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REVIEW ARTICLE

Direct Metal Laser Sintering: A Digitised Metal Casting Technology

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Abstract Dental technology is undergoing advancements at a fast pace and technology is being imported from various other fields. One such imported technology is direct metal laser sintering technology for casting metal crowns. This article will discuss the process of laser sintering for making metal crowns and fixed partial dentures with a understanding of their pros and cons.

Keywords Metal laser sintering · 3D printing technology · Laser sintered crowns

Introduction

Metal casting technology has been recognized in industries and arts for more than a century. Metal casting has had its origin in ancient China/Egypt, where the idea of making a wax replica, surrounding this replica with an investment material, letting this harden, then melting wax and burning out the wax to produce an intricate and accurate mold was conceived. The next step involved is melting the metal and pouring it into the cavity. In the literature, Dr. Swasey (1890) was the first to introduce a technique of making solid gold inlay. Martin (1891) was the first to use wax for making gold inlays. Dr. Philbrook (1896) introduced pressure casting method of producing gold inlays. It was about 10 years later Dr. Taggart (1907) presented a paper before the New York Odontological Group, in which he discussed his casting technique and machine. Taggart's success was mostly due to his improved casting machine, since his casting technique was not original; the idea of using wax to form the pattern was that of Martin (1891), and using pressure to cast the alloy was that of Philbrook (1896). Since then, casting technology has come a long way in producing accurate castings.

Casting technology is undergoing a radical shift and a process of industrialization is taking place in dentistry like in all other industries. Computer-assisted design (CAD)/CAM milling is familiar ground for dentists by now. This innovation was followed by scanning (digital impression concept) that emerged as a consequence of technology and equipment from other industries are being adapted for use in dentistry. The use of digital dental technology is on the rise and manufacturing processes are being automated. Dental restorations that have long been conventionally produced from metal through the use of casting techniques is getting automated; this technique is a direct import from 3D printing and rapid prototyping technologies used in general manufacturing.

CAM milling technology is often referred to as subtractive process, as milling involves taking a block of material and cutting away everything that is not necessary until the final restoration emerges. In contrast, additive processes involve adding material layer by layer to build the final product. Basically four different 3D printing technologies (additive process) are being used in dental industry: stereo lithography apparatus, digital light projection, jet and direct metal laser sintering (DLMS or DMLS or just MLS) [1]. Each system varies in the materials available, how these materials are solidified and how they can be used.

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Laser Sintering Technology

Laser sintering process was first introduced by Deckard and Beaman [2]. Laser sintering is also referred to as "3D printing" because it builds up framework in a series of successively thin layers (0.02–0.06 mm) [3]. A high powered laser beam is focused onto a bed of powdered metal and these areas fuse into a thin solid layer. Another layer of powder is then laid down and the next slice of the framework is produced and fused with the first. When all the layers have been built up, the solid copings and bridge frameworks are taken from the machine, sand blasted, polished, inspected and ultrasonically cleaned. The unused powder that remains is filtered and used in the next batch.

Laser sintering is the newest technology in metal manufacturing. DMLS is a manufacturing process for producing complex 3D components directly from 3D CAD data without using any machining [4]. DLMS requires three inputs: material, energy and CAD model. The material used is powder-based working material. MLS crowns have a primary composition of chrome cobalt alloy. Molybdenum, tungsten, silicon, cerium, iron, manganese and carbon are the other ingredients used. They are nickel and beryllium free. The material is a mix of particles of the size of 3–14 µm. Energy used is a high powered laser beam (200 W Ytterbium fiber optic laser). This energy is used to melt the alloy powder. *CAD model*: The machine reads in data from a CAD drawing and lays down successive layers of alloy powder and in this way builds up the model from a series of cross sections. These layers, correspond to the virtual cross section from the CAD model and are joined together to create the final shape. The standard data interface between CAD software and the machine is the STL file format. An STL file approximates the shape of a part using triangular facets. Smaller facets produce higher quality surface.

Direct Metal Laser Sintering (DLMS) Process

In the dental office, an impression of a tooth preparation is made to start with, after routine diagnosis and treatment planning. The impression could be a conventional or a digital impression. In the intermediate dental laboratory, the impression is casted and a model is prepared. The model is scanned, and the crown/bridge is designed using CAD design and sent to the central processing unit. The central processing unit is usually a remotely located laboratory with the laser sintering equipment. Special CAM software is used to import a CAD file, usually supplied in the STL format from a scanner/CAD software. CAM software further slices the parts into discrete horizontal layers.

Once there are sufficient numbers of crown copings and bridge framework (usually 90–120 units) for a job lot, laser starts production layer by layer in a period of only a few hours. Metal powder is spread across the working platform. A high powered laser beam is used to melt a bed of metal alloy powder by following a predetermined path layer by layer. This path is created by a CAD file. The machine produces several hundred dental prostheses out of metal powder. The speed is approximately 3 min/crown.

The DMLS process is performed by two different methods, powder deposition and powder bed method [5]; they differ in the way each layer of powder is applied. The powder bed method is more popular presently, as they offer faster speeds. Inside the build chamber area, there are two

Fig. 1 Schematic representation of laser sintering process

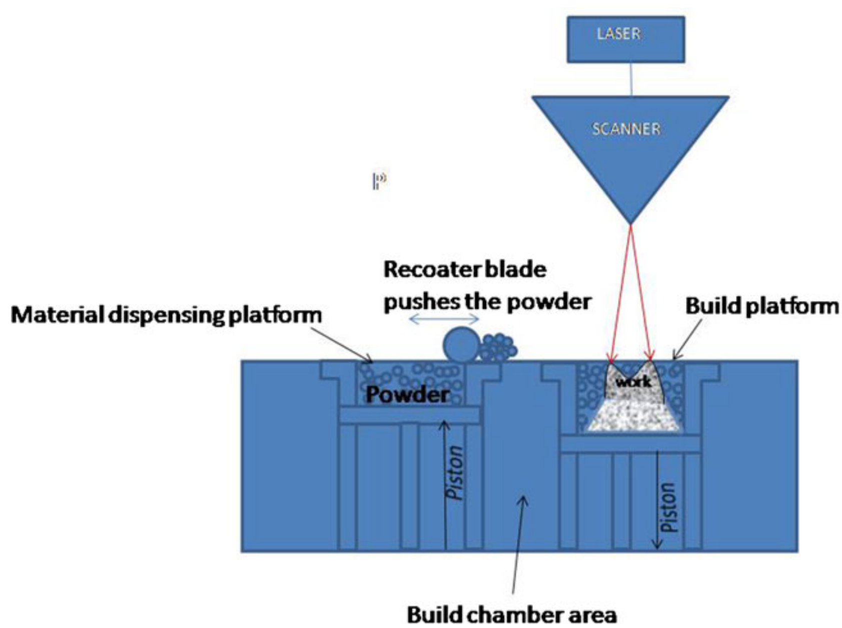

Fig. 2 Laser sintered crown and fixed partial denture copings before finishing

platforms, material dispensing platform and build platform (Fig. 1). The material dispensing platform along with a recoater blade is used to move new powder over the build platform. The metal powder is fused into a solid part by melting it using the focused laser beam. Parts are built up additively layer by layer, usually 20 μm thick. After a layer is built the build piston lowers the build platform and the next layer of powder is applied. This process allows for highly complex geometries to be created directly from the 3D CAD data, fully automatically without any tools, producing parts with higher accuracy and detailed resolution, good surface quality and excellent mechanical properties. Finally the support material is cut off from the copings/crowns/bridges (Fig. 2).

Discussion

CAD/CAM was introduced to dentistry two decades ago for ceramic inlays and onlays. This was followed by the introduction of Procera system (Nobel BiocareAB, Goteborg, Sweden) in 1991 for individualized dental restorations. This was followed by in-office chair side use of CAD/CAM by CEREC (Sirona Dental Systems LLC, Charlotte, NC). Palleson and van Dijken evaluated CAD/CAM ceramic over a period of 8 years and found them to be successful [6]. Subsequently rapid manufacturing approach that used metal powders in CAD model and 3D printing technology followed. In the literature, CAM and 3D printing (DLMS) have been used interchangeably, though both are different processes.

MLS crowns and bridges are made of a particle size of 3–14 μm. This combined with very fine point laser (0.1 mm) results in a density of 99.9 %, resulting in stronger copings. The densely sintered crowns have practically no voids. The process results in highly accurate, well detailed restorations. Marginal discrepancy is clinically acceptable with the restoration possessing consistent quality and strength [7–9]. DLMS is a clean alternative to casting. Messy tasks of deflasking, cleaning molds, elaborate steps can be dispensed with. The use of automated scanning and CAD software results in full control over the framework design. Coping thickness, pontic design and cement thickness can all be standardized with this method. Laser sintering is a computer-controlled, precise process that ensures consistent work quality. The possibilities of inclusions or defects that are commonly introduced in the manual casting methods are dispensed with. Multiple unit framework usually suffers from distortion in the conventional technique, DMLS is more predictable with improved marginal fit [7].

With a build envelope of 250 × 250 × 185 mm and the ability to grow multiple parts at one time, though the initial investment is high, they are very cost and time effective. A dental technician can produce at best about 20 units per day using conventional casting procedures used today whereas; use of fully automated laser sintering technology can produce about 450 units of high quality crowns and bridges in 24 h with an efficiency of 90 units per run of the machine [4]. For the dentist, chair side time is reduced and time required in the dental laboratory is enormously less.

The CAD/CAM technique contains fewer production steps compared to conventional techniques. The three main factors affecting the fit are: precision of the scanner, how effectively software can transform the scanning data into a 3D model in the computer and the precision of the milling machine. Scanners have a precision of 20 μm. During the CAD process of the framework, drill compensation is activated routinely. Milling burs require to be changed periodically as they are cutting hard metal alloys like Co–Cr.

Whenever a new method of fabrication of indirect restoration is introduced, first studies are directed at fit and marginal discrepancy. Laser sintered crowns were compared with conventionally fabricated crowns for internal fit in an in vivo study. Marginal gap found in this study was on an average less than 65 μm and this was comparatively lesser than the marginal gaps of 81–136 μm found in all ceramic restorations [10]. The gaps found in this study for laser sintered crowns were much lower than originally reported acceptable marginal gap widths (150–125 μm) [11, 12]. Another study compared the marginal fit and internal fit of metal ceramic crowns fabricated using laser sintering process and the influence of ceramic firing on the marginal and internal accuracy of these crowns using two different alloys. This was the first clinical study conducted using DLMS technique. Out of a total of 28 restorations fabricated, the mean marginal discrepancy and internal gaps were clinically acceptable. Ceramic firing altered the fit of the crowns only slightly [8].

In DLMS there is the concern of metal copings and their bond to veneering ceramic. Tara MA, Eshbach S, Bohlsen

F, Kern M placed 64 single crowns restorations fabricated using laser sintering method in 39 patients and found that there was no chipping of veneering ceramic during an observation period of 47 months. The failures noted were de-bonding in one case and a case of biologic failure. Authors concluded that the laser sintering process was a promising method of fabrication of porcelain fused to metal crowns [12]. Akova T, Ucar Y, Tukay A, Balkaya MC, Brantley WA compared the shear bond strength of laser sintered Co–Cr and cast Co–Cr and Ni–Cr base metal dental alloys to porcelain. Ten metal ceramic specimens prepared from cast Ni–Cr and Co–Cr alloys exhibited a mixed mode of failure (adhesive and cohesive) whereas five of the laser sintered metal ceramic specimens exhibited mixed failure mode and five specimens exhibited adhesive failure in the porcelain. They concluded that laser sintering was an alternative to conventional casting methods [13].

Anders Ortorp evaluated and compared marginal gap and internal fit in an in vitro study. A total of 32 three unit fixed dental prostheses were fabricated in Co–Cr alloy using conventional lost was method (LW), milled wax with lost-wax method (MW), milled Co–Cr(MC) and DLMS. Best fit was found in the DLMS group followed by MW, LW and MC. In all the four groups, best fit on abutments was along the axial walls and the largest discrepancy was occlusal [7].

Conclusion

Laser sintering is relatively new; manufacturers claim that the technique is easy to use, produces accurate restorations, simplified post processing procedures, free of porosity unlike conventional castings and improved electromechanical characteristics. But, further long term studies on the fit and properties of laser sintered crowns and fixed dental prostheses, if encouraging, could result in their widespread clinical use. The rapid advancements in the digitalized processes will continue, making this computerized technique more cost effective. More research will enable this technique to become more competitive.

References

1. Brown C (2011) 3D Printing and Laser sintering technologies. Inside Dental technology, AEGIS Communications, 2(7). Available from http://www.dentalaegis/idt/2011/08/3d-printing-and-laser-sintering-technologies. Accessed 13 June 2012
2. Deckard C, Beaman J (1988) Process and control issues in selective laser sintering. ASME Prod Eng Div (Publication) PED 33:191–197
3. Traini T, Mangano C, Sammons RL, Mangano F, Piattelli A (2008) Direct laser metal sintering as a new approach to fabrication of an isoelastic functionally graded material for manufacture of porous titanium dental implants. Dent Mater 24:1525–1533
4. International powder metallurgy directory (2011) Laser sintering-versatile production of tooling inserts, prototype parts and end products from metal powder. International powder metallurgy directory. http://www.ipmd.net/articles/articles/001087.html. Accessed 13 June 2012
5. DMLS (2011) retrieved on 13 Jun 2012 from http://custompartnet.com/wu/direc-metallaser-sintering. Accessed 13 June 2012
6. Pallesen U, van Dijken JW (2000) An 8-year evaluation of sintered ceramic and glass ceramic inlays processed by Cerec CAD/CAM system. Eur J Oral Sci 108:239–246
7. Ortorp A, Jonson D, Mouhsen A, Vult von Steyern P (2011) The fit of cobalt-chromium three unit fixed dental prostheses fabricated with 4 different techniques: a comparative in vitro study. Dent Mater 27:356–363
8. Quante K, Ludwig K, Kern M (2008) Marginal and internal fit of metal-ceramic crowns fabricated with a new laser melting technology. Dent Mater 24:1311–1315
9. Ucar Y, Akova T, Akyil MS, Brantley WA (2009) Internal fit evaluation of crowns prepared using a new dental crown fabrication technique: laser sintered CO–Cr crowns. J Prosthet Dent 102:253–259
10. Bindl A, Morman WH (2005) Marginal and internal fit of all-ceramic CAD/CAM crown copings on chamfer preparations. J Oral Rehabil 32:441–447
11. Kokubo Y, Ohkubo C, Tsumita M, Miyashita A, Von Steyern PV, Fukushima S (2005) Clinical marginal and internal gaps of Procera all ceramic crowns. J Oral Rehabil 32:526–530
12. Abou Tara M, Eshbach S, Bohlsen F, Kern M (2011) Clinical outcome of metal-ceramic crowns fabricated with laser-sintering technology. Int J Prosthodont 24:46–48
13. Akova T, Ucar Y, Tukay A, Balkaya MC, Brantley WA (2008) Comparison of the bond strength of laser sintered and cast base metal dental alloys to porcelain. Dent Mater 24:1400–1404