Comparative Evaluation of the Accuracy of Prostheses Fabricated using Newer Generation Technology

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Abstract: ***Context**: In the new age of manufacturing, 3D Printing and Milling have made impressive inroads into the dental world. During the manufacturing process, assessing the accuracy and fit of a prosthesis, decides the success rate of the restoration as a whole. Therefore, the accuracy of the crowns was measured and compared using newer additive and subtractive manufacturing techniques. **Aims and Objectives**: To compare and evaluate the accuracy of crowns manufactured by 3D Printing and Milling (in-vitro). **Methods and Material**: Two Co-Cr crowns were fabricated, one by 3D Printing and the other by Milling, on a tooth prepared in-vitro (die). The die and the intaglio surfaces of the crowns were scanned using the Shining 3D DS-EX Pro Scanner. The outer surface of the die scan was aligned with the scans of the intaglio surfaces of the DMLS as well as the Milled crown individually and 3D compared on the Geomagic Control X. **Results**: The accuracy of the alignment of the DMLS crown was found to be 90.3243% and that of the Milled crown was found to be 88.7988%. **Conclusions**: This showed that the 3D printed crown was 1.5255% more accurate than the Milled crown.*

Keywords: 3D Printing, Milling, Subtractive Manufacturing, Additive Manufacturing

1. Introduction

With the recent technological advancements, a new day has dawned for prosthodontic restorations. The chances of poorly fitting dental work have significantly reduced with the introduction of CAD/CAM (Computer-aided Design/ Computer-aided Manufacturing) Milling and digital 3D Printing. Patients do not have to endure the discomfort of foul-tasting and gag-inducing impression material. Their preferences of receiving a permanent, cosmetic crown in a single visit have also been addressed to. Many dentists, lab owners, technicians and technologically savvy individuals agree that digital impressions and manufacturing will replace traditional methods of fabricating dentures, partial bridges and crowns in the near future. CAD/CAM Milling and 3D Printing are now viable options for fabrication of prostheses. The success of CAD/CAM and digital printing depends on the speed, accuracy and cost of the machining. [1, 2]

Duret and Preston in the 1970s, were the first researchers to explore the application of CAD/CAM and its advent into the dental world. [3, 4] Shortly after this, Mörmann in the 1980s played a major role in the development of the CEREC® system. [5, 6]

CAD/CAM has now become a universally accepted technology in most modern laboratories and for some enterprising clinicians at their chairside.

In this era of jet-age where life is moving in the fast lane, patients have been fixated with the idea of getting dental treatment done at a supersonic speed. In the technological neighborhood, 3D Printing and Milling are still fairly new innovations. These technologies have been making impressive inroads into the dental world. The emergence of on-demand manufacturing is leading to dentists and manufacturers to give these advanced technologies some serious consideration. [7]

A short case-control study was done to evaluate the accuracies of a prosthetic crown manufactured by 3D printing and Milling.

Aim

To compare and evaluate the accuracy of crowns manufactured by 3D Printing and Milling: an in-vitro study.

Objectives

- To evaluate the accuracy of a crown manufactured by 3D Printing.
- To evaluate the accuracy of a crown manufactured by Milling.
- To compare the accuracies of crowns manufactured by 3D Printing and Milling digitally.

2. Method

A lower right molar (47) was prepared in-vitro, using a NSK FX Plus Airotor to receive a full metal crown with a deep chamfer margin of 1mm width throughout. 1.5mm of occlusal reduction on the cusps and 1mm of reduction in the grooves was done using a round-ended diamond bur. Bi-planer reduction of buccal, lingual, mesial and distal walls was done with a 6-degree taper overall and gradual transition between all prepared surfaces (Figure 1a). Occlusal verification was done using utility wax, wax caliper and a low-speed friction grip contra-angled hand piece. [8, 9]

The prepared tooth (Figure 1b) was scanned using the Shining 3D DS-EX Pro Scanner. [10]It had two scan modes (static and dynamic) that improved the occlusion precision. The scan time for scanning the die was 12 seconds. This scanner made use of a blue light source as white light scanners caused blurring due to chromatic aberration.
These scanned files were then saved in the STL format by the Exocad software [11] and the stalk of the scanned die was edited out with the intention of removing the unwanted surfaces (Figure 1c).

The subtractive technology represents the manufacturing of a material using a Computer Numerical Control (CNC) milling machine. In the presented paper, metal crowns were manufactured by a 5-axis CNC Arum 5x-400 milling machine. [12,13] The machine could manufacture dental crowns from various materials like zircon, wax, PEEK and Co-Cr. The CNC milling machines that are used in the dental practice have predefined shapes called pucks or blocks. However, the shortcomings in these milling machines wasthe limited capacity of movement of the machines. Complications may arise with the production of intricate geometrical shapes and the cutting of small structures that required higher accuracy and precision.

The SLM technique was developed at a German Research Project at Fraunhofer Institute in 1995. The Selective Laser Melting (SLM) or Direct Metal Laser Sintering (DMLS) technique, is a powder-based additive manufacturing process based on the basic principle of producing a prosthesis layer by layer from a 3D CAD (Computer Aided Design) model according to their shapes by selectively fusing metal powder through computer-aided laser control. [14,15] This technique offered many advantages over the conventional casting technique and it also saved raw materials and required fewer tools, in turn reducing costs. SLM provided a microstructure superior to those of casting and milling, with minimal internal porosity, good internal fit and accurate marginal adaptation. In the study that was conducted, the Mlab cusing R device, which was the precursor of the SLM technology, used for producing titanium alloys and Co-Cr alloys, was used. The SLM 125 machine [16] was used for the manufacturing process, which was carried out by the gradual deposition of powdered layers of the Co-Cr block with a thickness of 25 µm, followed by their laser melting. On the basis of a standardized production process, it was also possible to make prototypes of smaller sizes with high level of precision.

Current SLM devices provide metallic restorations made up of Co-Cr alloy for removable and fixed partial denture prosthesis without compromising the properties of the alloy or restoration at a fraction of the time and cost making this additive manufacturing process a popular choice in the future.

The innovative additive manufacturing concept of SLM offers many advantages compared with casting and milling techniques. SLM provides a microstructure superior to those of casting and milling, with minimal internal porosity, good internal fit and accurate marginal adaptation.

In the current paper, two crowns were manufactured from Co-Cr alloy using both methods (additive and subtractive). After production, both the crowns underwent post-processing (heat treatment, support removal and mechanical treatment). They were then individually scanned using a Shining 3D DS-EX Pro dental scanner. The data obtained was then edited in the Meshlab software [17] and compared with the reference model in the Geomagic Control X Softwares. [18]

It was important to know the exact percentage of chrome (Cr) and cobalt (Co) in the alloy to determine the physical and mechanical properties of the Co-Cr alloy as a whole. [19] The higher the amount of Cr in the alloy, the higher was its corrosion resistance. On the other hand, the higher the amount of Co in the alloy, the higher was its strength, hardness and modulus of elasticity. The percentages of individual elements were Cobalt: 66%, Chromium: 28%, Molybdenum: 5%, Silica: <1%, Iron: <1%, Manganese: <1%. Further elements used were Carbon: <0.1% and organic binder (for blanks in blank condition): 1-2%. The alloy was free of Nickel, Beryllium, Gallium and Cadmium according to DIN EN ISO 22674.

For production using the additive method, the metal powder EOS CobaltChrome SP2 (REF: 9011-0018) was used. This material was used for the production of dental crowns and bridges by additive technology and satisfied the requirements of the standard DIN EN ISO 22674. The size of its grain was between 10 µm and 30 µm.

The step bur 10 of 10.5mm length, was used to mill the inner surface of the crown whereas a cylinder pointed bur of 8.7mm length, was used to mill the occlusal surface of the crown.

Design of the CAD Model
The basis for both the subtractive and additive methods was the 3D model of the crown, which was prepared by a dental technician. [20] The 3D model of the crown was used as the CAD model for both the manufacturing processes.

Crown fabrication process
For preparation of the 3D model made using additive production, the CAMbridge software [21] was used. The 3D model was correctly positioned in the software; the support material was designed and placed on the production surface (Figure 1d). After completing the modifications, a file of the CLS format was generated, which was subsequently loaded into the Mlab cusing R device for the process of fabrication

of the crown by additive production (Figure 1e). The same 3D CAD model was used for the fabrication of the crown by subtractive production (Figure 1f). The material used was selected in the software and the contour edges were demarcated. The number and thickness of the anchors was entered and placement of the puck was defined. After entering of the appropriate data, the production process by subtractive and additive manufacturing was initiated. The prostheses produced were then annealed and modified to their final form.

Figure 1a: Tooth preparation done on a lower right molar on a typhodont, 1b: Prepared die, 1c: Die scan, 1d: Design of the 3D CAD Model on the CAMbridge software, 1e: Co-Cr crown manufactured by Direct Metal Laser Sintering method, 1f: Co-Cr crown manufactured by Milling method)

Scanning the Samples

To acquire the digital data of the surface of the manufactured dental crown, the Shining 3D DS-EX Pro dental scanner was used. The scanner was primarily intended for scanning dental plaster castings with a matt surface and with a constant coloring. The surface of the crowns produced was not matt; due to this reason, a chalk casing had to be deposited on all the surfaces of the crowns that were to be scanned. The internal surface of the crowns had to be evaluated; therefore, the acquired scans were cleaned and removed off any unwanted noise and at the same time only the area being evaluated was left.

Removal of the Superfluous Layer

These STL files of both the crowns manufactured by subtractive as well as additive manufacturing were imported on the Meshlab 2016.12 software (Figure 2a). The back-face was saved as fancy for the ease of removal of the superfluous layers. The tool, select faces in a rectangular region was chosen and the outer layer of each scan was deleted with great precision by using the sub-tool, delete the current set of selected faces.

The STL files of these modified scans (Figure 2b and 2c), with only the intaglio surface of each scan remaining, along with the die scan were then imported on the Geomagic Control X software (Figure 3a). The die scan was selected to be moved to reference. The function, 'Transform Alignment' was selected and the sub-option 'Rotate and Translate' was chosen. This facilitated each of the modified scans to Rotate and Translate in the X, Y and Z axes to accurately position each of them individually onto the die scan which had been fixed in position. This software helped to accurately and digitally align the scan of the DMLS as well as the Milled crowns to the scan of the prepared tooth respectively (Figure 3b).

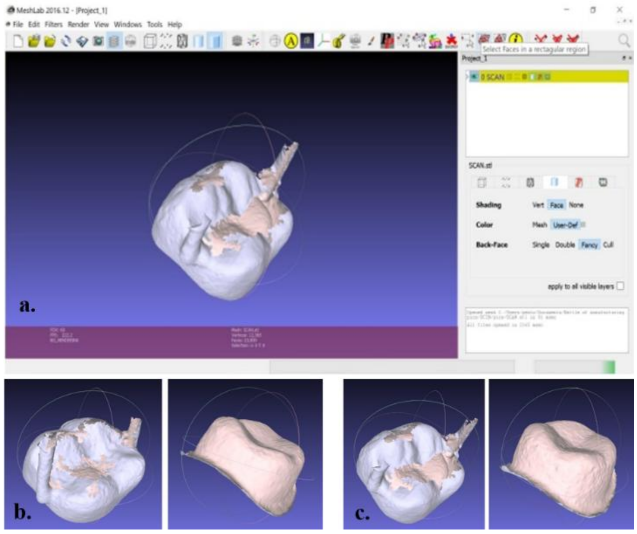


Figure 2a: Meshlab software used to remove the superfluous layer from the scan of the crowns, Pink- intaglio surface in question, Purple- Superfluous layer to be removed, 2b: Scan of the DMLS crown before and after removal of the superfluous layer, 2c: Scan of the Milled crown before and after removal of the superfluous layer)

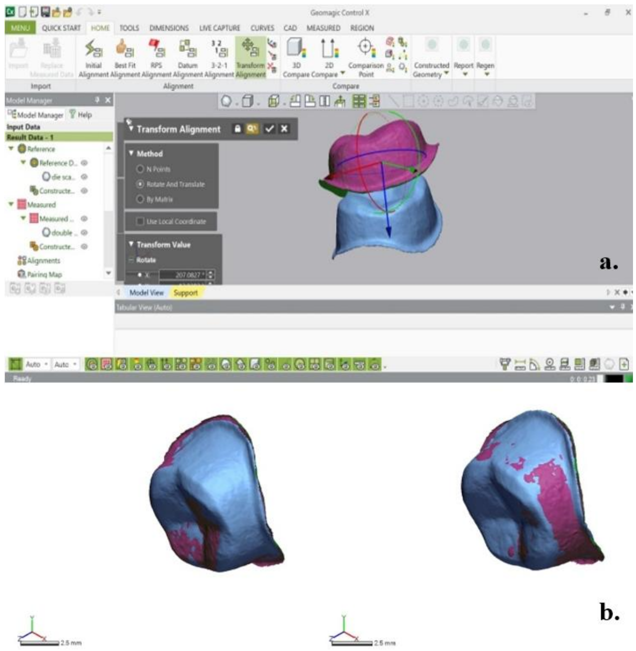


Figure 3a: Alignment of the scans of the crowns with the die scan done on the Geomagic Control X software, Blue- Die scan, Pink- Crown Scan, 3b: Result of the alignment, Left- DMLS crown scan aligned with the die scan, Right- Milled crown scan aligned with the die scan)

A 3D compared computer generated report was obtained for each alignment. This gave the accuracy along with various other measurements and parameters that were generated through this alignment.

3. Results

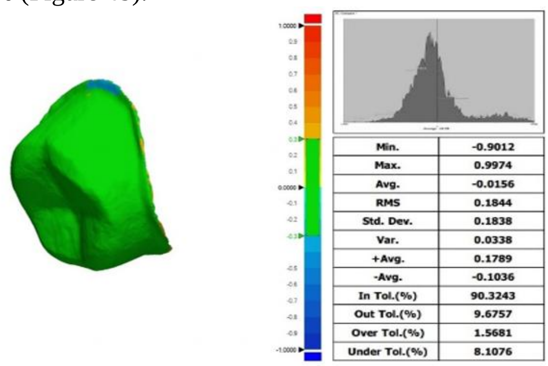
The result of the comparison was the percentage value of agreement of the scan with the reference model. This was the most suitable method of evaluation for the purpose of analysis in this study, because it provided data on deviations over the entire monitored surface of the crown, not only in isolated locations, which did not have to capture the maxima or minima.

For evaluation of deviations, it was necessary to determine the coordinate system of the reference model and a method of aligning the scan to the reference.

The toleration field for the maximum permitted deviation of production was set at ±30 um. The value of ± 100 um was selected as the maximum assessed deviation, i.e. the software evaluated the deviation from the reference model (die scan) in this range.

On 3D comparison in the Geomagic Control X software, the accuracy of the DMLS crown was found to be 90.3243% (Figure 4a) and that of the Milled crown was found to be 88.7988% (Figure 4b).

a.



b.

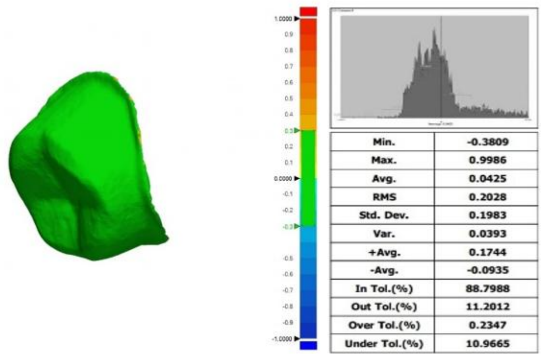


Figure 4a: 3D comparison of the DMLS crown on the Geomagic Control X software, 4b: 3D comparison of the Milled crown on the Geomagic Control X software)

These results show that the accuracy of the crown manufactured by 3D Printing is found to be 1.5255% more than that produced by Milling.

4. Discussion

A deep chamfer finish line was chosen for preparing the die, for the purpose of improving the strength of the crowns to be manufactured, reduce stress concentration and to have a distinct margin for the ease of scanning all the surfaces in question on the die. Tooth preparation of the die was done using a low-speed friction grip contra-angled hand piece as a low-speed handpiece provides better control over the amount of tooth structure being removed as opposed to a high-speed handpiece that could lead to over-preparation of the tooth.

Co-Cr was chosen as the alloy for the production of the crowns as it was biocompatible, had a multiphase structure, good hardness and tensile strength and had improved fatigue strength on heat treatment.

The 5-axis Milling Machine was chosen for the fabrication of the crown fabricated by subtractive manufacturing as it could produce highly intricate parts with precision. SLM was the technique of choice for fabricating the crown by additive manufacturing because it produced a stronger end product with fewer voids by the complete melting of the powder. The SLM 125 3D printer was used as it was precise, economical and capable of producing smaller, more intricate objects.

The Back-Face was saved as fancy on the Meshlab software for the purpose of easily distinguishing between the intaglio surface and the outer or superfluous layer of the scan. The reason for removing the superfluous surfaces from the acquired scans was that, distant surfaces could influence or disable alignment on these softwares, thus reducing the accuracy of the alignment.

The Shining 3D DS-EX Pro scanner was used for scanning the die and the crowns for a number of reasons. Some of them were that it was compact, powerful, easy to operate, had good efficiency, could be upgraded, was highly accurate, could scan quickly and had high quality optics and image sensors.

5. Conclusion

The DMLS crown had better accuracy because additive manufacturing is capable of producing complex shapes and micro-structures as compared to the crown fabricated by subtractive manufacturing that is unable to reproduce micro-details. The reason for this was that the crown was milled from pre-defined pucks or blocks and not by layering like in 3D Printing.

More knowledge should be imparted to general dentists about subtractive and additive manufacturing processes of a prosthesis so that they are able to implement these techniques in their day-to-day practice in order to fabricate a more precise, predictable and a cost-effective prosthesis as these technologies are the future of dentistry.

In order to move forward into the digital world of dentistry, the dentist needs to update his knowledge about the different softwares available for undertaking these digital tasks. An integrated knowledge of dental friendly softwares along with the principals involved in Prosthodontics is necessary in determining the success or failure of such modern processes and technology. A number of techniques and softwares are available that can be chosen from depending on the familiarity and skills of the individual using these softwares. Dentists can even enroll for training courses to acquire an in-depth knowledge about the working of these softwares. Their use requires patience, skill and immense precision.

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6. Future Scope

More research is required in this field with a detailed study on a larger scale. A study with a larger sample size using different additive and subtractive production tools and machinery should be carried out in the future. Various other parameters and materials used for the fabrication of prostheses may also be assessed.

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Conflict of Interests

The authors have no conflicts of interests.

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