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The Application of Rapid Prototyping in Prosthodontics

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Abstract

Dentists have used rapid prototyping (RP) techniques in the fields of oral maxillofacial surgery simulation and implantology. With new research emerging for molding materials and the forming process of RP techniques, this method is becoming more attractive in dental prosthesis fabrication; however, few researchers have published material on the RP technology of prosthesis pattern fabrication. This article reviews and discusses the application of RP techniques for prosthodontics including: (1) fabrication of wax pattern for the dental prosthesis, (2) dental (facial) prosthesis mold (shell) fabrication, (3) dental metal prosthesis fabrication, and (4) zirconia prosthesis fabrication. Many people could benefit from this new technology through various forms of dental prosthesis production. Traditional prosthodontic practices could also be changed by RP techniques in the near future.

Rapid prototyping (RP) techniques, also termed solid freeform fabrication (SFF) or layered manufacturing, have been employed to build complex 3D models in medicine since the 1990s.[1–4] The main advantage of RP techniques is that medical models can be created to have undercuts, voids, and complex internal geometries such as neurovascular canals or sinuses.[5] The RP model is now used mainly for an improved, cost-effective medical diagnosis and accurate surgical planning, which shortens the operation time and significantly reduces risk to the patient.[6,7]

In recent years, RP technique research progressed rapidly in the molding material and the forming process. This technology is no longer used exclusively for prototyping, but can be used to manufacture real functional parts. Therefore, RP is becoming more attractive in dental applications. RP techniques can also be used to design, develop, and manufacture dental prostheses such as copings, crowns, and fixed partial dentures (FPDs). Traditionally, dental prosthesis fabrication involves much labor-intensive and time-consuming hands-on work by dentists and technicians. Dental prosthesis fabrication has also been greatly dependent on the skills of dentists and technicians. Compared to traditional methods, new dental prosthesis work can be fabricated by RP techniques layer by layer directly from a computer model without part-specific tooling and human intervention. The labor cost will be substantially reduced, and better and faster dental restorations will be achieved. RP techniques are now regarded as a promising alternative for dental prosthesis production.

Many researchers have focused on data acquisition by using different 3D scanning devices and using computer-aided design (CAD) elaboration for the design of the prosthesis; however, publications regarding RP technology on prosthesis pattern fabrication are still rare. In this article, we review the applications of RP techniques in prosthodontics. We particularly focus on the fabrication of the wax pattern of the prosthesis, all-ceramic crowns, metal prostheses (including FPDs and framework for removal partial dentures [RPDs]), and casts for prostheses.

Dental prosthesis wax pattern fabrication

Traditionally, the fabrication of the wax pattern is the most critical and labor-intensive step in making the porcelain-fused-to-metal crown, pressed ceramic crown, and RPD framework. In this time-consuming task, the wax-up's quality is dependent on the skilled labor of the individual.

With the advent and popularity of RP technology, a new approach is possible for automatic wax-up fabrication. This approach simplifies the traditional fabrication process and accelerates the production turnaround period by using 3D imaging, CAD, and RP.[8–10] The new process involves the following three steps: (1) digitizing the master models with a 3D optical scanner (the full arch and opposing dentition digitization can be performed); (2) designing the wax pattern with the specialized CAD software, and (3) fabricating the wax-up with RP techniques, such as fused deposition modeling and 3D printing (3DP). RP application has four advantages. The first advantage is a high production rate. With RP techniques, the dental laboratory can easily reach a production rate of over 150 units per hour. The second advantage is the quality control of wax copings, which results in a high precision fit and constant wall thickness. The third advantage is a reduced spruing time. The final advantage is the reduced finishing work needed on cast copings. The irregularities in wax coping thickness can be avoided, as they usually create extra work for finishing the metal after the cast.[11,12]

The digital dental wax-up making systems (in this report) were produced by their manufacturers. The WaxPro system (Cynovad, Montreal, Canada) includes a rapid 3D scanner and a powerful design station to provide a computer-aided design/computer aided manufacture (CAD/CAM) for fabricating the dental wax-ups with high speed, mass production, and industrial quality. By using WaxPro, only the following two steps are needed: (1) simultaneous scanning and design with Cynovad's Pro 50 and (2) fabricating the wax-ups with 3DP.

After the wax pattern is fabricated by RP, the traditional lost-wax process is still needed. The process is more affordable than laser melting or sintering direct manufacturing processes, which still remain out of the financial reach of most dental laboratories.

Rapid prototyping of dental (facial) prosthesis mold (shell)

Mold (shell) for metal casting

Compared to conventional methods of casting production (including the construction of tooling and the pouring of a casting), ceramic molds can be produced for metal parts directly by CAD models. These molds are created on a computer screen by using RP techniques. Three-dimensional printing, such as the direct shell production casting process, produces ceramic casting molds for metal casting using a layer-by-layer printing process.[13–15] The process involves a multijet printhead depositing liquid binder onto a layer of ceramic powder. After a mold is "printed," it is fired to create a rigid ceramic mold. This mold (shell) can then be poured in molten metal, producing a functional metal cast part. Curodeau et al used 3DP to produce ceramic molds with embedded surface macrotextures and to cast functional orthopedic implants out of high-resistance cobalt-chrome alloy.[16] RP techniques eliminate most of the labor-intensive and time-consuming steps of the traditional investment casting process. They also bypass the need for design and manufacturing of wax and core tooling, wax and core molding, wax assembly, shell dipping and drying, and wax removal.

Mold for facial prosthesis

Over the past decade, RP techniques have been applied successfully to the fabrication of a facial prosthesis.[17–19] Pattern fabrication via RP has been effective; however, conventional flasking and investing procedures were still needed to make the actual prosthesis. An innovative design and production method (of the negative mold of the facial prosthesis) for casting the actual prosthesis with silicon directly (by using CAD and RP techniques) has been proposed. Instead of fabricating a positive RP pattern of the prosthesis (after the design and fitting stages), the prosthesis computer model is referenced to generate a CAD model of a mold. The mold's cavity then forms the negative profile of the actual prosthesis. The fabricated mold is used to cast the actual prosthesis in polyurethane, medical-grade elastomer, or silastic materials. The use of the mold eliminates conventional flasking and investment procedures, and shortens the prosthesis-making process.[20] In addition, the generated resin mold can be preserved, because the mold is durable and permits multiple pourings. The preservation of the mold is an important step because the silicon prosthesis usually requires a replacement every 2 years (due to discoloration or deterioration of the silicone elastomer). This direct mold production (via RP fabrication) has already been introduced in a clinic. Qiu et al reported that a patient with a total rhinectomy was scheduled for a nasal prosthesis. Based on the 3D model of the patient's face (reconstructed with the CT data), a four-piece mold for the nasal prosthesis was prototyped using a CAD and RP procedure. Conventional silicone was processed with this physical mold to fabricate the definitive nasal prosthesis.[21] Ciocca et al made a negative volume (of a designed .STL file) of the external ear and transformed this pattern into a new STL file for the mold design. Three-dimensional printing was then used to fabricate the mold for the actual prosthesis with silicon.[22]

Mold for complete denture

We found only ten publications (written within the last 20 years) on the field of designing and fabricating a complete denture with a computer. The lack of research articles reveals that advanced manufacturing technology has not been successfully applied in this field.[23–25] Researchers at Peking University developed a novel CAD and RP system to make individualized flasks (molds) for a complete denture. The process includes establishing a 3D graphic database of artificial teeth for parameterization positioning, getting 3D data of edentulous models and rims in centric relation, exploring a CAD route and developing software for complete dentures, fabricating physical flasks (molds) by 3DP, and finishing the complete denture using a traditional laboratory procedure.[26] Although the system is still in its experimental set-up phase, five complete dentures have been successfully designed and fabricated by this system. On the edentulous plaster models, the dentures were in centric balanced occlusion with a good fit. As a next step, laboratory quantitative tests and clinical experiments should be conducted to improve the system.

Direct dental metal prosthesis fabrication

Metal prostheses are often used in a dental prosthetic clinic. The lost-wax casting method is the traditional way to fabricate a metal prosthesis. This method is a lengthy and labor-intensive process that comprises many manual steps such as fabricating, embedding and burning out the wax pattern, metal casting, and postprocessing. With the introduction of a CAD/CAM milling system, a metal prosthesis can be fabricated by milling (according to the CAD design); however, this milling process is also time consuming, and the milling tools are exposed to heavy abrasion. Moreover, most of the material is wasted, and spatial restrictions limit the production of complex shapes such as the framework for the RPD.[27,28]

Recently, RP technology, especially selective laser melting (SLM) and selective laser sintering (SLS) technology, has attracted great attention among researchers for its brisk fabrication of high-precision metal parts with different materials and shapes.[29] SLS/SLM are layer-wise, material-addition techniques that allow generation of complex 3D parts by selectively consolidating successive layers of powder material on top of each other, using thermal energy supplied by a focused and computer-controlled laser beam. In addition, the remaining unprocessed powder can be reused. Dental prostheses are very suitable for processing by means of SLS/SLM due to their complex geometry and their ability to be customized without lengthy manual pre- or postprocessing.

This new proposed CAD/RP procedure consists of three main steps: the digital geometry captures and processes the dental cast; the shape of the components for the dental frameworks are modeled digitally; and the framework is produced through a computer by means of SLS/SLM.[30] A CAD/RP (SLM) process for RPD metal framework fabrication has been performed at Peking University. This process simplifies the traditional framework fabrication process and accelerates the production turnaround period (1.5 hours) by using 3D imaging, CAD, and RP. In this process, specifically developed CAD packages are employed to construct the framework, and an SLM system is used to fabricate the designed metal RPD framework.[31] Although optimization research of the processing parameters and clinical applications are still necessary, this proposed CAD/RP procedure provides an efficient and fast method to digitally design and manufacture biocompatible metal frameworks for complex dental prostheses.

All-ceramic restoration fabrication

Since the 1980s, research and development of dental CAD/CAM milling systems has been actively pursued worldwide.[32] Recently, commercial dental CAD/CAM milling systems have been successfully introduced for specific fields such as all-ceramic restorations. These milling systems enabled zirconia ceramics to be used as a standard material for dental prosthetic restorations; however, the disadvantage of this system is the considerable amount of raw material waste, because the unused portions of the monoblocks must be discarded after milling, and recycling of the excess ceramic material is not feasible. The milling tools are also exposed to heavy abrasion and therefore withstand only short running cycles. Moreover, microscopic cracks can be introduced into the ceramic surface due to the tooling process of this brittle material.[33]

RP techniques, so-called generative manufacturing techniques, exhibit the potential to overcome the described deficiencies.[34–37] A direct inkjet fabrication procedure (for the fabrication of the green-zirconia all-ceramic dental restoration via a slurry microextrusion process) has been proposed.[34] After fabrication of the green restoration, the definitive restoration is obtained by a sintering or laser-assisted densification process. This novel technique is a promising CAD/RP system with great potential to produce all-ceramic dental restorations with high accuracy, cost efficiency, and a minimum of material consumption. This technique is still in the experimental stage.

The direct inkjet system allows for the printing of a suspension with a high solid content of zirconia powder and drop-on-demand inkjet printheads. The ideal pseudoplastic and extrusion behavior of zirconia powder slurries are controlled by the solids loading, pH value, and drying speed of the slurries after delivery. This control permits the slurry to be extruded at low extrusion pressure and have good shape-keeping ability. The dimensional accuracy of the restoration is also affected by the extrusion parameters such as the nozzle size, extrusion rate, nozzle traveling speed, and distance between the nozzle head and the substrate or the previously delivered layer.[38–41]

After the slurry extrusion, a green part of the dental restoration needs to be sintered in the furnace at a temperature of 900°C to 950°C for 5 to 8 minutes. After sintering, the crown must have shrinkage, about 25% in width and about 27% in height. The microstructure of the sintered restoration is identical to that made via the traditional dental restoration process. Another novel laser-assisted densification process for fabricating dental zirconia restorations was developed at the University of Connecticut. These dental zirconia restorations are produced by a slurry extrusion, followed by laser densification of the extruded slurries. A tailored direct inkjet printing process was developed by Ebert et al.[33] This process allows for the printing of a suspension with a high solid content of zirconia powder. The process also allows the use of direct inkjet printing technology with conventional drop-on-demand inkjet printheads, to build up dental prosthetic restorations (made of high-strength zirconia ceramics).[33] However, the CAD/RP system for fabrication of dental all-ceramic restorations is still in its experimental stage. The specific zirconia powder slurries with suitable rheological behavior and extrusion conditions, as well as optimization of the drying process and a tailored multiple-stage sintering process, have yet to be investigated and developed.

Conclusion

RP techniques have been substantially employed in dentistry, but applications of RP in prosthodontics are relatively rare. This article discussed the applications of RP techniques in prosthodontics. Dental prostheses can be fabricated layer by layer directly from a computer model easily and rapidly by various RP techniques without part-specific tooling and human intervention. This technique is a revolutionary change for dental prosthesis fabrication. With the development and research of the diversity for RP systems and correspondingly built materials, it is possible to generate different kinds of dental prostheses for different applications. These applications include dental prosthesis wax pattern, dental (facial) prosthesis mold (shell), dental metal prosthesis, and ziconia prostheses. We believe that RP techniques are playing a more important role in prosthodontics and will become one of the mainstream technologies for digital fabrication of dental prostheses.

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