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Review Article

Rapid Prototyping Technologies in Prosthetic Dentistry

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Abstract

Background: Recently, rapid prototyping technology is the future of quick and direct production. This technology found applications with metal framework of fixed partial dentures, framework of removable partial dentures, facial prostheses and titanium implants in prosthetic dentistry. Laser beam sintered the selected areas on the alloy powders and the restoration is produced layer by layer at single stage.

Purpose: This literatures compared the internal fit, accuracy, bond strength, marginal adaptations, connection between the veneer porcelain, fracture strength marginal and internal gaps of laser-sintered dental prosthesis with conventional casting techniques.

Materials and Methods: PubMed and Google scholar electronic database search from 2007 to January 2017 was reviewed. 103 studies were first reviewed by abstract and subsequently by full-text reading.

Results: The literature discuss the advantages and disadvantages of laser sintering method from different aspects. They found that internal fit, marginal adaptations, Accuracy of laser-sintered metal restoration are better than that obtained with the traditional casting techniques. In another hand, no difference was observed in the study of internal adaptations, connection between the veneer porcelain, internal gap and porcelain surface treatments between laser sintered and conventional casted metal restoration. Immediate implant loading could be achieved in a reasonable operative time.

Conclusions: Laser sintering seems to be an alternative technique to conventional casting of dental alloys. Complex shapes from metal alloys can easily be produced with these devices. These systems can be helpful to obtained fixed restorations, facial prostheses, titanium implants, surgical models and stents. The new laser-sintering technique appears promising for dental application, but additional studies of properties of laser sintered.

Keywords: *Rapid Prototyping; Prosthetic Dentistry; Laser Sintered*

Introduction

Currently, there is much research activity on the development of alternative processes that utilize modern technology to fabricate dental restorations more quickly at lower cost. This technology found applications with metal of fixed dentures, framework of removable partial dentures, facial prosthesis and titanium implants in prosthetic dentistry.

By using different rapid prototyping (RP) technologies, final net shape metallic parts can be fabricated. It is a one-step process in which tooling is eliminated thereby reducing production time and cost. The process is suitable for low volume production of materials difficult to process and for fabrication of complex parts of high aggregate value for the automotive and aerospace industries [1].

Laser sintering is a promising new technology which may replace casting of the base metal alloys. An additive manufacturing layer technology, selective laser sintering (SLS) involves the use of a high power laser (for example, a carbon dioxide laser) to fuse small particles of plastic, metal, ceramic, or glass powders into a mass that has a desired three-dimensional shape. The laser selectively fuses powdered material by scanning cross-sections generated from a 3-D digital description of the part (for example from a CAD file or scan data) on the surface of a powder bed. After each cross-section is scanned, the powder bed is lowered by one layer thickness, a new layer of material is applied on top, and the process is repeated until the part is completed [2,3].

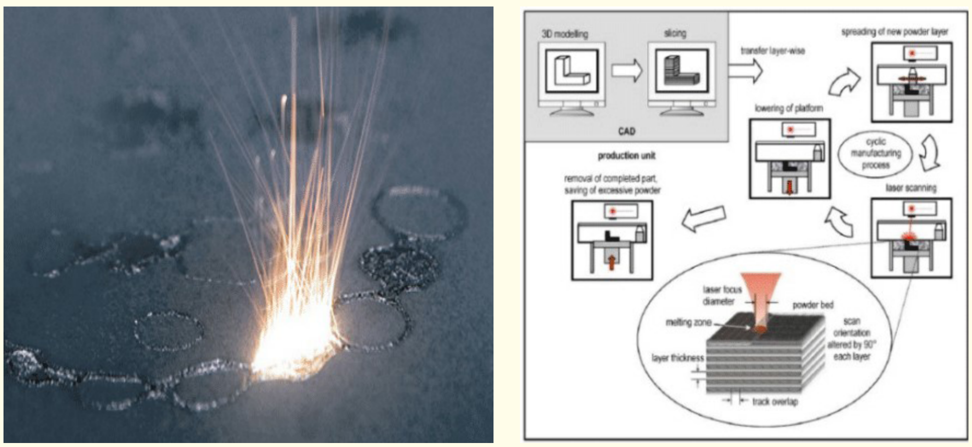

Figure 1: *An EOSINT DMLS system laser-sintering cobalt-chrome dental copings and bridges in a batch. Each bridge can be a different custom design, based on dental data from an individual patient (Courtesy EOS) [4].*

The SLS machine preheats the bulk powder material in the powder bed somewhat below its melting point, to make it easier for the laser to raise the temperature of the selected regions the rest of the way to the melting point. Compared with other methods of additive manufacturing, SLS can produce parts from a relatively wide range of commercially available powder materials. These include polymers such as nylon (neat, glass-filled, or with other fillers) or polystyrene, metals including steel, titanium, alloy mixtures, and composites and green sand. The physical process can be full melting, partial melting, or liquid phase sintering. Depending on the material, up to 100% density can be achieved with material properties comparable to those from conventional manufacturing methods.

The performance of SLS processing depends on several parameters which include the dimension of the laser beam at the focus, the power rating of the laser, scanning speed, the average particle size of the basic powder, layer thickness, track overlap and process atmospheric conditions [4,5].

Cobalt-chromium (Co-Cr) alloys have been widely used in dentistry for removable partial dentures, metal frames, and porcelain-fused-to-metal crowns, mainly because alloys are strong, resistant to corrosion, and relatively inexpensive, when compared to gold alloys and some all-ceramic materials.

Recent research has shown that different melting and casting techniques used in the dental laboratory with Ni-Cr and Co-Cr alloys significantly influenced the ultimate tensile strength and percentage elongation, and it was emphasized that the dental laboratory should select the appropriate casting protocol for each alloy composition [6].

The laser-sintered Co-Cr alloy had a fine-grained microstructure, and there was some difficulty in revealing full details by electrolytic etching, whereas the cast Ni-Cr alloy had a well-defined dendritic microstructure. The laser-sintered Co-Co alloy coping had intimate interfacial attachment to dental porcelain and more biocompatible than the Ni-Cr alloys because some patients have nickel allergy. Other advantages of the Ni-Cr and Co-Cr base metal dental casting alloys are their high strength and high modulus of elasticity.

Once the dental cast was scanned, virtual surveying and design of the framework on a 3-dimensional computer model was accomplished. A rapid prototype machine was used for direct fabrication of the alloy framework. The successful application of CAD/CAM/RP technologies for the fabrication of removable partial denture (RPD) alloy frameworks and easy production of objects with complicated shapes from metal alloys has been confirmed [7,8].

Compared to the cast structure the removable partial dentures produced with the aid of computers have a higher strength than a conventional model cast and both the fatigue resistances as well as the risk of a clamp breakage are lower [9,10].

Figure 2: *Stages of production for a laser sintered removable partial denture: Dental prosthesis directly after manufacturing, with support structures removed and surface polished, after completion (left to right-Image courtesy of EOS GmbH) [4].*

The comparison of the internal adaptations of base metal alloys produced by conventional casting and laser sintering did not reveal any significant difference between the two methods and indicated that laser sintering is a reliable method for clinical applications [12].

In order to have clinical longevity, metal-ceramic prostheses must have an acceptable fit to the prepared tooth structure. Recent studies have shown that laser-sintered Co-Cr crown specimens have satisfactory internal fit on dies and that metal-ceramic bonding of dental porcelain to air-abraded disc specimens of the laser-sintered Co-Cr alloy was not significantly different from that to similar cast specimens of the Co-Cr alloy [13].

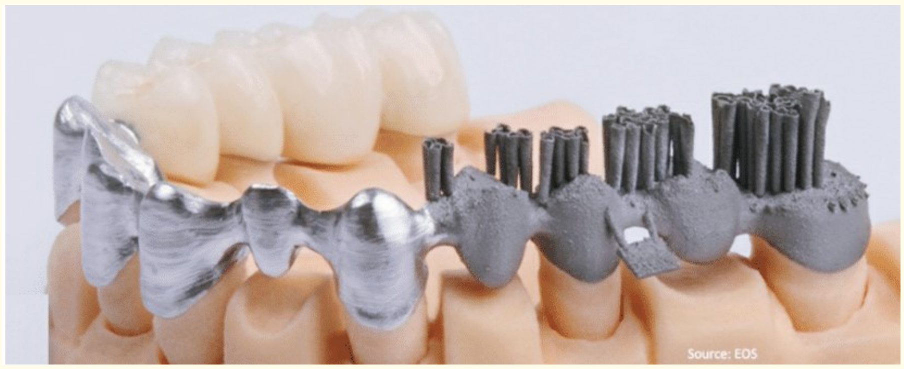

Figure 3: *Image shows the progression from 3D Printed framework, to polished part, and then finally veneered finished product. Note the rectangular tracking tag that holds the serial number identifying each part [4].*

Direct metal laser sintering (DMLS) is an additive manufacturing metal fabrication technology, occasionally referred to as selective laser sintering (SLS) or selective laser melting (SLM), that generates metal prototypes and tools directly from computer aided design (CAD) data. DMLS uses a variety of alloys, allowing prototypes to be functional hardware made out of the same material as production components. Since the components are built layer by layer, it is possible to design organic geometries, internal features and challenging passages that could not be cast or otherwise machined. DMLS produces strong, durable metal parts that work well as both functional prototypes or end-use production parts [14-16].

In this system where production up to fourteen base metal units can be made in one unit, a total of 90 units of base metal alloys can be fabricated in one step, There is less need for post-production modification compared to casting, and consequently greater profits are achieved [7-17].

To evaluate and compare the marginal and internal fit of Co-Cr, *in vitro* a total of 32 three-unit Co-Cr FDPs were fabricated with four different production techniques: conventional lost wax method (LW), milled wax with lost-wax method (MW), milled Co-Cr (MC), and direct laser metal sintering (DLMS). Best fit was found in the DLMS group followed by MW, LW and MC. In all four groups, best fit in both abutments was along the axial walls and in the deepest part of the chamfer preparation. The greatest misfit was present occlusally in all specimens [18]. Biomaterials used in dentistry as implantable devices in bone must possess adequate mechanical and physicochemical properties to achieve a high degree of biocompatibility and biofunctionality.

Currently oral implants are manufactured from commercially pure titanium or Ti–6Al–4V (90% titanium, 6% aluminum, 4% vanadium) alloy. Although alloys have superior physical and mechanical properties, commercially pure titanium is universally considered the material of choice in implant dentistry, because of its exceptionally good corrosion resistance and biocompatibility.

Until recently implants were produced by machining titanium rods, followed, by most manufacturers, by modification of the titanium surfaces, by applying different surface treatments or coatings to improve stability and enhance osseointegration. In the last few years the development of direct laser metal sintering (DLMS) processes have substantially broadened the field of application of titanium alloys and allowed implants to be produced more economically than by traditional techniques. Among the several direct metal forming techniques, selective laser sintering offers great potential benefits in the field of the biomaterials, especially in implant dentistry, due to its capability to directly build three-dimensional (3D) metallic components from metal powder with minimal or no post-processing requirements [19,20].

The DLMS procedure is a revolutionary technique to build titanium dental implants starting from a virtual 3D model. The results of the mechanical tests indicate that SLS resulted in a functionally graded material with a compact sintered titanium core with a modulus similar to that of machined titanium while the modulus of the porous titanium present on the implant surface was reduced and more "similar" to that of bone. laser metal sintering proved to be an efficient means of construction of dental implants with a functionally graded material which is better adapted to the elastic properties of the bone. Such implants should minimize stress shielding effects and improve long-term performance [16,21].

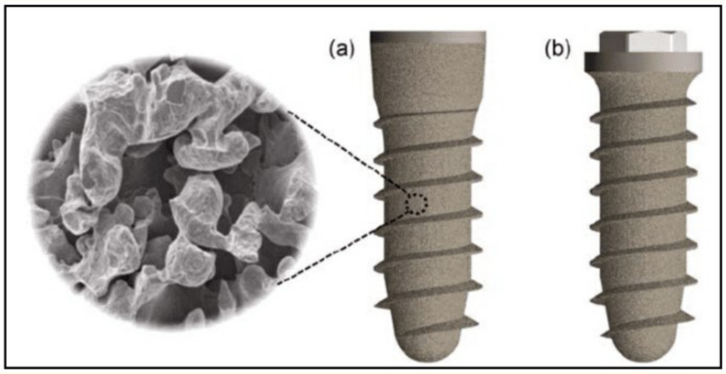

Figure 4: *Porous titanium dental implant screw, branded as TiXos, with excellent osseointegration characteristics produced by the direct metal laser sintering technique. The implants are supplied with (a) internal hex and (b) external hex, featuring a highly porous surface with interconnected pores [11].*

One of the biggest challenges in implantology is the pre-surgery determination of the optimum location, angulation and depth to place an implant. Dental surgical guides are designed to help dentists surgeon make those decisions. Creating a dental surgical drill guide using a traditional fabrication method usually high costs and takes a few days. Using 3D printing to create 3D printed surgical guides can bring those numbers down and only a few hours.

For complicated cases, surgeons dentists can 3D print several different surgical guides models so they can have options during the surgery. There are several types of 3D printed surgical guides: non-limiting, partially restricting or completely limiting surgical guides [22,23,26].

In the study on surface properties, microstructure, composition, mechanical properties and fragility of titanium alloy implants produced with SLS, Implants produced in this way exhibit Early bone response and better adaptation to the elastic properties of the bone tissue [19,20].

In a study the shear bond strengths of base metal obtained by laser sintering to dental porcelain, it was stated that this new technique is suitable for substructure production; But studies on the physical and chemical properties of the obtained products should be continued [2].

Because of the different coefficients of thermal expansion between the veneering ceramic and alloy coping, the ceramic firing might affect the marginal fit. An excellent marginal adaptation will minimize the plaque accumulation and reduce the chance for recurrent caries and periodontal disease. Quante K, Ludwig K, Kern M made a *vivo* investigation and they found that Crowns fabricated with laser melting technology have a clinical fit within an acceptable range [24].

In the study comparing marginal adaptations, the lowest marginal openings were obtained in the laser sintered substructures (51.78 μm). When the rapid prototyping method was used, average edge clearance of 69.64 μm was obtained and average edge clearance obtained by conventional casting method was 80.39 μm [25].

Another study evaluated the clinical outcome of posterior single-unit metal-ceramic crowns fabricated using computer-aided design/computer-assisted manufacture laser-sintering technology. Sixty restorations were placed in 39 patients and cemented with glass-ionomer cement. Follow-ups were performed annually, Observed period of 47 months. The results suggest that the clinical outcome of posterior single-unite metal-ceramic crowns fabricated using laser-sintering technology is promising.

A three-dimensional sensing system used in conjunction with Geomagic Studio 10.0 software and an AFS-360 laser rapid prototyping machine to design a prosthesis for a large maxillofacial defect, and have investigated a method of using base-plate wax to refine the rapid prototyping wax prosthesis that incorporates facial details and adaptable margins, and which cannot be created in any other way because of the resolution of rapid prototyping and the strength of the materials. This method is able to facilitate the production of highly realistic facial prostheses, design and fabrication of facial prostheses based on the CAD/CAM system is a safe, quick, and precise way of processing a facial prosthesis that will conform well to the patient's appearance [24].

Results

The literature discuss the advantages and disadvantages of laser sintering method from different aspects. They found that internal fit, marginal adaptations, Accuracy of laser-sintered metal restoration are better than that obtained with the traditional casting techniques. In another hand, no difference was observed in the study of internal adaptations, connection between the veneer porcelain, internal gap and porcelain surface treatments between laser sintered and conventional casted metal restoration. Immediate implant loading could be achieved in a reasonable operative time.

Conclusions

Laser sintering seems to be an alternative technique to conventional casting of dental alloys. Complex shapes from metal alloys can easily be produced With these devices. These systems can be helpful to obtained fixed restorations, facial prostheses, titanium implants, surgical models and stents. The new laser-sintering technique appears promising for dental application, but additional studies of properties of laser sintered.

Laser sintering technology has an advantage relating to the minimization of human error during the manufacturing procedures, maintaining a consistent quality of restorations. Furthermore, the construction costs of prostheses might be reduced through large-scale production at one time.

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