly increased at 1–100 μm of the surface roughness compared to a smooth surface [113]. Increased surface roughness of dental implants can be achieved by machining, plasma spray coating, grit blasting, acid etching, sandblasting, anodizing, and applying a biomimetic coating, or other combinations of the several mentioned techniques [114–117] resulted in greater bone apposition [118] and reduced healing time [119].

4.2 Reconstruction of the Craniomaxillofacial Skeleton

Reconstruction of the craniomaxillofacial skeleton, resulting from resection of benign and malignant tumor, osteomyelitis, or osteoradionecrosis, still remains a challenge for the surgeon [120].

4.2.1 Natural Bone Grafts

Since the nineteenth century, autologous bone has been successfully used as bone substitute [121]. Different donor sites are described in the current literature. Intraoral donor sites include the symphysis of the mandible, mandibular ramus, and maxillary tuberosity [122]. The common extraoral donor sites for non-vascularized bone grafts are the iliac crest and rib. The non-vascularized iliac crest graft is a treatment possibility for reconstruction of moderate mandibular defects [123], whereas the costochondral graft from the rib is used predominantly for condylar reconstruction [124, 125]. During the past decade, a variety of donor sites for vascular bone flaps and soft tissue have been recommended. The osteocutaneous radial forearm free flap [126, 127], fibular free flap [127, 128], scapula free flap [128], and iliac crest free flap [129] are the most commonly utilized donor sites for vascularized reconstruction.

Allogenic bone refers to the bone that is harvested from one individual and transplanted into another individual, both of the same species. Due to the limitations of autologous bone grafting, allogenic grafts are considered an effective alternative. Allografts, to a limited extent, can be customized by being machined and shaped to fit the defect. It can be available in a variety of forms, including cortical and cancellous. The disadvantage, however, is that compared to autografts, they have a higher failure rate due to their immunogenicity [130, 131].

Xenograft bone has been taken from a donor of another species [122], usually of bovine origin. Mineral xenograft has been applied in oral and maxillofacial surgery for several years [132]. Demineralized bone, harvested from human donors, has

been frequently used in craniofacial reconstruction [133, 134]. The demineralization is achieved through the process of acidification, resulting in a matrix containing type I collagen and osteoinductive growth factors, predominantly BMP. Based on porosity, it can be easily formed and remodeled intraoperatively [135, 136].

4.2.2 Synthetic Bone Grafts

Craniofacial reconstruction using alloplastic implants has shown to be associated with low rates of infection and other types of morbidity [137]. Computer-aided designed and manufactured (CAD/CAM) titanium implants which are prefabricated are a reasonable option for secondary reconstruction [138]. The major disadvantages are the thermosensitivity and limited possibility of intraoperative customization [136]. Synthetically manufactured bioactive glass-ceramic is an option as a single CAD/CAM implant for craniofacial reconstruction with good clinical outcomes. As opposed to titanium implants, it allows intraoperative remodeling and adjustment without thermosensitivity [139]. Calcium phosphates belong to the group of bioactive synthetic materials. The most commonly used are hydroxyapatite, tricalcium phosphate, and biphasic calcium phosphate [140–142]. Calcium phosphates are osteoconductive, do not cause any foreign body response, and are nontoxic [136].

Hard tissue replacement (HTR)-sintered polymers consist of poly(methyl methacrylate (pMMA), poly(hydroxyethyl methacrylate) (pHEMA), and calcium hydroxide. The porosity of the plastic allows for the indwelling growth of blood vessels as well as connective tissue [136]. HTR implants can be used for the reconstruction of large defects of the cranio-orbital region when combined with simultaneous bone tumor resection [143]. The implants are fixated with titanium or resorbable plates and screws.

Polyetheretherketone (PEEK) is a synthetic material that has been used for a number of years in neurosurgery due to its excellent biocompatibility, good mechanical strength, and radiographic translucency. In recent years, studies of maxillofacial reconstructions have been reported using PEEK for the construction of patient-specific implants [144–146]. The major disadvantage of computer-designed PEEK is its high cost [147].

Porous polyethylene (PPE) or high-density polyethylene (HDPE) is a linear highly compressed (sintered) aliphatic hydrocarbon. It is a biocompatible, durable, and stable material. Furthermore, it shows rapid surrounding soft tissue ingrowth without capsule formation around it [137, 148, 149]. PPE has proven to be a reasonable alternative to PEEK as a material for craniofacial reconstructions. The use of this material seems to be safe and has minimal morbidity [149]. In summary, autografts are osteoconductive, osteoinductive, and osteogenic; however, they have limited availability and have donor-site morbidity. Allografts are osteoconductive and osteoinductive but are not osteogenic; they carry the same disadvantages as autografts with the addition of having disease transmission risk. Xenografts are osteoconductive, but not osteoinductive or osteogenic, and carry the potential for foreign body reaction. Alloplastic materials are osteoconductive but often costly [150].

5 Maintenance of Structural Integrity and Fixation

5.1 Plates and Screws

Today, nearly all the metal plates and screws for the fixation of the craniomaxillofacial skeleton consist of titanium and are stored in sets that can be re-sterilized. Titanium is the most biocompatible and corrosion-resistant metal and has an innate ability to fuse with human bone [151, 152]. Therefore, it has received much attention in the area of craniofacial reconstruction [153]. Prior to the use of titanium, several other materials were applied for craniofacial applications. These metals, which included stainless steel and vitallium, an alloy from cobalt, chrome, and molybdenum, have fallen out of favor because of their corrosion profile and/or lack of inertness [154, 155]. Furthermore, vitallium and stainless steel produce more artifacts on computed tomography scans and magnetic resonance imaging than titanium [156–158]. There exist miniplates of different shapes with corresponding osteosynthesis screws of different lengths (Fig. 3.3) [159].

5.1.1 Midface

Osteosynthesis screws are also based on different systems. For the midface, osteosynthesis is based on systems 1.0, 1.3, 1.5, and 2.0. The numbers refer to the outer screw thread diameter in mm. Low profile plates are recommended for the infraorbital rim because the structural forces are not significant in this region. In contrast, increased stability with stronger implants is needed for the zygomaticomaxillary buttress where high masticatory forces are transmitted [160, 161].

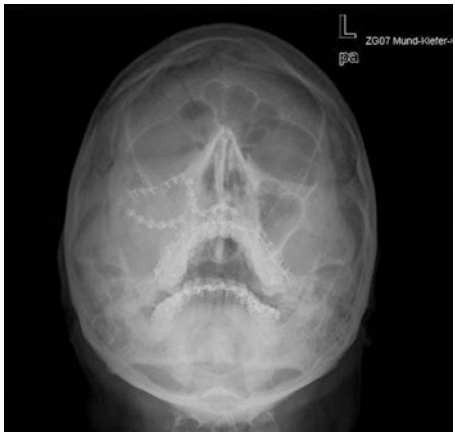

Fig. 3.3 Postoperative x-ray of a complex midface fracture treated with several malleable fixation plates

Depending on the size and location of the orbital defect, reconstruction can be achieved by using implants of various materials with different benefits and disadvantages. Currently, the ideal implant material for orbital reconstruction still remains unclear [153]. The use of silastic implants, bioactive glass, and porous polyethylene to bridge the bony defect has been extensively documented in the literature [162–164]. In addition, titanium mesh (Fig. 3.4) or pre-shaped plates, such as the 3D titanium orbital plate, are applied in special cases [165, 166]. Biodegradable polyglycolic acid [167] and polydioxanone [168] are options as resorbable alloplastic materials. Alternatively, autogenous transplants can be used [169–172]. Considering donor-site morbidity of autologous transplants and infections with nonresorbable materials, resorbable implants for reconstruction could be recommended [168].

5.1.2 Mandible

Different osteosynthesis plating systems are in use for application to the mandible. According to Arbeitsgemeinschaft für Osteosynthesefragen (AO)/Association for the study of Internal Fixation (ASIF) principles, the types of plates include mandible plates 2.0, locking plates 2.0, (locking) reconstruction plates, dynamic compression plates, and universal fracture plates [173–176]. Mandibular miniplates are designed to be used with monocortical screws (Fig. 3.5). Bicortical screws can be used for additional stability in selected cases. In approaches with limited space (e.g., condylar and subcondylar regions), plates of modified design, such as the compression plate, the trapezoid plate, or the delta plate, are applied [177, 178]. Lag screw osteosynthesis of fractures of the mandibular condyle is a method to combine functional stability with simple removal of osteosynthesis materials, without re-exposure of the temporomandibular joint region [179, 180].

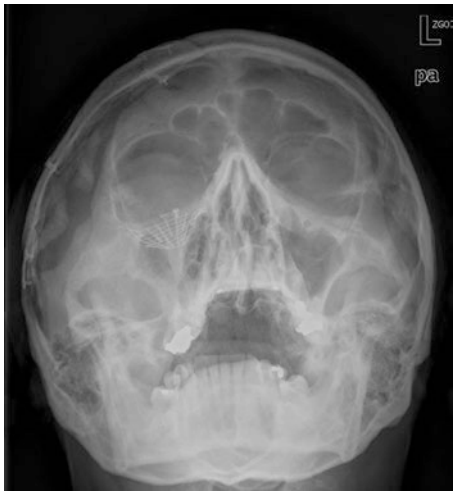

Fig. 3.4 Postoperative x-ray of an orbital floor fracture treated with a titanium mesh

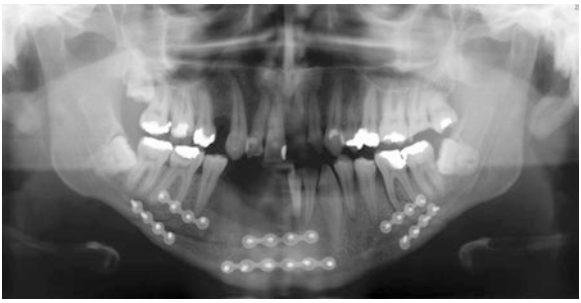

Fig. 3.5 Postoperative x-rays shows fracture fixation with six mandibular miniplates 2.0

5.1.3 Absorbable Materials

Absorbable osteosynthetic material is an option to make metal removal unnecessary [181]. A complete resorption occurs approximately 1 year in experimental models [182]. Further advantages are the absence of thermal sensitivity and radiological artifacts [136]. Use of bioresorbable miniplates has been suggested in the pediatric population because of possible growth disturbances associated with titanium-based hardware [183]. A variety of biodegradable implants are commercially available in the field of oral and maxillofacial surgery. Polymers of α-hydroxy acids as glycolic acid (PGA), L-lactic and D, L-lactic acids (PLLA, PDLLA), and their copolymers are the substances largely used as osteosynthesis materials [184–188]. These materials have proven clinical success throughout the world; however, there are some arguments against biodegradable fixation. The complications of biodegradable fixation are infections, foreign body reactions, malocclusions, and malunions [188]. Furthermore, the duration of surgery is more challenging and costly [187, 189].

6 Summary

Oral and maxillofacial surgery is an incredible and evolving field. Injuries, defects, and pathologies to the head, neck, and face, as well as hard and soft tissues of the oral region, are often taken care of by specialists extensively trained as oral and maxillofacial surgeons. As further research is completed and scientists continue exploration of materials and methods, techniques and strategies are altered to benefit the patient in clinical settings. In this chapter, we focused on the use of different grafting materials, both natural and synthetic for bone regeneration and defect repair, growth factors that aid in healing and growth of tissues, as well as fixation devices used in the repair of maxillofacial bone fractures. The techniques discussed are effective; however, future work needs to be outlined in order to improve efficiency and efficacy, both inside and outside of the operating room.

References

1. Fahmy, M. D., et al. (2016). Three-dimensional bioprinting materials with potential application in preprosthetic surgery. *Journal of Prosthodontics, 25*(4), 310–318.
2. Boyne, P. J. (2001). Application of bone morphogenetic proteins in the treatment of clinical oral and maxillofacial osseous defects. *JBJS, 83*(1_suppl_2), S146–S150.
3. Rifkin, D. B., & Moscatelli, D. (1989). Recent developments in the cell biology of basic fibroblast growth factor. *The Journal of Cell Biology, 109*(1), 1–6.
4. Sykaras, N., et al. (2000). Implant materials, designs, and surface topographies: Their effect on osseointegration. A literature review. *International Journal of Oral & Maxillofacial Implants, 15*(5).
5. Hjørting-Hansen, E. (2001). Bone grafting to the jaws with special reference to reconstructive preprosthetic surgery: A historical review (Übersicht). *Mund-, Kiefer-und Gesichtschirurgie, 6*(1), 6–14.
6. Hirsch, J. M. (2001). Volumetry of simulated bone grafts in the edentulous maxilla by computed tomography: An experimental study. *Dentomaxillofacial Radiology, 30*, 153–156.
7. Sjöström, M., On healing of titanium implants in iliac crest bone grafts. 2006.
8. Springer, I. N., et al. (2004). Particulated bone grafts–effectiveness of bone cell supply. *Clinical Oral Implants Research, 15*(2), 205–212.
9. Alberius, M. G. (1999). Per, *Some basic factors essential to autogeneic nonvascularized onlay bone grafting to the craniofacial skeleton*. *Scandinavian Journal of Plastic and Reconstructive Surgery and Hand Surgery, 33*(2), 129–146.
10. Albrektsson, T., & Albrektsson, B. (1978). Microcirculation in grafted bone: A chamber technique for vital microscopy of rabbit bone transplants. *Acta Orthopaedica Scandinavica, 49*(1), 1–7.
11. Chen, N. T., et al. (1994). The roles of revascularization and resorption on endurance of craniofacial onlay bone grafts in the rabbit. *Plastic and Reconstructive Surgery, 93*(4), 714–722; discussion 723-4.
12. Lin, K. Y., et al. (1990). The effect of rigid fixation on the survival of onlay bone grafts: An experimental study. *Plastic and Reconstructive Surgery, 86*(3), 449–456.
13. Pinholt, E. M., et al. (1994). Revascularization of calvarial, mandibular, tibial, and iliac bone grafts in rats. *Annals of Plastic Surgery, 33*(2), 193–197.
14. Goldstein, J., Mase, C., & Newman, M. H. (1993). Fixed membranous bone graft survival after recipient bed alteration. *Plastic and Reconstructive Surgery, 91*(4), 589–596.
15. Goldstein, J. A., Mase, C. A., & Newman, M. H. (1995). The influence of bony architecture on fixed membranous bone graft survival. *Annals of Plastic Surgery, 34*(2), 162–167.
16. Phillips, J. H., & Rahn, B. A. (1988). Fixation effects on membranous and endochondral onlay bone-graft resorption. *Plastic and Reconstructive Surgery, 82*(5), 872–877.
17. Phillips, J. H., & Rahn, B. A. (1990). Fixation effects on membranous and endochondral onlay bone graft revascularization and bone deposition. *Plastic and Reconstructive Surgery, 85*(6), 891–897.
18. Hara, S., Mitsugi, M., & Tatemoto, Y. (2017). Variation of plate fixation for mandibular advancement with intraoral vertical ramus osteotomy using endoscopically-assisted intraoral rigid or semi-rigid internal fixation: Postoperative condylar seating control for mandibular advancement. *International Journal of Oral and Maxillofacial Surgery, 46*, 158.
19. Rao, S. S., Baliga, S. D., & Bhatnagar, A. (2018). Management of extensive maxillofacial injury related to a Tyre Blast: A rare case report. *The Saudi Dental Journal, 30*(1), 97–101.
20. Esposito, M., et al. (2006). The efficacy of various bone augmentation procedures for dental implants: A Cochrane systematic review of randomized controlled clinical trials. *International Journal of Oral & Maxillofacial Implants, 21*(5).
21. Trippel, S. B. (1997). Growth factors as therapeutic agents. *Instructional Course Lectures-American Academy of Orthopaedic Surgeons, 46*, 473–476.

22. Urist, M. R., & Strates, B. S. (1971). Bone morphogenetic protein. *Journal of Dental Research, 50*(6), 1392–1406.
23. Wozney, J. M., et al. (1988). Novel regulators of bone formation: Molecular clones and activities. *Science, 242*(4885), 1528–1534.
24. Karsenty, G. (1998). Genetics of skeletogenesis. *Developmental Genetics, 22*(4), 301–313.
25. Kingsley, D. M. (1994). The TGF-beta superfamily: New members, new receptors, and new genetic tests of function in different organisms. *Genes & Development, 8*(2), 133–146.
26. Ducy, P., & Karsenty, G. (2000). The family of bone morphogenetic proteins. *Kidney International, 57*(6), 2207–2214.
27. Rosen, V. (2006). BMP and BMP inhibitors in bone. *Annals of the New York Academy of Sciences, 1068*(1), 19–25.
28. Hotz, G., & Herr, G. (1994). Bone substitute with osteoinductive biomaterials—Current and future clinical applications. *International Journal of Oral and Maxillofacial Surgery, 23*(6), 413–417.
29. Bhanot, S., & Alex, J. C. (2002). Current applications of platelet gels in facial plastic surgery. *Facial Plastic Surgery, 18*(1), 27–34.
30. Assoian, R. K., et al. (1983). Transforming growth factor-beta in human platelets. Identification of a major storage site, purification, and characterization. *Journal of Biological Chemistry, 258*(11), 7155–7160.
31. Wiltfang, J., et al. (2003). Sinus floor augmentation with β-tricalciumphosphate (β-TCP): Does platelet-rich plasma promote its osseous integration and degradation? *Clinical Oral Implants Research, 14*(2), 213–218.
32. Overall, C. M., Wrana, J., & Sodek, J. (1989). Independent regulation of collagenase, 72-kDa progelatinase, and metalloendoproteinase inhibitor expression in human fibroblasts by transforming growth factor-beta. *Journal of Biological Chemistry, 264*(3), 1860–1869.
33. Bonewald, L., & Mundy, G. (1990). Role of transforming growth factor-beta in bone remodeling. *Clinical Orthopaedics and Related Research*, (250), 261–276.
34. Lieberman, J. R., Daluiski, A., & Einhorn, T. A. (2002). The role of growth factors in the repair of bone: Biology and clinical applications. *JBJS, 84*(6), 1032–1044.
35. Cho, T. J., Gerstenfeld, L. C., & Einhorn, T. A. (2002). Differential temporal expression of members of the transforming growth factor β superfamily during murine fracture healing. *Journal of Bone and Mineral Research, 17*(3), 513–520.
36. Dimitriou, R., Tsiridis, E., & Giannoudis, P. V. (2005). Current concepts of molecular aspects of bone healing. *Injury, 36*(12), 1392–1404.
37. Andrew, J., et al. (1995). Platelet-derived growth factor expression in normally healing human fractures. *Bone, 16*(4), 455–460.
38. Hock, J. M., & Canalis, E. (1994). Platelet-derived growth factor enhances bone cell replication, but not differentiated function of osteoblasts. *Endocrinology, 134*(3), 1423–1428.
39. Hallman, M., & Thor, A. (2008). Bone substitutes and growth factors as an alternative/complement to autogenous bone for grafting in implant dentistry. *Periodontology 2000, 47*(1), 172–192.
40. Sonmez, A. B., & Castelnuovo, J. (2014). Applications of basic fibroblastic growth factor (FGF-2, bFGF) in dentistry. *Dental Traumatology, 30*(2), 107–111.
41. Hatch, N., & Franceschi, R. (2008). FGF2 induced expression of the pyrophosphate generating enzyme, PC-1, is mediated by Runx2 and Msx2. *Journal of Musculoskeletal & Neuronal Interactions, 8*(4), 318.
42. Takayama, S., et al. (2001). Periodontal regeneration by FGF-2 (bFGF) in primate models. *Journal of Dental Research, 80*(12), 2075–2079.
43. Marx, R. E. (2004). Platelet-rich plasma: Evidence to support its use. *Journal of Oral and Maxillofacial Surgery, 62*(4), 489–496.
44. Gibble, J. W., & Ness, P. M. (1990). Fibrin glue: The perfect operative sealant? *Transfusion, 30*(8), 741–747.

45. Matras, H. (1985). Fibrin sealant in maxillofacial surgery. Development and indications. A review of the past 12 years. *Facial Plastic Surgery, 2*(4), 297–313.
46. Whitman, D. H., Berry, R. L., & Green, D. M. (1997). Platelet gel: An autologous alternative to fibrin glue with applications in oral and maxillofacial surgery. *Journal of Oral and Maxillofacial Surgery, 55*(11), 1294–1299.
47. Dohan, D. M., et al. (2006). Platelet-rich fibrin (PRF): A second-generation platelet concentrate. Part I: Technological concepts and evolution. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontics, 101*(3), e37–e44.
48. De Pascale, M. R., et al. (2015). Platelet derivatives in regenerative medicine: An update. *Transfusion Medicine Reviews, 29*(1), 52–61.
49. Dohan Ehrenfest, D. M., Rasmusson, L., & Albrektsson, T. (2009). Classification of platelet concentrates: From pure platelet-rich plasma (P-PRP) to leucocyte- and platelet-rich fibrin (L-PRF). *Trends in Biotechnology, 27*(3), 158–167.
50. Miloro, M., et al. (2004). *Peterson's principles of oral and maxillofacial surgery* (2nd ed.). Hamilton, ON/London: B C Decker.
51. Singer, A. J., & Clark, R. A. (1999). Cutaneous wound healing. *The New England Journal of Medicine, 341*(10), 738–746.
52. Dohan, D. M., et al. (2006). Platelet-rich fibrin (PRF): A second-generation platelet concentrate. Part II: Platelet-related biologic features. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontics, 101*(3), e45–e50.
53. Dauendorffer, J. N., Fraitag, S., & Dupuy, A. (2013). Basal cell carcinoma following platelet-rich plasma injection for skin rejuvenation. *Annales de Dermatologie et de Vénéréologie, 140*(11), 723–724.
54. Dohan, D. M., et al. (2006). Platelet-rich fibrin (PRF): A second-generation platelet concentrate. Part III: Leucocyte activation: A new feature for platelet concentrates? *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontics, 101*(3), e51–e55.
55. Del Fabbro, M., Bortolin, M., & Taschieri, S. (2011). Is autologous platelet concentrate beneficial for post-extraction socket healing? A systematic review. *International Journal of Oral and Maxillofacial Surgery, 40*(9), 891–900.
56. Del Fabbro, M., et al. (2017). Healing of Postextraction sockets preserved with autologous platelet concentrates. A systematic review and meta-analysis. *Journal of Oral and Maxillofacial Surgery, 75*(8), 1601–1615.
57. Eshghpour, M., et al. (2014). Effect of platelet-rich fibrin on frequency of alveolar Osteitis following mandibular third molar surgery: A double-blinded randomized clinical trial. *Journal of Oral and Maxillofacial Surgery, 72*(8), 1463–1467.
58. Al-Hamed, F. S., et al. (2017). Efficacy of platelet-rich fibrin after mandibular third molar extraction: A systematic review and meta-analysis. *Journal of Oral and Maxillofacial Surgery, 75*(6), 1124–1135.
59. Bilginaylar, K., & Uyanik, L. O. (2016). Evaluation of the effects of platelet-rich fibrin and piezosurgery on outcomes after removal of ımpacted mandibular third molars. *British Journal of Oral and Maxillofacial Surgery, 54*(6), 629–633.
60. Canellas, J., Ritto, F. G., & Medeiros, P. J. D. (2017). Evaluation of postoperative complications after mandibular third molar surgery with the use of platelet-rich fibrin: A systematic review and meta-analysis. *International Journal of Oral and Maxillofacial Surgery, 46*(9), 1138–1146.
61. Varghese, M. P., Manuel, S., Kumar, S., & K, L. (2017). Potential for osseous regeneration of platelet-rich fibrin—A comparative study in mandibular third molar impaction sockets. *Journal of Oral and Maxillofacial Surgery, 75*(7), 1322–1329.
62. Gürbüzer, B., et al. (2010). Scintigraphic evaluation of Osteoblastic activity in extraction sockets treated with platelet-rich fibrin. *Journal of Oral and Maxillofacial Surgery, 68*(5), 980–989.
63. Moraschini, V., & Barboza, E. S. P. (2015). Effect of autologous platelet concentrates for alveolar socket preservation: A systematic review. *International Journal of Oral and Maxillofacial Surgery, 44*(5), 632–641.

64. Khairy, N. M., et al. (2013). Effect of platelet rich plasma on bone regeneration in maxillary sinus augmentation (randomized clinical trial). *International Journal of Oral and Maxillofacial Surgery, 42*(2), 249–255.
65. Lemos, C. A. A., et al. (2016). Effects of platelet-rich plasma in association with bone grafts in maxillary sinus augmentation: A systematic review and meta-analysis. *International Journal of Oral and Maxillofacial Surgery, 45*(4), 517–525.
66. Pocaterra, A., et al. (2016). Effectiveness of platelet-rich plasma as an adjunctive material to bone graft: A systematic review and meta-analysis of randomized controlled clinical trials. *International Journal of Oral and Maxillofacial Surgery, 45*(8), 1027–1034.
67. Del Fabbro, M., Gallesio, G., & Mozzati, M. (2015). Autologous platelet concentrates for bisphosphonate-related osteonecrosis of the jaw treatment and prevention. A systematic review of the literature. *European Journal of Cancer, 51*(1), 62–74.
68. Kim, J.-W., Kim, S.-J., & Kim, M.-R. (2014). Leucocyte-rich and platelet-rich fibrin for the treatment of bisphosphonate-related osteonecrosis of the jaw: A prospective feasibility study. *British Journal of Oral and Maxillofacial Surgery, 52*(9), 854–859.
69. Lopez-Jornet, P., et al. (2016). Medication-related osteonecrosis of the jaw: Is autologous platelet concentrate application effective for prevention and treatment? A systematic review. *Journal of Cranio-Maxillofacial Surgery, 44*(8), 1067–1072.
70. Mohanty, S., Pathak, H., & Dabas, J. (2014). Platelet rich fibrin: A new covering material for oral mucosal defects. *Journal of Oral Biology and Craniofacial Research, 4*(2), 144–146.
71. Oyama, T., et al. (2004). Efficacy of platelet-rich plasma in alveolar bone grafting. *Journal of Oral and Maxillofacial Surgery, 62*(5), 555–558.
72. Marukawa, E., et al. (2011). Reduction of bone resorption by the application of platelet-rich plasma (PRP) in bone grafting of the alveolar cleft. *Journal of Cranio-Maxillofacial Surgery, 39*(4), 278–283.
73. Lee, C., et al. (2009). A quantitative radiological assessment of outcomes of autogenous bone graft combined with platelet-rich plasma in the alveolar cleft. *International Journal of Oral and Maxillofacial Surgery, 38*(2), 117–125.
74. Kütük, N., et al. (2014). Effect of platelet-rich plasma on fibrocartilage, cartilage, and bone repair in Temporomandibular joint. *Journal of Oral and Maxillofacial Surgery, 72*(2), 277–284.
75. Lin, S. L., et al. (2018). Effect of arthrocentesis plus platelet-rich plasma and platelet-rich plasma alone in the treatment of temporomandibular joint osteoarthritis: A retrospective matched cohort study (a STROBE-compliant article). *Medicine (Baltimore), 97*(16), e0477.
76. Hegab, A. F., et al. (2015). Platelet-rich plasma injection as an effective treatment for Temporomandibular joint osteoarthritis. *Journal of Oral and Maxillofacial Surgery, 73*(9), 1706–1713.
77. Bousnaki, M., Bakopoulou, A., & Koidis, P. (2018). Platelet-rich plasma for the therapeutic management of temporomandibular joint disorders: A systematic review. *International Journal of Oral and Maxillofacial Surgery, 47*(2), 188–198.
78. Cömert Kiliç, S., Güngörmüş, M., & Sümbüllü, M. A. (2015). Is arthrocentesis plus platelet-rich plasma superior to arthrocentesis alone in the treatment of Temporomandibular joint osteoarthritis? A randomized clinical trial. *Journal of Oral and Maxillofacial Surgery, 73*(8), 1473–1483.
79. Zhu, Y., et al. (2013). Basic science and clinical application of platelet-rich plasma for cartilage defects and osteoarthritis: A review. *Osteoarthritis and Cartilage, 21*(11), 1627–1637.
80. Kim, T.-H., et al. (2014). Comparison of platelet-rich plasma (PRP), platelet-rich fibrin (PRF), and concentrated growth factor (CGF) in rabbit-skull defect healing. *Archives of Oral Biology, 59*(5), 550–558.
81. Miron, R. J., et al. (2017). Injectable platelet rich fibrin (i-PRF): Opportunities in regenerative dentistry? *Clinical Oral Investigations, 21*(8), 2619–2627.
82. Kobayashi, E., et al. (2016). Comparative release of growth factors from PRP, PRF, and advanced-PRF. *Clinical Oral Investigations, 20*(9), 2353–2360.

83. Su, C. Y., et al. (2009). In vitro release of growth factors from platelet-rich fibrin (PRF): A proposal to optimize the clinical applications of PRF. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontics, 108*(1), 56–61.
84. Manzano, G., Herrero, L. R., & Montero, J. (2014). Comparison of clinical performance of zirconia implants and titanium implants in animal models: A systematic review. *The International Journal of Oral & Maxillofacial Implants, 29*(2), 311–320.
85. Shin, D., et al. (2011). Peripheral quantitative computer tomographic, histomorphometric, and removal torque analyses of two different non-coated implants in a rabbit model. *Clinical Oral Implants Research, 22*(3), 242–250.
86. Andreiotelli, M., Wenz, H. J., & Kohal, R. J. (2009). Are ceramic implants a viable alternative to titanium implants? A systematic literature review. *Clinical Oral Implants Research, 20*(Suppl 4), 32–47.
87. Branemark, P. I., et al. (1969). Intra-osseous anchorage of dental prostheses. I. Experimental studies. *Scandinavian Journal of Plastic and Reconstructive Surgery, 3*(2), 81–100.
88. Branemark, P. I., et al. (1977). Osseointegrated implants in the treatment of the edentulous jaw. Experience from a 10-year period. *Scandinavian Journal of Plastic and Reconstructive Surgery. Supplementum, 16*, 1–132.
89. Adell, R., et al. (1981). A 15-year study of osseointegrated implants in the treatment of the edentulous jaw. *International Journal of Oral Surgery, 10*(6), 387–416.
90. Heydecke, G., et al. (2003). Oral and general health-related quality of life with conventional and implant dentures. *Community Dentistry and Oral Epidemiology, 31*(3), 161–168.
91. Heydecke, G., et al. (2005). The impact of conventional and implant supported prostheses on social and sexual activities in edentulous adults results from a randomized trial 2 months after treatment. *Journal of Dentistry, 33*(8), 649–657.
92. Junker, R., et al. (2009). Effects of implant surface coatings and composition on bone integration: A systematic review. *Clinical Oral Implants Research, 20*(Suppl 4), 185–206.
93. Linkevicius, T., & Vaitelis, J. (2015). The effect of zirconia or titanium as abutment material on soft peri-implant tissues: A systematic review and meta-analysis. *Clinical Oral Implants Research, 26 Suppl 11*, 139–147.
94. Ozkurt, Z., & Kazazoglu, E. (2011). Zirconia dental implants: A literature review. *The Journal of Oral Implantology, 37*(3), 367–376.
95. Javed, F., et al. (2013). Is titanium sensitivity associated with allergic reactions in patients with dental implants? A systematic review. *Clinical Implant Dentistry and Related Research, 15*(1), 47–52.
96. Siddiqi, A., et al. (2011). Titanium allergy: Could it affect dental implant integration? *Clinical Oral Implants Research, 22*(7), 673–680.
97. Bianco, P. D., Ducheyne, P., & Cuckler, J. M. (1996). Titanium serum and urine levels in rabbits with a titanium implant in the absence of wear. *Biomaterials, 17*(20), 1937–1942.
98. Weingart, D., et al. (1994). Titanium deposition in regional lymph nodes after insertion of titanium screw implants in maxillofacial region. *International Journal of Oral and Maxillofacial Surgery, 23*(6 Pt 2), 450–452.
99. Meyer, U., et al. (2006). Fast element mapping of titanium wear around implants of different surface structures. *Clinical Oral Implants Research, 17*(2), 206–211.
100. Gahlert, M., et al. (2007). Biomechanical and histomorphometric comparison between zirconia implants with varying surface textures and a titanium implant in the maxilla of miniature pigs. *Clinical Oral Implants Research, 18*(5), 662–668.
101. Kohal, R. J., et al. (2009). Biomechanical and histological behavior of zirconia implants: An experiment in the rat. *Clinical Oral Implants Research, 20*(4), 333–339.
102. Kim, H. K., et al. (2015). Comparison of peri-implant bone formation around injection-molded and machined surface zirconia implants in rabbit tibiae. *Dental Materials Journal, 34*(4), 508–515.
103. Cionca, N., Hashim, D., & Mombelli, A. (2017). Zirconia dental implants: Where are we now, and where are we heading? *Periodontology 2000, 73*(1), 241–258.

104. Sandhaus, S. (1968). Technic and instrumentation of the implant C.B.S. (Cristalline Bone Screw). *Informatore Odonto-Stomatologico, 4*(3), 19–24.
105. Schulte, W., & Heimke, G. (1976). Das Tübinger Sofortimplantat. *Die Quintessenz, 27*(1), 17–23.
106. Sandhaus, S. (1991). Cerasand ceramic implants. *Attualità Dentale, 7*(12), 14–18.
107. Ehrl, P., & Frenkel, G. (1981). Klinische Ergebnisse mit einem enossalen Extensionsimplantat aus Al203-Keramik nach drei Jahren. *Die Quintessenz, 32*, 2007–2015.
108. Silva, N. R., et al. (2010). Performance of zirconia for dental healthcare. *Materials, 3*(2), 863–896.
109. Andreiotelli, M., & Kohal, R. J. (2009). Fracture strength of zirconia implants after artificial aging. *Clinical Implant Dentistry and Related Research, 11*(2), 158–166.
110. Silva, N. R., et al. (2009). Reliability of one-piece ceramic implant. *Journal of Biomedical Materials Research. Part B, Applied Biomaterials, 88*(2), 419–426.
111. Depprich, R., et al. (2008). Osseointegration of zirconia implants compared with titanium: An in vivo study. *Head & Face Medicine, 4*, 30.
112. Smeets, R., et al. (2016). Impact of dental implant surface modifications on Osseointegration. *BioMed Research International, 2016*, 6285620.
113. von Wilmowsky, C., et al. (2014). Implants in bone: Part I. A current overview about tissue response, surface modifications and future perspectives. *Oral and Maxillofacial Surgery, 18*(3), 243–257.
114. Jemat, A., et al. (2015). Surface modifications and their effects on titanium dental implants. *BioMed Research International, 2015*, 791725.
115. Oue, H., et al. (2015). Influence of implant surface topography on primary stability in a standardized osteoporosis rabbit model study. *Journal of Functional Biomaterials, 6*(1), 143–152.
116. Hong, D. G. K., & Oh, J. H. (2017). Recent advances in dental implants. *Maxillofacial Plastic and Reconstructive Surgery, 39*(1), 33.
117. Jung, U. W., et al. (2012). Surface characteristics of a novel hydroxyapatite-coated dental implant. *Journal of Periodontal & Implant Science, 42*(2), 59–63.
118. Buser, D., et al. (2004). Enhanced bone apposition to a chemically modified SLA titanium surface. *Journal of Dental Research, 83*(7), 529–533.
119. Cochran, D. L., et al. (2002). The use of reduced healing times on ITI implants with a sand-blasted and acid-etched (SLA) surface: Early results from clinical trials on ITI SLA implants. *Clinical Oral Implants Research, 13*(2), 144–153.
120. Kumar, B. P., et al. (2016). Mandibular reconstruction: Overview. *Journal of Maxillofacial and Oral Surgery, 15*(4), 425–441.
121. Macewen, W. (1885). Cases illustrative of cerebral surgery. *The Lancet, 125*(3221), 934–936.
122. Simion, M., & Fontana, F. (2004). Autogenous and xenogeneic bone grafts for the bone regeneration. A literature review. *Minerva Stomatologica, 53*(5), 191–206.
123. Handschel, J., et al. (2011). Nonvascularized iliac bone grafts for mandibular reconstruction – Requirements and limitations. *In Vivo, 25*(5), 795–799.
124. Poswillo, D. (1974). Experimental reconstruction of the mandibular joint. *International Journal of Oral Surgery, 3*(6), 400–411.
125. El-Sayed, K. M. (2008). Temporomandibular joint reconstruction with costochondral graft using modified approach. *International Journal of Oral and Maxillofacial Surgery, 37*(10), 897–902.
126. Connolly, T. M., et al. (2017). Reconstruction of midface defects with the osteocutaneous radial forearm flap: Evaluation of long term outcomes including patient reported quality of life. *Microsurgery, 37*(7), 752–762.
127. Dean, N. R., et al. (2012). Free flap reconstruction of lateral mandibular defects: Indications and outcomes. *Otolaryngology and Head and Neck Surgery, 146*(4), 547–552.
128. Dowthwaite, S. A., et al. (2013). Comparison of fibular and scapular osseous free flaps for oromandibular reconstruction: A patient-centered approach to flap selection. *JAMA Otolaryngology. Head & Neck Surgery, 139*(3), 285–292.

129. Moscoso, J. F., & Urken, M. L. (1994). The iliac crest composite flap for oromandibular reconstruction. *Otolaryngologic Clinics of North America, 27*(6), 1097–1117.
130. Roberts, T. T., & Rosenbaum, A. J. (2012). Bone grafts, bone substitutes and orthobiologics: The bridge between basic science and clinical advancements in fracture healing. *Organogenesis, 8*(4), 114–124.
131. Goldberg, V. M., & Akhavan, S. (2005). Biology of bone grafts. In *Bone regeneration and repair* (pp. 57–65). Humana Press.
132. Aludden, H. C., et al. (2017). Lateral ridge augmentation with Bio-Oss alone or Bio-Oss mixed with particulate autogenous bone graft: A systematic review. *International Journal of Oral and Maxillofacial Surgery, 46*(8), 1030–1038.
133. Moss, S. D., et al. (1995). Transplanted demineralized bone graft in cranial reconstructive surgery. *Pediatric Neurosurgery, 23*(4), 199–204; discussion 204-5.
134. Elsalanty, M. E., & Genecov, D. G. (2009). Bone grafts in craniofacial surgery. *Craniomaxillofacial Trauma & Reconstruction, 2*(3), 125–134.
135. Salyer, K. E., et al. (1992). Demineralized perforated bone implants in craniofacial surgery. *The Journal of Craniofacial Surgery, 3*(2), 55–62.
136. Neumann, A., & Kevenhoerster, K. (2009). Biomaterials for craniofacial reconstruction. *GMS Current Topics in Otorhinolaryngology, Head and Neck Surgery, 8*, Doc08.
137. Menderes, A., et al. (2004). Craniofacial reconstruction with high-density porous polyethylene implants. *The Journal of Craniofacial Surgery, 15*(5), 719–724.
138. Eufinger, H., & Wehmoller, M. (2002). Microsurgical tissue transfer and individual computer-aided designed and manufactured prefabricated titanium implants for complex craniofacial reconstruction. *Scandinavian Journal of Plastic and Reconstructive Surgery and Hand Surgery, 36*(6), 326–331.
139. Siebert, H., et al. (2006). Evaluation of individual ceramic implants made of Bioverit with CAD/CAM technology to reconstruct multidimensional craniofacial defects of the human skull. *Mund-, Kiefer- und Gesichtschirurgie, 10*(3), 185–191.
140. Biskup, N. I., et al. (2010). Pediatric cranial vault defects: Early experience with beta-tricalcium phosphate bone graft substitute. *The Journal of Craniofacial Surgery, 21*(2), 358–362.
141. Verret, D. J., et al. (2005). Hydroxyapatite cement in craniofacial reconstruction. *Otolaryngology and Head and Neck Surgery, 133*(6), 897–899.
142. Rezaei, M., et al. (2018). Nano-biphasic calcium phosphate ceramic for the repair of bone defects. *The Journal of Craniofacial Surgery, 29*(6), e543–e548.
143. Eppley, B. L. (2002). Craniofacial reconstruction with computer-generated HTR patient-matched implants: Use in primary bony tumor excision. *The Journal of Craniofacial Surgery, 13*(5), 650–657.
144. Scolozzi, P., Martinez, A., & Jaques, B. (2007). Complex orbito-fronto-temporal reconstruction using computer-designed PEEK implant. *The Journal of Craniofacial Surgery, 18*(1), 224–228.
145. Ng, Z. Y., & Nawaz, I. (2014). Computer-designed PEEK implants: A peek into the future of cranioplasty? *The Journal of Craniofacial Surgery, 25*(1), e55–e58.
146. Nieminen, T., et al. (2008). Amorphous and crystalline polyetheretherketone: Mechanical properties and tissue reactions during a 3-year follow-up. *Journal of Biomedical Materials Research. Part A, 84*(2), 377–383.
147. Lethaus, B., et al. (2011). A treatment algorithm for patients with large skull bone defects and first results. *Journal of Cranio-Maxillo-Facial Surgery, 39*(6), 435–440.
148. Ridwan-Pramana, A., et al. (2015). Porous polyethylene implants in facial reconstruction: Outcome and complications. *Journal of Cranio-Maxillo-Facial Surgery, 43*(8), 1330–1334.
149. Eski, M., et al. (2007). Contour restoration of the secondary deformities of zygomaticoorbital fractures with porous polyethylene implant. *The Journal of Craniofacial Surgery, 18*(3), 520–525.
150. Wang, W., & Yeung, K. W. (2017). Bone grafts and biomaterials substitutes for bone defect repair: A review. *Bioactive Materials, 2*(4), 224–247.

151. Steinmann, S., et al. (1986). *Biological and biomechanical performance of biomaterials*. Amsterdam: Elsevier Science.
152. Actis, L., et al. (2013). Antimicrobial surfaces for craniofacial implants: State of the art. *Journal of the Korean Association of Oral and Maxillofacial Surgeons, 39*(2), 43–54.
153. Mok, D., et al. (2004). A review of materials currently used in orbital floor reconstruction. *The Canadian Journal of Plastic Surgery, 12*(3), 134–140.
154. Gross, P. P., & Gold, L. (1957). The compatibility of Vitallium and Austanium in completely buried implants in dogs. *Oral Surgery, Oral Medicine, Oral Pathology, 10*(7), 769–780.
155. Simpson, J. P., Geret, V., Brown, S. A., & Merrit, K. (1981). *Implant retrieval: Material and biologic analysis* (Vol. 601, pp. 395–422). NBS Spec Publ.
156. Barone, C. M., et al. (1994). Effects of rigid fixation device composition on three-dimensional computed axial tomography imaging: Direct measurements on a pig model. *Journal of Oral and Maxillofacial Surgery, 52*(7), 737–740; discussion 740-1.
157. Fiala, T. G., Novelline, R. A., & Yaremchuk, M. J. (1993). Comparison of CT imaging artifacts from craniomaxillofacial internal fixation devices. *Plastic and Reconstructive Surgery, 92*(7), 1227–1232.
158. Sullivan, P. K., Smith, J. F., & Rozzelle, A. A. (1994). Cranio-orbital reconstruction: Safety and image quality of metallic implants on CT and MRI scanning. *Plastic and Reconstructive Surgery, 94*(5), 589–596.
159. Meslemani, D., & Kellman, R. M. (2012). Recent advances in fixation of the craniomaxillofacial skeleton. *Current Opinion in Otolaryngology & Head and Neck Surgery, 20*(4), 304–309.
160. McRae, M., & Frodel, J. (2000). Midface fractures. *Facial Plastic Surgery, 16*(2), 107–113.
161. Nastri, A. L., & Gurney, B. (2016). Current concepts in midface fracture management. *Current Opinion in Otolaryngology & Head and Neck Surgery, 24*(4), 368–375.
162. Haug, R. H., Nuveen, E., & Bredbenner, T. (1999). An evaluation of the support provided by common internal orbital reconstruction materials. *Journal of Oral and Maxillofacial Surgery, 57*(5), 564–570.
163. Kinnunen, I., et al. (2000). Reconstruction of orbital floor fractures using bioactive glass. *Journal of Cranio-Maxillo-Facial Surgery, 28*(4), 229–234.
164. Romano, J. J., Iliff, N. T., & Manson, P. N. (1993). Use of Medpor porous polyethylene implants in 140 patients with facial fractures. *The Journal of Craniofacial Surgery, 4*(3), 142–147.
165. Metzger, M. C., et al. (2006). Anatomical 3-dimensional pre-bent titanium implant for orbital floor fractures. *Ophthalmology, 113*(10), 1863–1868.
166. Scolozzi, P., et al. (2009). Accuracy and predictability in use of AO three-dimensionally preformed titanium mesh plates for posttraumatic orbital reconstruction: A pilot study. *The Journal of Craniofacial Surgery, 20*(4), 1108–1113.
167. Balogh, C., et al. (2001). Lactic acid polymer implants in the repair of traumatic defects of the orbital floor. *Revue de Stomatologie et de Chirurgie Maxillo-Faciale, 102*(2), 109–114.
168. Gierloff, M., et al. (2012). Orbital floor reconstruction with resorbable polydioxanone implants. *The Journal of Craniofacial Surgery, 23*(1), 161–164.
169. Chowdhury, K., & Krause, G. E. (1998). Selection of materials for orbital floor reconstruction. *Archives of Otolaryngology – Head & Neck Surgery, 124*(12), 1398–1401.
170. Krishnan, V., & Johnson, J. V. (1997). Orbital floor reconstruction with autogenous mandibular symphyseal bone grafts. *Journal of Oral and Maxillofacial Surgery, 55*(4), 327–330; discussion 330-2.
171. Celikoz, B., Duman, H., & Selmanpakoglu, N. (1997). Reconstruction of the orbital floor with lyophilized tensor fascia lata. *Journal of Oral and Maxillofacial Surgery, 55*(3), 240–244.
172. Johnson, P. E., & Raftopoulos, I. (1999). In situ splitting of a rib graft for reconstruction of the orbital floor. *Plastic and Reconstructive Surgery, 103*(6), 1709–1711.
173. Ellis, E., 3rd. (1999). Treatment methods for fractures of the mandibular angle. *International Journal of Oral and Maxillofacial Surgery, 28*(4), 243–252.
174. Rastogi, S., et al. (2016). Assessment of bite force in patients treated with 2.0-mm traditional miniplates versus 2.0-mm locking plates for mandibular fracture. *Craniomaxillofacial Trauma & Reconstruction, 9*(1), 62–68.

175. Flores-Hidalgo, A., et al. (2015). Management of fractures of the atrophic mandible: A case series. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, 119*(6), 619–627.
176. Sauerbier, S., et al. (2008). The development of plate osteosynthesis for the treatment of fractures of the mandibular body – a literature review. *Journal of Cranio-Maxillo-Facial Surgery, 36*(5), 251–259.
177. Chaudhary, M., et al. (2015). Evaluation of trapezoidal-shaped 3-D plates for internal fixation of mandibular subcondylar fractures in adults. *Journal of Oral Biology and Craniofacial Research, 5*(3), 134–139.
178. Kang, D. H. (2012). Surgical management of a mandible subcondylar fracture. *Archives of Plastic Surgery, 39*(4), 284–290.
179. Eckelt, U., & Hlawitschka, M. (1999). Clinical and radiological evaluation following surgical treatment of condylar neck fractures with lag screws. *Journal of Cranio-Maxillo-Facial Surgery, 27*(4), 235–242.
180. Luo, S., et al. (2011). Surgical treatment of sagittal fracture of mandibular condyle using long-screw osteosynthesis. *Journal of Oral and Maxillofacial Surgery, 69*(7), 1988–1994.
181. Gerlach, K. L. (2000). *Resorbable polymers as osteosynthesis material*. *Mund Kiefer Gesichtschir, **4 Suppl 1***, S91–S102.
182. Eppley, B. L., & Sadove, A. M. (1995). A comparison of resorbable and metallic fixation in healing of calvarial bone grafts. *Plastic and Reconstructive Surgery, 96*(2), 316–322.
183. Stanton, D. C., et al. (2014). Use of bioresorbable plating systems in paediatric mandible fractures. *Journal of Cranio-Maxillo-Facial Surgery, 42*(7), 1305–1309.
184. Suuronen, R., Kallela, I., & Lindqvist, C. (2000). Bioabsorbable plates and screws: Current state of the art in facial fracture repair. *The Journal of Cranio-Maxillofacial Trauma, 6*(1), 19–27; discussion 28–30.
185. Eppley, B. L. (2005). Use of resorbable plates and screws in pediatric facial fractures. *Journal of Oral and Maxillofacial Surgery, 63*(3), 385–391.
186. Pietrzak, W. S. (2012). Degradation of LactoSorb fixation devices in the craniofacial skeleton. *The Journal of Craniofacial Surgery, 23*(2), 578–581.
187. Ferretti, C. (2008). A prospective trial of poly-L-lactic/polyglycolic acid co-polymer plates and screws for internal fixation of mandibular fractures. *International Journal of Oral and Maxillofacial Surgery, 37*(3), 242–248.
188. Agarwal, S., et al. (2009). Use of resorbable implants for mandibular fixation: A systematic review. *The Journal of Craniofacial Surgery, 20*(2), 331–339.
189. Bell, R. B., & Kindsfater, C. S. (2006). The use of biodegradable plates and screws to stabilize facial fractures. *Journal of Oral and Maxillofacial Surgery, 64*(1), 31–39.