Advancements in craniofacial prosthesis fabrication: A narrative review of holistic treatment

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The treatment of craniofacial anomalies has been challenging as a result of technological shortcomings that could not provide a consistent protocol to perfectly restore patient-specific anatomy. In the past, wax-up and impression-based maneuvers were implemented to achieve this clinical end. However, with the advent of computer-aided design and computer-aided manufacturing (CAD/CAM) technology, a rapid and cost-effective workflow in prosthetic rehabilitation has taken the place of the outdated procedures. Because the use of implants is so profound in different facets of restorative dentistry, their placement for craniofacial prosthesis retention has also been widely popular and advantageous in a variety of clinical settings. This review aims to effectively describe the well-rounded and interdisciplinary practice of craniofacial prosthesis fabrication and retention by outlining fabrication, osseointegrated implant placement for prosthesis retention, a myriad of clinical examples in the craniofacial complex, and a glimpse of the future of bioengineering principles to restore bioactivity and physiology to the previously defected tissue. *[J Adv Prosthodont 2018;10:430-9]*

KEYWORDS: Craniofacial; Computer-aided design and computer-aided manufacturing (CAD/CAM); Prosthesis; Implants; Bioengineering

INTRODUCTION

For nearly three decades, computer-aided design/computer-aided manufacturing (CAD/CAM) technology has revolutionized the practice of restorative dentistry. The goal of standardizing its use was to commercialize materials used in restoration, increase the consistency and efficiency of prosthesis fabrication, and reduce production costs.[1] Three-dimensional (3D) technologies can allow the user to design a prosthesis using CAD/CAM software and then fabricate a complex restoration, such as crowns, fixed dental prostheses (FDPs), and craniofacial prostheses using the desired material type. Currently, the technology can manufacture simple crowns, fixed dental prostheses, removable dental prostheses, or even craniofacial structures.[2] Given the broad scope of 3D bioprinting, its application is being increasingly adopted in multiple disciplines, including maxillofacial prosthodontics, otolaryngology, and plastic and reconstructive surgery.[3]

In contemporary medicine, 3D bioprinting has made significant contributions to the field of tissue engineering and regenerative medicine. Optimal cell distribution ability, in addition to 3D scaffold architecture, makes this technique unique compared to other scaffold production technologies. One limitation of this technique is the deposition of bioma-

terials, with micrometer precision, in "cell-friendly conditions". Bioinks' properties are one of the most crucial factors when bioprinting a scaffold and cells simultaneously. Fulfillment of the biological requirements and the structural requirements for acceptable printability make it challenging.[4]

Fundamentally, 3D bioprinting entails an additive manufacturing process that operates in a layer-by-layer maneuver, offering significant advantages over alternative methods of prosthesis fabrication. The fabrication process itself is rapid and customizable, and improves on more costly traditional prosthetic implants.[5] The customizability of 3D printing can result in superior functional and esthetic results.[6] Maxillofacial anomalies, such as those resulting from craniofacial birth defects, trauma, and tumor resection, have been treated in the past decade with 3D printed prostheses of the eyes, nose, and ears, among other anatomically complex facial features.[7-9] The advantages of using CAD data to design maxillofacial prostheses over traditionally invasive surgical techniques include reduced surgery time and anesthetic exposure, as well as a lowered risk for iatrogenic infection.[10]

Preoperative digital scanning allows the clinician to assess the defect and plan for prototype design, which allows a better understanding of the complex dynamics surrounding the artificial implant, rotational movements of the temporomandibular joint.[11] The planning phase with 3D software also can provide a model for patient-specific surgical templates, and serve as a visual analog to educate patients during consultation appointments prior to the procedure.[12,13] In vivo stability, durability, and esthetics of the prosthesis are significant factors that ultimately determine procedural success.

For instance, osseointegrated implants can be used to increase the adhesiveness and retention of prostheses. Although biomedical adhesives and other retentive frameworks have been previously used, osseointegrated implants may reduce the risk of adjacent soft tissue irritation.[14]

Throughout this review, the design, fabrication, and medical applications of maxillofacial prostheses will be discussed. Rehabilitative soft tissue organs, such as the eyes, ears, and nose, will be examined as suitable sites of delivery to treat an anatomical abnormality.

PROSTHESIS FABRICATION

The protocol for craniofacial prosthesis design entails data capture and patient-specific design on a virtual platform, followed by fabrication and placement of the prosthetic organ. Digital capture and rapid prototyping is preferred over conventional waxing and impression schemes due to speed, commercialization, and unmatched accuracy in design.[15]

Fantini et al.[16] demonstrated that the defect must first be analyzed by digitalizing the face using 3D laser scanning. Bibb and his colleagues explained that computed tomography (CT) is also suitable for analyzing facial anatomy of a patient prior to the design phase.[17] Positioning and trimming of the molded prosthesis can also be maneuvered using CT data.[18] Haptic CAD systems can minimize error in

design and expedite the process of surgical planning.[19,20] Tomographic imaging is fundamental in data acquisition of the deficient facial structure in order to appraise the desired surface area, dimensions, morphology, and orientation of the previously intact tissue.[21]

Although conventional imaging techniques, such as CT and MRI, have been popular in prosthesis design, the exposure to radiation has led some to use optical modeling as a safer mode of data acquisition.[22] In more complex cases requiring the restoration of large defects or circumventing delicate vital structures, the virtual prosthesis must be designed using the healthy contralateral surface as a template.[23]

The mould and substructure of the prosthesis can subsequently be designed using the numerical and visual data acquired from laser scans obtained from different angles. Ciocca et al.[24] used eight laser measurements on an auricular cast to form 3D volume clouds in their data acquisition and, in the data elaboration phase, fine-tuned the design with these clouds to smoothen irregular surfaces, delete abnormalities, organize the network of points, and erase surface gaps in the digitalized image. In many instances of auricular prosthesis manufacturing, the combination of a single bar and implants is employed in a substructure for retention.[25] After scanning the facial defect and digitizing a layer-by-layer 3D construction composed of multiple slices, virtual adjustments are made on the computer to produce a blueprint of an ideal prosthesis that is personalized to the patient. As mentioned, substructures for assembling and positioning the final prosthesis are similarly designed. After the design is complete, the stereolithographic (STL) data is transferred to a 3D printer.

In a clinical case of nasal prosthesis rehabilitation conducted by Qiu et al.,[26] a four-piece resin mould, combined with a photopolymer, was prototyped and assembled so that it could be filled with the traditional silicone material. A silicone mould can also be used as a template to fill the prosthesis-shaped defect with silicone material.[27] The printing process entails the fabrication of layers in the same orientation so that they can articulate together as a uniform, durable tissue replacement.[28]

The type of powder used for printing depends on the printer itself, and often a high-grade industrial composite powder or synthetic polymer, such as polystyrene, is used.[29] Following the intricate process of CAD-supported prosthesis fabrication, the interim prosthesis requires the removal of excess material, and both intrinsic and extrinsic color application to match the skin color of the patient before delivering the final prosthesis.[30]

One mode of additive manufacturing technology is electron beam melting (EBM) in which electron beam melts layers of metal powder. EBM contributes to making innovative designs easily, and has been introduced as a potential future technique for orthopedic implants. In this regard, patients benefit from a customized implant by means of novel diagnostic and manufacturing techniques. Incorporation of functional regions intended for biological anchorage in the

design of the implant leads to manufacturing of well-shaped implant. In brief, electron beam scans each layer of metal powder according to the layer in formation obtained from the 3D digital geometry, and melts the metal powder under vacuum (10^{-3} to 10^{-4} millibar). The most recently created layer is lowered by 0.05 to 0.1 mm, and a new powder layer is deposited on top. The procedure continues by melting and fusing the layers until the final 3D geometry is achieved. Biocompatible behavior of EBM Ti6Al4V implants in hard and soft tissue has been demonstrated in previous studies[31]; however, the shape and surface properties of the porous network have not yet been optimized for specific clinical indications. Apart from the geometry and porosity of EBM-manufactured implants, surface chemistry and structure is another crucial factor for bone response to biomaterials that may affect and induce bone ingrowth. Custom-designed jaw prostheses can be made using EBM to reconstruct maxillary or mandibular defects resulting from surgery, trauma, or congenital deformities.[31]

IMPLANT USE FOR RETENTION

The use of extraoral osseointegrated implants for the attachment of craniofacial prostheses has profoundly influenced rehabilitation. CT scans to evaluate the best location for surgical implant placement based upon bone width and depth are also necessary. Curi et al.[32] performed a retrospective study that analyzed important variables necessary for successful prosthesis retention, such as implant success, survival rates, and soft tissue response among others. Magnets and bar-and-clips were also considered valid components for prosthesis retention.[32] Mechanical stability of the implant has allowed it to be a useful tool for the retention of prostheses, as evidenced by four decades of its successful use in clinical practice. The timing of implant placement can also be flexible as it can be placed either during the major reconstructive procedure or at a postoperative follow-up appointment.[33] However, in patients suffering from malignancies, radiation therapy would compromise the bone that could potentially serve as a promising site for implant placement, giving rise to adjunctive treatments to allow for the maintenance of osteogenic potential required to support subsequent implant surgery.[34] One-stage or two-stage surgical protocols are common in implant delivery under general anesthesia, while Karakoca et al.[35] explained that the process of osseointegration could last between 3 to 6 months, depending on implant location.

In extensive case report conducted by Balik et al.,[37] patients were instructed to clean the tissue surrounding the implant with soap and water after prosthesis attachment to avoid adverse reactions.[36] Routine follow-up visits are usually required to examine the soft tissue response, which is an indicator for implant success with specific numerical grades correlating to the degree of irritation or presence of infection.[37]

Bone-anchored hearing aids or bone-anchored prostheses in children can be inserted by means of osseointegrated implants. Bone augmentation makes it feasible to find space for 3-mm implants even in 1-year-old children with thinner temporal bone. A surgical risk that should be considered is the distance to the durasigmoid sinus, and shorter air cells. Implant survival and adverse skin reactions show no difference compared with age-matched implant cohort.[38]

CLINICAL APPLICATIONS

1. Nasal Prostheses

Patients recovering from trauma, as well as those with congenital malformations or a history of cancer of the nose, may benefit from nasal prostheses. Since the 1500s, such prostheses have been retained largely by non-permanent methods, including eye glasses and adhesive products.[39]

Nasal prostheses may also serve a functional purpose, especially if the affected area involves the maxilla or the palate. In such cases, design of the nasal prosthesis and retention should take into consideration any other prosthodontic rehabilitations the patient may need.[40] Likewise, patient confidence in such prostheses is diminished when retention is inadequate.[41] Presently, the literature contains many options for retention methods, including: eyeglasses/spectacle extensions that engage undercuts in facial contours, magnets, adhesives, attachment to maxillary obturators, and osseointegrated implants.[42]

Depending on the financial status or time pressures, some patients may opt for a simpler solution. An alternative to surgery is an autopolymerizing resin maxillofacial prosthesis attached to spectacles. A process for creation of such a prosthesis can be utilized, beginning with an irreversible hydrocolloid impression, creation of a waxed-up prosthesis for try-in (with feather edge margins to ensure marginal adaptation with patient's skin), followed by a flasking of the wax model, boilout of wax, and casting with autopolymerizing resin. Oil-based paints are used to customize the prosthesis for the patient according to skin appearance. At the final appointment, cyanoacrylate is used to adhere the prosthesis to spectacles and water-resistant color is added to create a life-like, polychromatic prosthesis.[40] Finally, texture adjustments are made to match the skin surface. Each case is different, with regard to site, size, and etiology of the facial defect, patient's age, overall health and individual preferences are used to personalize the methods of reconstruction.[43] Cost-effective and esthetically favorable prosthetic rehabilitation is preferable due to a minimal pathologic recurrence, complexity of the surgical reconstruction procedure, and risks associated with radiation therapy.[41]

More recently, osseointegrated implants have become a treatment option to provide patients with a more permanent prosthesis. The survival and success rates for such implants have been described in the literature. The most common adverse outcome for extra-oral implants has been shown to be soft tissue infection.[44] Life-long follow-up and maintenance of such implants will be necessary, to ensure early detection of complications and continuity of patient quality of life.[45]

A 6-year survival rate, described by Roumanas et al.,[46]

was 87% for piriform and nasal implants. The authors noted that it was possible to attain high survival rates for implants of piriform and/or nasal sites, granted that careful radiographic and preoperative planning is completed.[44] For such implant-retained prostheses, a survey of 28 health care centers creating such prostheses revealed that few nasal prostheses were placed for a reliable estimate of the trend on attachment use.[47] There are a variety of attachment options for implant-retained prostheses, including clip, magnet, or other retention strategies. Further studies are required to determine the most effective attachment technique for patients with implant-retained prostheses.[45]

Implant recipient site is another variable for reconstruction of facial defects. Commonly, the nasal bones, premaxillary area (through the nasal fossae), and the anterior wall of the frontal sinus have been sites for implant placement for nasal prostheses. In a case study by Proussaefs, the frontal process of the maxillary bone was used as the site of one implant while the premaxilla was the site for two additional implants.[48] A bar connected the three implants and a removable nasal prosthesis was attached to the bar with two clips. After twelve months, no signs of adverse outcomes were present.[46] Similarly, the zygomatic arch may be a potential site for implant placement, especially for patients with oral cavity or upper lip cancers requiring excision.[49] More studies should be carried out in the future to consider novel sites of implant placement for nasal prostheses.

Implants appear to offer promising reconstructive outcomes for many patients. However, expectations should be modified based on the patient demographics. In a study of 111 implants placed for nasal defects, age, sex, and tumor histology did not affect the outcome.[50] In contrast, other key demographic variables can appreciably influence implant outcome, including history of smoking, extent of rhinectomy, use of radiotherapy, hyperbaric oxygen treatment, depth and placement of the implant, and type of retention (bar and/or magnets) impacted implant outcome. The overall success rate was 89% and the success rate was 94% in patients who did not receive radiotherapy.[47] By modifying the defect immediately after rhinectomy, the ability to safely place hygienic soft tissue grafts with favorable primary stability increased. For large, full-thickness nasal defects, an implant-retained prosthesis is a viable option. Such prostheses can be created with 3D printing techniques, traditional silicone, or other methods that can closely simulate the patient's original features. CAD/CAM can have many advantages over conventional techniques, including increased precision, biocompatibility, and lower costs.[51] This is particularly important in light of information from a study by Hooper et al. that surveyed patients who received facial prostheses. After 14 months, only 17% of patents were wearing their original prostheses, and the majority of replacement prostheses were in various stages of repair or replacement due to color fade or wear of the silicone material of the previous prosthesis.[52]

Although externally-retained nasal prostheses may appear less natural in appearance and inferior to autogenous facial reconstruction, such surgical approaches are not an option for every patient.[53] In a study of ten patients with a total of 44 facial implants, six of which were for nasal defects, there were notably high failure rates for the glabellar and midfacial region implants.[48] The average time between placement and failure was 6 months and ranged from one to 18 months. Taking the anatomical and reconstructive needs of the patient into account, it is the opinion of the authors that success rates are generally good for facial reconstruction and that most implants are able to retain their associated prosthesis and that such implants are a viable alternative to autogenous reconstruction. In addition, rehabilitation with single-stage osseointegrated implants and prostheses using intrinsic pigmentation may be able to offer fast treatment time and esthetic confidence.[54]

2. Auricular Prostheses

The complexity and uniqueness of each patient's ear makes reconstructive surgery a difficult option. Tjellström et al. discussed the feasibility of implant-retained auricular prostheses, which led to increased simulations and treatment plans for restoring microtia.[55-58] As stated previously, CT scans are used to assess the suitability of the implant recipient sites and to reliably predict post-operative esthetic outcomes.[59] Following the design of a template for presurgical planning and the removal of any remnant auricular tissue that could potentially decrease the esthetic quality of the prosthesis, imaging techniques are executed to design the shape of the auricle based on the contralateral ear, in many cases. While using one method of image acquisition may offer a limited capacity for accuracy in prosthesis design, Wang et al. integrated both CT scanning and 3D photography to accurately fabricate the prosthesis with intricate detail.[60,61] Many clinicians, including Wang et al.,[61] use a software for presurgical soft tissue analysis in addition to bone depth and quality. In their specific case report, the implant locations were determined in the template and subsequently placed. Similar to the aforementioned protocol for achieving a successful prosthetic surgery, the use of selective laser sintering (SLS) technology and bar/resin complex installation for retention of the prosthesis was performed, and they reported that the original esthetic quality of the native ear was successfully duplicated.

Traditional techniques to restore auricular defects require a surgical procedure to harvest an autologous donor cartilage that will be used as a foundation to support overlying soft tissue. These traditional techniques suffer from several shortcomings: (1) the surgery is technically demanding due to the complex 3D geometry of the auricular cartilage; (2) reconstruction is associated with considerable morbidity due to the presence of two surgical sites, the donor and graft recipient sites[62]; (3) there is a difference in biophysical properties between the donor site and the native cartilage; and (4) the availability of cartilage is limited at the donor site.[62-64]

As a means to reduce morbidity at the surgical site and reduce technical difficulty of preparing donor cartilage to resemble the native ear, prefabricated synthetic material can

be used, for example, porous, high-density polyethylene (MedPor, Stryker Corporation, Kalamazoo, MI, USA).[65] However, these prefabricated frameworks are not customized for patient-specific anatomy. They are also associated with greater incidence of framework rejection and tissue necrosis than autogenous cartilage reconstruction.[63]

Additive manufacturing techniques combined with 3D design and manufacturing capabilities, in combination with advances in tissue bioengineering, can now be used to produce biocompatible, accurate, custom tissue-engineered implants for auricular reconstruction that mimic the native ear.[64]

These improvements are driven primarily by recent breakthroughs in scaffold design and manufacturing and in material science. The design of patient-specific scaffolds requires the use of 3D image-based techniques that would allow for the digital design of the general anatomic skeleton of the auricle, based on data acquired from the actual patient (e.g.: 3D scans of the contralateral auricle). Custom design features such as periodically or randomly placed pores with certain geometries are also included in the design of the skeleton. Once the digital design is finalized, the design file is exported for manufacturing. The digitally designed skeletons are typically fabricated from biocompatible materials using additive manufacturing technology. As discussed above, a variety of scaffold materials are available to fabricate the auricular skeleton.[66] An example of such material is polycaprolactone (PCL) that can be laser sintered with considerable accuracy (0.7 mm) as described by Zopf et al.,[67] 2015.

Alternatively, molds made from patient specific designs can be fabricated using 3D additive manufacturing technology and packed with biocompatible skeleton material. Reiffel et al.,[64] 2013, used this technique to fabricate patient-specific skeletons made of collagen type I gel. The molds were printed from acrylonitrile butadiene styrene (ABS).

Once the anatomically accurate, patient-specific auricular skeleton is fabricated, it is seeded with cells (chondrocytes or mesenchymal stem cells) with the aid of growth factors (basic fibroblast growth factor; b-FGF, and tissue growth factor; TGF-B2) and hydrogels such as type I collagen gel and hyaluronic acid.

When compared to mesenchymal stem cells and cells of other cartilaginous sources, auricular chondrocytes have been shown to be particularly advantageous in auricular scaffold fabrication because the resulting tissue-engineered cartilage is histologically and mechanically comparable to native ear cartilage.[68-70] The seeded skeleton is then incubated to allow for cartilage growth and tissue expansion, before implantation.

In addition to shape complexity, tissue-engineering of auricular cartilage is further complicated by its complex composition. In auricular reconstruction, both cartilaginous and fat tissues may need to be regenerated. Lee et al.[71] described a technique to regenerate both the auricular cartilage and periauricular adipose. In this technique, the skeleton was fabricated as described above using CAD/CAM PCL that is laden with hydrogel. The skeleton was seeded with

chondrocytes and adipocytes differentiated from adipose-derived stromal cells. These adipocytes were used to engineer fat tissues surrounding the tissue engineered cartilage. The scaffold was also covered with a layer of poly-ethylene-glycol (PEG) that served as a support to the main structure. In vitro assays for evaluating the chondrogenesis and adipogenesis of this composite structure demonstrated that ear regeneration using this technology is a distinct possibility. In this research, NN algorithm was developed to create the cell-printed structure with a free-form shape. CAD models including the external shape of the ear-shaped major part and its conciliatory layer part were designed in CATIA V5 (Dassault Systemes), and sent out to the stereolithography (STL) file format. The algorithm produced a series of 2D pattern data from STL file data for printing the conciliatory layer, framework, and cell-loaded hydrogel.

Recently, Markstedt et al.[4] concluded that a bioink composed of nano-fibrillated cellulose and alginate is a proper hydrogel for 3D bioprinting with living cells for growth of cartilage tissue.

Clinically, the CAD/CAM auricle scaffolds will require the use of an overlying vascular soft tissue to maintain the viability of the implanted scaffold. Soft tissue coverage can be developed using a number of methods including simple subcutaneous implantation, tissue expansion followed by subcutaneous implantation, or staged implantation using a prelaminated regional flap or a free tissue flap.[67]

3. Ocular Prostheses

After losing an eye, the psychological effects tend to provide a greater challenge than the actual loss of function. Eye loss is commonly associated with several different causes, such as trauma, glaucoma, or cancer. When surgical enucleation is indicated, enucleation is preformed, the entire globe of the eye as well as a portion of the optic nerve are removed. Depending on extent of malignancy or trauma, bony supports may also be removed. This results in compromised aesthetics and loss of volume.[72-74] Currently, intra-orbital implants made of nonporous hydroxyapatite or porous polyethylene are used.[72] In addition to aesthetics, these materials must be scratch resistant and easy to polish. If a prosthesis fails to furnish these characteristics, the surface of the prosthesis is prone to microbial accumulation and biofilm formation, ultimately leading to inflammation and infection. Fortunately, such complications are relatively rare.

The goal of these prostheses is to restore the patient's facial aesthetics and minimize the psychological effects of anophthalmia, while maintaining health of the remaining structures.[73,74] Prior to receiving the prosthesis, some patients may require additional volume replacement by dermis-fat grafts or free radial forearm flaps.[75] Extensive bony and soft tissue destruction may require orbital exenteration, where the margins of orbital resection extends beyond the orbital region, including the frontal bone and portions of the cheek. Due to the large mass volume of these areas, they are difficult to restore via the previously listed conventional

methods.[76-78] The use of osseointegrated implants has greatly improved the retention and support of these prostheses, producing ideal aesthetics.[76] However, orbital implant supported ocular prostheses are not free of complications, such as peri-implantitis and soft tissue inflammation, and have poor long term success.[76-78]

One of the most important steps in creating a custom prosthesis is the impression stage. With a high-quality impression, a custom prosthesis can be constructed that allows for excellent tissue adaptation, thereby enhancing tissue health within the socket.[74] A custom impression tray can be created using a autopolymerizing polymethyl methacrylate resin.[79] Regardless of whether the tray is stock or custom, ocular impression trays must be adjusted for areas of overextension or interference.[75,79] In the center of the impression tray, a syringe is attached that allows impression material to be easily injected into the anopthalmic socket. The impression material is irreversible hydrocollioid.[79] Having the patient in a relaxed facial position allows the impression material to capture the natural drape of the tissues.[80]

A positive impression of the initial negative impression is then made in either silicon putty or irreversible hydrocolloid, and a wax pattern is constructed from the positive impression. Trying the wax in the eyes allows for evaluation of tissue adaptation and corneal prominence. Once the basics are established. An iris matching the adjacent eye is added in the position of the contralateral gaze.[80] The wax pattern is then flasked and subsequently packed with the scleral polymer. In terms of aesthetic realism, the color of the iris is arguably one of the most important aspects of the prosthesis aesthetically.[81] The iris can then be created using pigments or acrylic paints and finished with a clear light cure material. To better match the contralateral eye, this is done in person under a daylight. To preserve the integrity of the various colors used, each layer is painted and cured separately. Alternatively, the iris can be created through digital imaging. This requires much less skill than the painting technique and saves a considerable amount of time. Importantly, the aesthetic result is similar.[81] The sclera is also color matched to the contralateral eye. Red nylon fibers are also added to provide the appearance of blood vessels. These steps are very time intensive.[80,82]

The construction of an orbital implant supported ocular prosthesis is very similar to a conventional prosthesis. Implants are placed to aid in ideal positioning of the prosthesis, referencing a natural eye position, lid contour, and aesthetic details that mimic the contralateral eye.[77] Unfortunately, orbital implants often show poorer prognosis compared to implants for auricular and nasal prostheses. In patients who have received radiation, implants are successful only 33 - 58% of the time. This may be attributed to the lack of remodeling potential in the orbital rim, which has thin periosteum and is not ideal for implant osseointegration. Maintaining healthy peri-implant soft tissues has also proved to be difficult for patients with ocular prostheses. Between 55 - 88% of patients with auricular or nasal prostheses are free of peri-implant inflammation, compared to only 34% of

patients with an ocular prosthesis.[78]

Several types of attachment can be used between the implant and prosthesis, including magnets with a retentive bar or conventional abutments.[77,78] By using magnetic attachment, stress on the implant system may be reduced while still maintaining function. Conventional attachments are used for extremely large tissue defects but is avoided wherever possible for patient ease. If a new prosthesis is made in the future, the same implants can be used. The disadvantage of the magnetic implant supported prosthesis is the initially added laboratory time and cost. This, however, is reduced over time due to the ease of creating new prostheses, assuming the implants are successful.[77]

As technology continues to progress and strides are made in the world of 3D printing and the use of CAD/CAM systems, new options will be available to create these prostheses more rapidly at a lower cost. Additionally, a more precise duplication of the contralateral iris and eye characteristics can be achieved.[83] This becomes increasingly important as changes in the volume and shape of the socket with age may require re-fabrication of a previously well-fitting prosthesis.[84] Technology will allow new prostheses to be made more easily with a success rate that will demonstrate effectiveness in the survival of implants in the non-ideal orbital region.

FUTURE AIMS: TISSUE ENGINEERING

Artificial transplantation or transplanted organs is a fruitful treatment for incurable end-stage diseases or tissue misfortune. However, such interventions are limited by organ availability, quality of life issues with chronic immunosuppression, and its potential for serious complications. Tissue engineering has developed as a way to design and develop these anatomical parts and has become an integral part of regenerative medicine.[85-94] Tissue engineering is an interdisciplinary field that applies the principles and strategies of material science, bioengineering, and life sciences toward the assembly of biologic substitutes that will restore tissue form and function after damage by disease or traumatic processes.[95-97] The general principles of tissue engineering include merging living cells with a natural or synthetic scaffold that is likewise biodegradable to fabricate a 3D living construct that is structurally, functionally, and biomechanically equivalent to or superior to the tissue that is to be substituted.[98] The success of tissue engineering endeavors depends on an accurate selection of four key factors including scaffolds, growth factors, extracellular matrices and cells.[94,97,99]

Scaffolds are 3D tissue structures that guide the association, development and differentiation of the cells. Scaffolds should be biocompatible and outlined to meet both nutritional and biological requirements for the particular cell populace.[100] Growth factors are soluble peptides equipped for binding cellular receptors and creating either a permissive or inhibitory cellular response toward differentiation and/or proliferation of tissue.[101] ECM (Extracellular matrix) should be equipped for providing the ideal conditions for cell adhesion, growth, and differentiation inside the con-

struct by producing a system capable of controlling environmental factors such as temperature, pH, oxygen tension, and mechanical tensions.[102] These conditions are dictated by the particular cell lines and the characteristics of the scaffold.[102] Eventually, the fabrication of a practical construct contains an appropriate supply of cells that are ideally non-immunogenic, highly proliferative, and simple to harvest, and possess the ability to differentiate into an assortment of cell types with specific functions.[95,98,103] In cases where direct harvest is not attainable, as observed in numerous patients with broad end-stage organ failure or cells with restricted proliferative capacity in culture, stem cells are imagined as being an alternative source of cells.[100,104,105]

CONCLUSION

The evolution of craniofacial prostheses over the past few decades as clinicians has shifted focus from impression-based fabrication toward rapid prototyping maneuvers, in addition to the integration of implantology to enhance the physical retention of these artificial organs. Patient-specific, diagnostic assessment and intervention is becoming more and more effective with the rise in CAD/CAM technology to restore the native anatomy of craniofacial defects. Not only can prosthetic rehabilitation be perfected through these aims, but rapid prototyping can be utilized by bioengineers to reconstruct these soft tissues and restore their esthetics and function. This literature review summarizes the advancements in both surgical and prosthodontic modalities of treatment and the application of novel technologies, such as rapid prototyping and tissue bioengineering.

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