Prototyping for Surgical and Prosthetic Treatment

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Abstract: Techniques of rapid prototyping were introduced in the 1980s in the field of engineering for the fabrication of a solid model based on a computed file. After its introduction in the biomedical field, several applications were raised for the fabrication of models to ease surgical planning and simulation in implantology, neurosurgery, and orthopedics, as well as for the fabrication of maxillofacial prostheses. Hence, the literature has described the evolution of rapid prototyping technique in health care, which allowed easier technique, improved surgical results, and fabrication of maxillofacial prostheses. Accordingly, a literature review on MEDLINE (PubMed) database was conducted using the keywords *rapid prototyping*, *surgical planning*, and *maxillofacial prostheses* and based on articles published from 1981 to 2010. After reading the titles and abstracts of the articles, 50 studies were selected owing to their correlations with the aim of the current study. Several studies show that the prototypes have been used in different dental-medical areas such as maxillofacial and craniofacial surgery; implantology; neurosurgery; orthopedics; scaffolds of ceramic, polymeric, and metallic materials; and fabrication of personalized maxillofacial prostheses. Therefore, prototyping has been an indispensable tool in several studies and helpful for surgical planning and fabrication of prostheses and implants.

Key Words: Rapid prototyping, surgical planning, maxillofacial prosthetics

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Since the discovery of x-rays, diagnostic imaging methods have been developed over the years. After the introduction of computed tomography (CT) and magnetic resonance imaging, new possibilities of diagnostic and prosthetic-surgical planning appeared because these images can be observed in different slices and can even be reconstructed three-dimensionally. After this technological evolution, the rapid prototyping (RP) techniques were introduced in the 1980s in the field of engineering for the fabrication of a solid model based on a computed file.[1,2]

Rapid prototyping is an expression that represents a set of additive technologies based on the construction of physical three-dimensional structures, layer by layer, based on its respective digital models. Firstly, the digital model is sliced, and its transversal sections are physically reproduced through automated processes of layer-by-layer construction in raw materials such as powder, solid, or liquid. The RP technologies allow fabrication of these three-dimensional physical structures, known as rapid prototypes, without amendments, with complex geometries, and containing mobile parts that are difficult or even impossible to be obtained by other construction techniques.[3,4] In addition, this technique allows visualization and testing of objects before definitive fabrication, which reduces costs, and it is essential in the modern market.[5]

After its introduction in the biomedical area, several applications were suggested, mainly for the fabrication of models to ease surgical planning and simulation,[1,2,6,7] in implantology,[8] neurosurgery,[9–11] orthopedics,[12] as well as in maxillofacial prostheses.[9,13–17]

Fabrication of the solid replica of a patient's anatomy simplifies the surgical and prosthetic procedures. The models support diagnostic, surgical planning and simulation, fabrication of personalized implants, fabrication of maxillofacial prostheses, and communication between professional and patient to improve comprehension, enhance adequate information about the case, and reduce the surgical period by 20%.[18–20]

Hence, a literature review was conducted to describe the evolution of the RP technique in health care to ease the technique and improve surgical results and fabrication of maxillofacial prostheses.

MATERIALS AND METHODS

A literature review was conducted on MEDLINE (PubMed) database using the keywords *rapid prototyping*, *surgical planning*, and *maxillofacial prostheses* and based on articles published from 1981 to 2010. After reading the titles and abstracts of the articles, 50 studies were selected because of their the correlations with the aim of the current study.

Literature Review

Kodama,[21] from the Nagoya Industrial Research Institute, was the first author who published reports about RP, which was defined as a technology that allows fabrication of models and prototypes based on the three-dimensional model obtained by CAD system, digitalization, or CT.

Petzold et al[22] stated that a physical prototype (model) can be fabricated by both subtractive and additive approaches in industry and/or medicine. The subtractive technique is usually conducted by conventional machining such as milling. The model data for this method are acquired by digitalization or scanning through a probe of surface contact that can capture data of external anatomy instead of

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the internal structure of the object. Therefore, this technique is used for the fabrication of small models such as metallic and/or ceramic crowns in dentistry.

However, according to Weiss[23] and Wohlers,[4] the additive technologies can randomly produce complex shapes such as cavities usually present in human anatomy. Use of this method has demonstrated a significant reduction in production time. In addition, complex models that are difficult and/or impossible to be fabricated by conventional machining can be easily obtained. According to the authors, the main advantage of this method for dental-medical pieces is its ability to reproduce small details such as slices, empty spaces, and internal complex geometries (neurovascular canals or sinus, etc) in the model.

According to Wohlers,[4] the RP has allowed several advances in the dental-medical area, mainly in surgical planning, which improve procedures carried out by the surgeon owing to the better comprehension and visualization of the anatomy in complex pathologies of bone or vascular structures. Furthermore, the dental-medical area represents the third largest group of RP applications.

For Seitz,[24] the prototypes can be replicas of bone or soft tissues such as skin, vascular system, and nasal passage. They can be used for surgery planning and simulation, improved diagnostic quality, fabrication of implants and prostheses, information about the surgery to the patient, and orientation during surgical procedure. Handling of this model allows evaluation of each individual's anatomy.

Many studies showed that the prototypes have been used for different applications in the dental-medical area such as maxillofacial and craniofacial[3] surgery[25,26]; implantology[8]; neurosurgery[9–11]; orthopedics[12]; scaffolds of ceramic, polymeric, and metallic materials; and also fabrication of personalized maxillofacial prostheses.[4,13–17] Prototyping has been an indispensable tool in several studies as described in Table 1.

According to D'Urso et al,[9] prototyping allows reconstruction of the cranium for the correction of bone failures (cranioplasty), evidencing the real proportions of failures and allowing fabrication of restorative prostheses with different materials such as methyl methacrylate, titanium (meshes), or hydroxyapatite. The advantages of this method for cranioplasty are reduced surgical time and easier technique that results in reduced infection rate and better aesthetics.

Nakajima et al[42] reported the use of the three-dimensional model in the cerebrovascular region for the reconstruction of magnetic resonance images to plan the surgery of 16 patients with different anomalies to determine the advantages and limitations of this computer-assisted system of surgical planning for the treatment of vascular lesions.

Clinkenbeard et al[43] used the RP technique to manufacture details of a model of a tree with tracheobronchial structure. The aim of the study was to demonstrate that manufacturing respiratory structures by RP could generate a proper standard of model for studies of respiratory ways. Adaptations of these models for representations may promote pharmaceutical research to develop drugs that can be inhaled by aerosol.

Beer et al[44] described the application of RP associated with the treatment of skin cancer. The aim of the study was based on a process using three-dimensional photography, RP, and metal spray to fabricate a shield for the protection of the healthy tissue during radiotherapy.

According to Ulbrich et al,[45] there are 5 general applications of RP in health that require different materials and technologies of RP. These application are (1) biomodels in polymer or stone for surgical planning and training; (2) guides in polymer for perforation of bone; (3) scaffolds of metals, ceramics, polymers or biocompatible composites; (4) dense implants that can be fabricated in metal, composite, polymer or ceramic; and (5) fabrication of prostheses.

TABLE 1. Applications of the Prototyping Method

Author	Year	Prototyping Type	Purpose
Winder et al[27]	1999	Medical RP (MRP)	Surgical guide for titanium implants
Coward et al[28]	1999	Stereolithography	Auricular prosthesis
Ng et al[29]	2002	Stereolithography	Prosthetic sockets
Tay et al[30]	2002	CAD/CAM	Socket for orthopedic prosthesis
Sykes et al[13]	2004	Rapid prototyping technique	Maxillofacial prostheses
Tsuji et al[31]	2004	CAD/CAM	Maxillofacial prosthesis
Jiao et al[15]	2004	CAD/CAM	Auricular prosthesis
Gibson et al[12]	2005	Different techniques of RP	Oral and maxillofacial surgeries, orthopedic applications and forensic thanatology
Campbell et al[32]	2005	Systems of RP	Review about RP in South America
Al Mardini et al[33]	2005	CAD/CAM associated to image mirror	Auricular prosthesis
Winder et al[5]	2005	Medical RP (MRP)	Guided surgeries
Lal et al[34]	2006	Stereolithography	Surgical guide for implants
Ciocca and Scotti[35]	2004	CAD/CAM associated to laser scanning	Auricular prosthesis
Ciocca et al[36]	2007	CAD/CAM virtual construction	Auricular prosthesis
Turgut et al[37]	2006	Stereolithography	Auricular prostheses
Wu et al[17]	2007	Stereolithography	Facial prostheses
Robiony et al[38]	2008	Stereolithography	Surgical guide
Karayazgan-Saracoglu et al[14]	2009	CAD/CAM	Auricular prosthesis
Azari et al[39]	2009	CAD/CAM	Literature review on dentistry
Cohen et al[40]	2009	3-dimensional stereolithography	Mandibular reconstruction
Tang et al[41]	2010	Rapid prototyping	Reconstruction of ocular orbit

The fabrication of a maxillofacial prosthesis similar to the area adjacent to the defect and with adequate fit was a challenge to the maxillofacial professional.[46] However, the introduction of the RP reduced the time and improved the accuracy and quality for fabrication of maxillofacial prostheses. Prototyping has been largely used for fabrication of maxillofacial prostheses to obtain three-dimensional anatomic models.[13]

For Jiao et al,[15] fabrication of auricular prostheses by CAD/CAM are advantageous because a highly qualified technician is not necessary to sculpt an ear in wax. The procedure is carried out in a computer, and the patient can visualize the result at the screen before fabrication.

Truscott et al[16] present the use of RP for an implant in the patient's arm. In this study, the authors demonstrated that the visual representation of bone structures could be ready within 24 and 48 hours after receiving the data from CT for less complex cases. After approval of the images by the surgeon, a model of RP can be available within 24 hours. This model of RP can be used for interaction with the surgeon to project the implant.

Wu et al[17] described the fabrication of a nasal prosthesis by prototyping (SLS). According to the authors, this method is advantageous for both patient and the maxillofacial prosthetist. In addition, the laboratorial period for sculpting was significantly reduced because the nasal waxing was automatically fabricated by the machine. Besides, the accuracy of the computed model allows satisfactory reproduction of the facial contours. However, this process is still expensive owing to the cost of the equipments.

Karayazgan-Saracoglu et al,[14] reported that several techniques have been used for waxing of auricular prostheses that are clinically refined. However, most of the techniques are difficult, lengthy and require high level of artistic ability. According to the authors, although the auricular prosthesis sculpted by hand is considered satisfactory, it is inferior in comparison to the prosthesis obtained by prototyping.

DISCUSSION

Prototyping is a widely used method reported in the worldwide literature since the last decade. This technique has been used in medical and dental areas for surgical planning and prosthesis fabrication.[8–14,25,26] After obtaining an image of the cranium in helical CT with thin slices (1 mm) and three-dimensional reconstructions, techniques of mirroring and interpolation of images are used to project the model in real dimensions. There are several types of prototyping for creation of biomodels (replication of the morphology of a biologic structure in solid substance). Methods of RP were developed based on the acquisition of reconstructed images and using laser that solidifies a liquid polymer or photo-sensible resin to obtain the object. Then, an accurate replica of the cranium is produced as well as an ideal implant based on the bone failure with different synthetic materials (titanium mesh, methyl methacrylate, hydroxyapatite, and others). The fabrication of the prosthesis can result from models determined by graphic software or manual techniques based on a prototyped cranium.[8–14,25,26]

The RP generates a piece based on the gradual union of liquids, powders, or sheets instead of the machining processes that subtract material of the original piece to obtain the subject. The RP machines produce pieces in plastic, wood, ceramic or metals, layer-by-layer, according to transversal sections of the piece obtained from a three-dimensional model.[3–5]

The advantages reported in the studies are reduced surgical period (from 16% to 41%[1–3]), planning and review of the surgical procedure previously to the surgery, accurate fabrication of prostheses, and didactical method for anatomy teaching. Besides, this technique allows better understanding for the patient about its pathology and the procedure to be conducted.[14,17,39]

There are 4 purposes for the three-dimensional model used for surgical planning: (1) selection of the appropriate intervention (observation, surgical embolization, surgery, or radiosurgery), (2) evaluation of the operative risk in surgical cases, (3) visualization of the relations between the pathology and the normal state as well as selection of noninvasive surgery and postoperative period, and (4) localization of intraoperative lesions with video images. The models were also used to improve training of the professionals.[42]

In general, the models in dentistry are obtained after impression when some material dissolves into the mouth after a period. All dental professionals state that impression, or negative image of the teeth and adjacent structures, is necessary to obtain a model that can be used to fabricate a restoration in the laboratory. For more than 1 century, this technique has been taught in the dentistry schools as a cheap and easy technique. However, this technology requires manual skill, which means that the dental technicians should be able to work with the models obtained after impression.[39] On the other hand, there are many studies reporting inaccuracies and failures of casting[47–49] that can be overcome with the development of techniques of computed image and prototyping for prostheses fabrication.[39]

Although the RP is fast and efficient, it is more expensive than the conventional method. However, if the patient's trauma, production cost (hours/professionals), abilities, specialized storage, and waste of material are considered, the costs of RP are a minor factor. The high level of accuracy and speed of the process of three-dimensional photography eliminate previous problems as inaccuracy. In addition, this technique allowed the fabrication of maxillofacial prostheses with higher precision and quality in a shorter period.[3,8–14,25,26]

CONCLUSIONS

After the evolution of diagnostic imaging methods, the RP techniques were introduced to fabricate models and prototypes based on the three-dimensional model (model obtained by a CAD system through digitalization or CT). This technique has been helpful for surgical planning and fabrication of prostheses and implants. In addition, it has been used for surgery planning and simulation, improvement of diagnostic quality, fabrication of implants, information about the surgery to the patient, orientation during surgery, and fabrication of maxillofacial prostheses with higher precision and quality in a shorter period.

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