

INTAGLIO SURFACE TRUENESS OF MILLED VS 3D PRINTED PROVISIONAL OCCLUSAL VENEERS - AN IN VITRO STUDY

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ABSTRACT:

Aim of the study: The latest CAD/CAM technologies allow provisional restorations to be produced by milling or 3D printing methods. The two methods differ in terms of cost, speed and working protocol. An important factor of a successful provisional restoration is the fidelity of the intaglio surface and its adaptation to the preparation surface. How faithful is the adaptation of these temporary restorations to the preparation surface and are there differences between the manufacturing methods in terms of intaglio surface trueness? **Materials and Methods:** A preparation for occlusal veneer was performed on an upper molar of a typodont. The preparation was scanned with an intraoral scanner (Medit i700) and the table-top restauration was designed using a CAD software. Based on the CAD design, 45 restorations were produced using the two technologies: 15 milled restorations from Telio CAD (Ivoclar), 15 milled restorations from Brilliant Crios (Coltene), and 15 3D printed restorations (GC Temp Print resin). The intaglio surfaces of the milled and printed restorations were scanned using the same intraoral scanner. In order to assess the intaglio surface trueness, each scan was superimposed and compared to the original CAD design file of the restauration with the help of a metrology grade, quality control software. **Results:** Statistically significant differences were found between the analysed groups of values. The printed restoration group showed slightly higher deviation values than the milled ones, the Telio CAD group with an average of 37 microns and the Brilliant Crios group with an average of 36 microns. **Conclusions:** The milled occlusal veneers showed slightly better results of the intaglio surface trueness while both milled and printed restorations showed trueness values within the accepted limit, indicating a clinically acceptable fit.

Key words: occlusal veneer, CAD/CAM, milled resin restoration, 3D printed restoration, trueness

inadequate morphology of the final result. Additionally, ceramic milled restorations need to be finished usually a crystallization, sintering and/or glazing procedure in a dental furnace [3-5].

In recent years a new treatment approach emerged in the dental office in the shape of printers which use additive manufacturing. The process involves a 'layer by layer' construction of the prosthetic restoration followed by several postprocessing steps. Also commonly known as 3D printing, it can take the shape of different techniques: vat polymerization, extrusion of thermoplastic material or selective laser

INTRODUCTION

Nowadays, chairside CAD/CAM restorations are replacing more and more the conventional approach of rehabilitating damaged teeth, using either subtractive or additive manufacturing techniques [1,2]. The subtractive technique uses a CAD file as guide for the milling machine which in turn mills the prosthetic restoration from a hard block of material (ceramic, acrylic or hybrid). There are several factors that can influence the characteristics of the final restoration including the state of wear of the milling tool or the initial thickness of the restoration which can lead to chipping or

which method is the most accurate (cross section and visual evaluation under microscope, optical coherence tomography, scanning of the preparation and intaglio surface of the crown) [13,14].

The purpose of this study was to evaluate the internal fit of milled and 3D printed occlusal veneers obtained with subtractive and additive techniques.

MATERIALS AND METHODS

A precise preparation for occlusal veneer was performed on the upper left molar of a typodont (AG-3; Frasco, Tettang, Germany). During preparation, the typodont was inserted in the mandibular articulation of a dental mannequin (Phantom head PK-2 TSE; Frasco, Tettang, Germany). The preparation was scanned with an intraoral scanner (Medit i700, Medit Corp, Seoul, South Korea) (Fig.1) which was calibrated beforehand according to the manufacturer's indications. The restoration was designed using a dedicated dental CAD software (DentalCAD 3.0 Galway, Exocad GmbH, Darmstadt, Germany) (Fig.2).

sintering [6-8]. Additive methods allow for more complex geometry, less waste of material and a greater number of restorations finished in one stage. However, there are also limitations that come with the additive techniques such as long printing time, inconsistent postprocessing and dimensional alteration of the restorations. Also, now 3D printing can be used mainly for manufacturing provisional restorations, complete dentures which can reduce their use in the dental office [9,10].

One key aspect in fixed prosthodontics is the internal and marginal fit of a restoration which dictates the longevity of both the restored tooth and the prosthetic treatment. A minimal space between the restoration and the tooth ensures the ideal conditions for pulpal vitality and periodontal integration [11,12]. Having a poorly fitted restoration leads to a larger layer of cement, which in turn dissolves easier leading to microleakage, secondary caries and painful pulpal response. Evaluating the internal fit of a restoration can be achieved in several ways, even though there is no consensus on

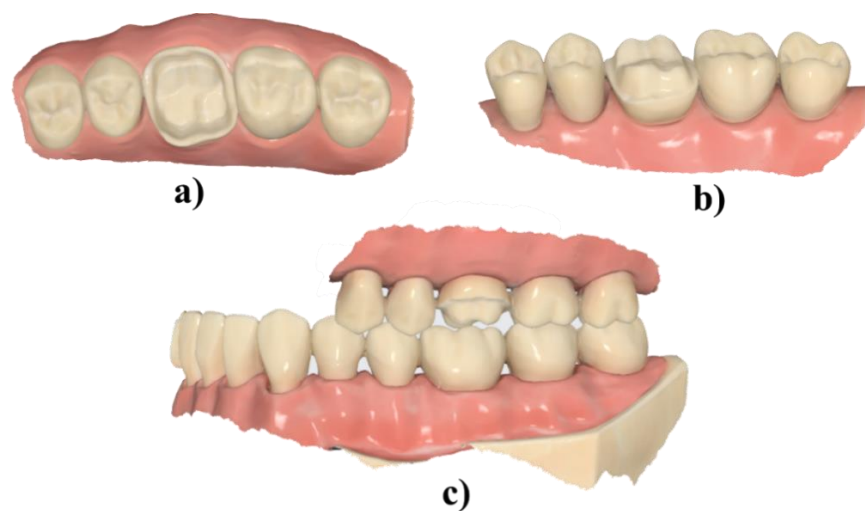


Figure 1. IOS (intraoral scanner) scans of the occlusal veneer preparation on the upper left molar: a) occlusal view; b) buccal view; c) occlusion with antagonist.

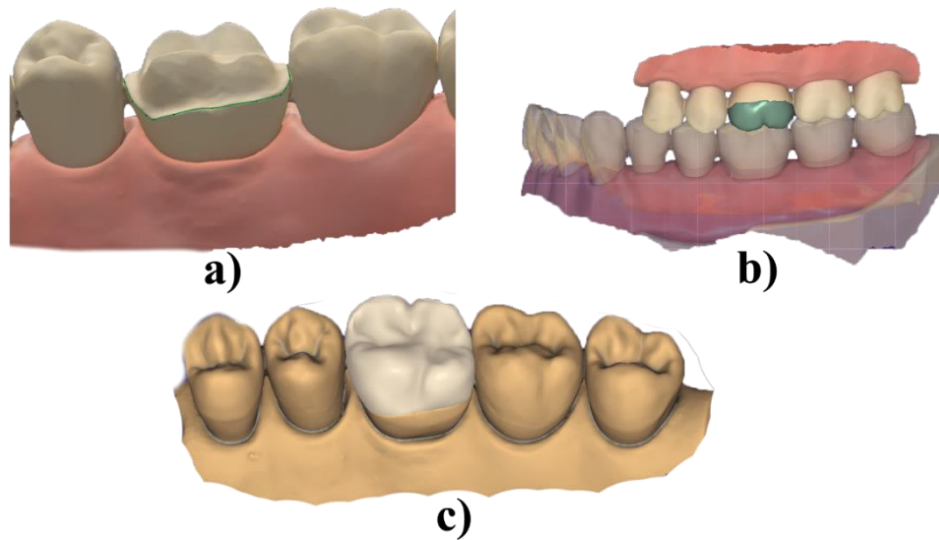


Figure 2. Design of the occlusal veneer: a) margin tracing; b) restauration in occlusion; c) final design.

Japan) a biocompatible Class IIa material for temporary restorations. All the 15 restorations were printed in the same printing cycle and were post-processed together according to the resin manufacturer. Post processing of the printed restorations was done with the Prusa CW1 wash & cure station (Prusa Research, Prague, Czech Republic) by immersion in isopropanol solution (>99%) for 5 minutes, drying for 4 minutes and final polymerization for 4 minutes.

All the milled and printed provisional restorations were fixed with the occlusal surface on wax sheets to facilitate the scanning process of the intaglio surface. The intaglio surfaces of each milled and printed restorations were scanned using the same intraoral scanner (Medit i700) (Fig.3).

Based on the CAD design, multiple provisional restorations were produced using two different technologies: milling and 3D printing. Planmill 40 milling machine (Planmeca, Helsinki, Finland) was used to produce 15 milled restorations from Telio CAD (Ivoclar Vivadent Ltd. Schaan, Liechtenstein) alongside 15 milled restorations from Brilliant Crios (Coltene, Altstätten, Switzerland). The maintenance and calibration of the milling machine was carried out according to the manufacturer's instructions after each milling, and new milling burrs were used for each new milling. For the 3D printed restorations, Prusa SL1 3D printer (Prusa Research, Prague, Czech Republic) was used to produce 15 printed restorations from GC Temp PRINT resin (GC Corp., Tokyo,



Figure 3. Intaglio surface scans of printed and milled restorations.

superimposed and compared to the original CAD design file of the restoration with the help of a metrology grade, quality control software (Geomagic Control X, Version:16.0.2.16496, 3D Systems, Wilsonville, OR, USA). The reference data was uploaded into the software and the area of interest was isolated to the intaglio surface area (Fig.4).

The original CAD design file of the occlusal veneer was used as the reference model as it is designed to best fit the scanned surface of the abutment, and the provisional printed or milled restorations strive to achieve the same surface trueness. In order to assess the intaglio surface trueness of all the printed and milled restorations, each intaglio surface scan had to be

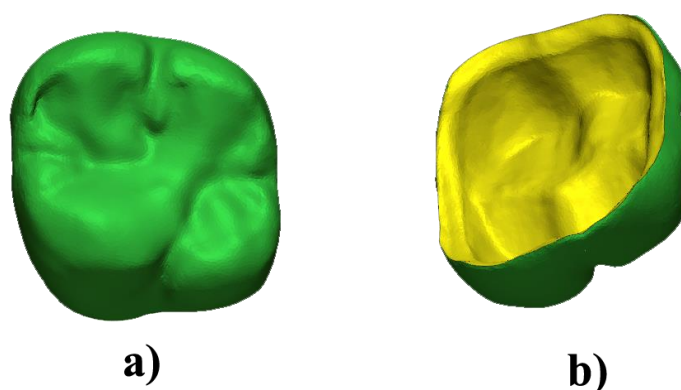


Figure 4. Reference data: a) occlusal view; b) intaglio surface view with the area of interest isolated.

the “best fit alignment” in order to superimpose the IOS mesh over the reference mesh with a precise overlapping of the interest area (Fig.5).

The intaglio surface scans of the printed and milled restorations were also imported into the software and were subjected to the “initial alignment” procedure, followed by

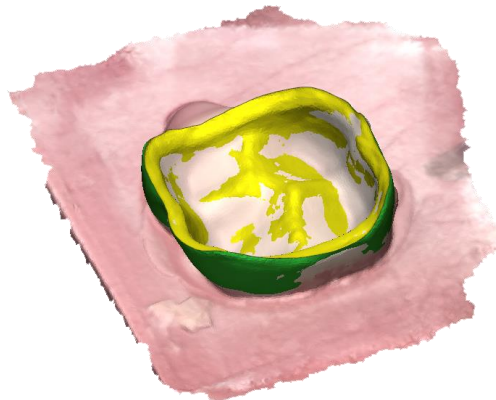


Figure 5. Superimposition of the IOS mesh over the reference mesh with a precise overlapping of the interest area.

displays the deviation patterns of the investigated surfaces between ± 0.05 mm (50 μ m), outward displacement being presented on the color-coded map towards the red spectrum, inward displacement being presented towards the blue spectrum, and the green areas where there is less than $\pm 1\mu$ m difference indicating no deviation (Fig.6).

The “3D Compare” function of the software projects all paired points onto the reference data in order to present the standard deviation results between the measured and reference data. The “3D Compare” function was applied on all the superimposed samples to obtain the numerical values of the standard deviation alongside a color-coded map for each comparison. The color-coded map

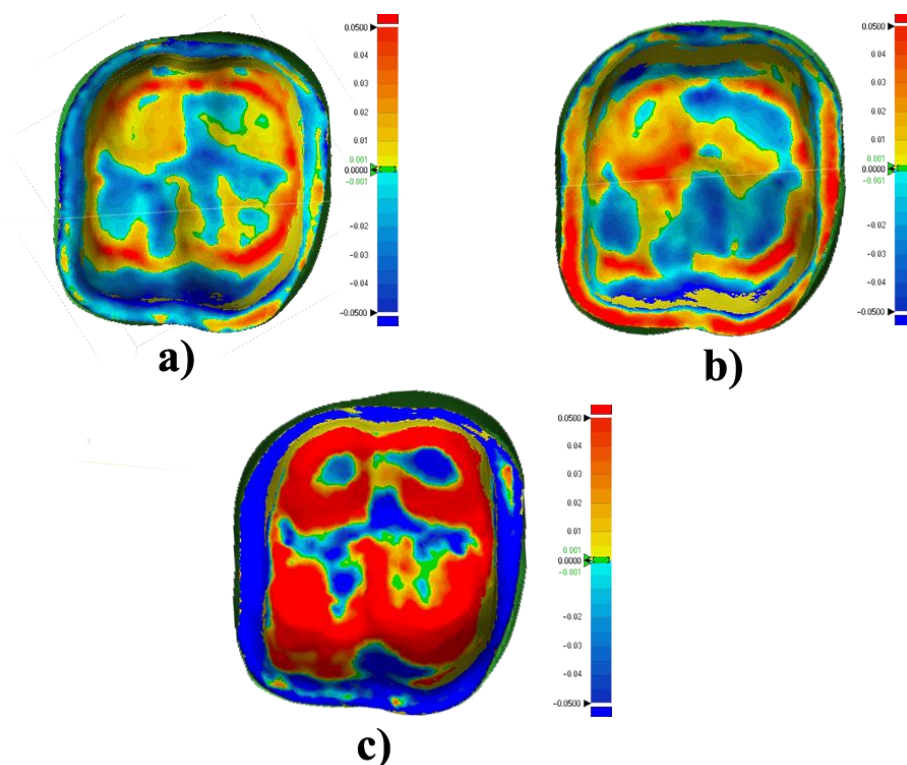


Figure 6. Color-coded map generated by the 3D comparison of the intaglio surface: a) Telio CAD sample; b) Brilliant Crios sample; c) GC Temp PRINT sample.

Smirnov test for normality of distribution, which revealed that the numerical data had a parametric distribution. A one-way ANOVA test was performed on the parametric data set, and the post hoc test (Newman-Keuls test) was also run. A significance level of $\alpha = 0.05$ was chosen.

The numerical data of the standard deviations of each comparison were organized and analysed in a dedicated statistical program (Medcalc Software, West-Vlaanderen, Belgium). The whole set of data was subjected to the Kolmogorov-

RESULTS

The intaglio surface trueness values of the tested sample groups are summarized in the Table 1.

Group	Mean	SD
3D Printed - Temp Print (GC)	48.9518 μm	0.0068 μm
Milled - Telio CAD (Ivoclar)	37.6880 μm	0.0060 μm
Milled - Brilliant Crios (Coltene)	36.8128 μm	0.0072 μm

Table 1. Mean and standard deviation (SD) of the intaglio surface trueness values.

(Newman-Keuls) presented significant difference ($P < 0.05$) between the milled groups and the printed group but no statistically significant difference between the two milled groups (Table 2).

The analysis showed that there is a statistically significant difference between the groups under study, rejecting the null hypothesis ($P < 0.001$). The post hoc test

Group	n	Different ($P < 0.05$) from factor nr.
(1) 3D Printed - Temp Print (GC)	1 5	(2)(3)
(2) Milled - Telio CAD (Ivoclar)	1 5	(1)
(3) Milled - Brilliant Crios (Coltene)	1 5	(1)

Table 2. Student-Newman-Keuls test for all pairwise comparisons of the analysed groups.

microns. The milled restoration groups exhibited closely comparable outcomes, with the Telio CAD group averaging 37

The printed restoration group showed higher deviation values than the milled ones, with an average intaglio surface trueness of 48

the printed group and the milled restorations groups. (Fig.7).

microns and the Brilliant Crios group averaging 36 microns. A roughly 11 microns difference was observed between

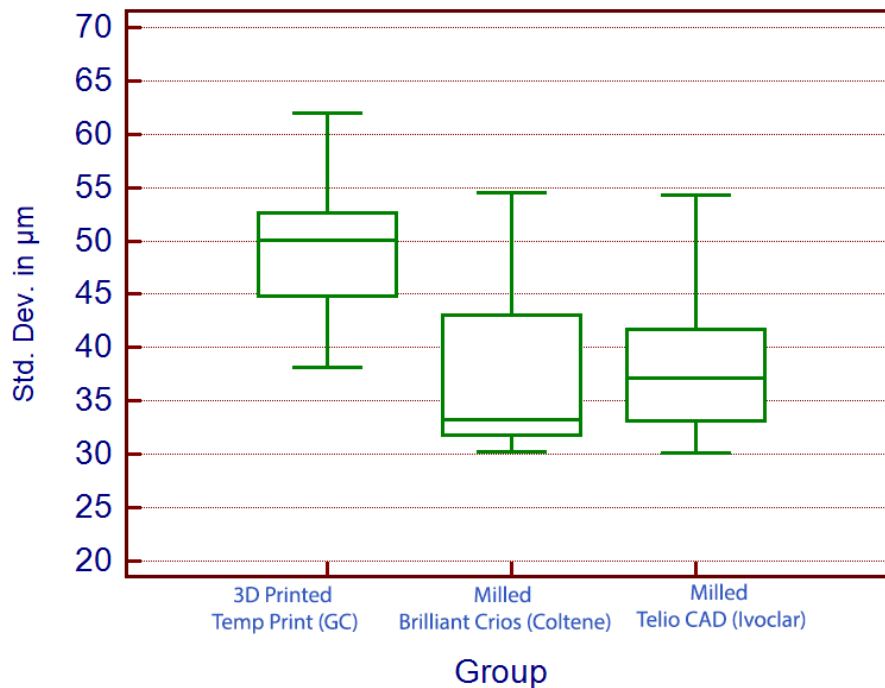


Figure 7. Boxplot displaying the intaglio surface trueness values of the tested sample groups.

Additive process can also lead to less accurate restorations due to several factors. These factors include: the build angle in which some areas will be more exposed to light curing than others leading to different degrees of polymerization shrinkage; the position of the support attachments can lead to errors of the unsupported areas. A support pin positioned too close to the margin of the restoration can lead to damage during the removal of the pin. Alharbi et al. investigated the influence of build angle and thickness of the support on the accuracy of printed crowns and concluded that a build angle of 45-90 degrees provides the highest accuracy and the smallest support area [18,19].

Build direction can also influence the mechanical properties of the material,

DISCUSSIONS

Marginal and internal fit are essential for the longevity of a crown and ensure the seal and retention of the restoration. The internal fit of a prosthetic restoration can be influenced by several factors directly dependent on the manufacturing process: milling or printing. During the subtractive process, the diamond burs used by the milling machine suffer changes that are more and more evident with each milled restoration. Even though these diamond burs are replaced after a specific number of uses (established by the manufacturer), there is no "wear" control during this "working interval". As the diamond coating gets worn out, it progressively affects the accuracy of the milled restorations [15-17].

on the surface. If there are small, microscopic areas where residual resin has not been completely dissolved and washed away by the previous alcohol wash protocol, these resin areas will harden during the post-polymerization process. The restoration no longer presents a toxic risk, but the area will result as an addition on the restoration surface, which will decrease the fidelity of the surface. It should be also taken into consideration that the curing station in which the restorations are placed for post-curing cannot guarantee that UV light reaches the entire effective surface of the restoration uniformly and in the same proportion, which may again lead to differences in fidelity.

The purpose of this study was to evaluate the differences in marginal and internal fit between milled and printed interim crowns. The current study findings showed that milled restorations provide slightly better accuracy than those obtained through additive manufacturing. One potential explanation for these results can be found in the necessary postprocessing steps of both additive and subtractive technologies. The milled resins did not require any post polymerization step, meaning that there was no polymerization shrinkage, thus no alteration of the overall geometry. For the printed restorations, the polymerization process is not equal on all the surfaces therefore, some areas will be overexposed to the light curing. The alcohol bath may decrease the thickness of the restoration by dissolving surface areas of the restoration leading to areas with deficient fit.

However, the accuracy results for both milled and printed restorations were within the accepted limit of <50 microns. This indicates that both manufacturing variants and all materials tested in the present study predict a clinically acceptable fit. No

vertical printing having more compressive strength than those printed horizontally. [20]

There are a few studies which show that DLP as well as Polyjet printers generate high accuracy restorations and provide clinical alternatives to the conventional methods [21,22].

The properties of 3D printed resins have been compared to those of milled CAD-CAM resins, but the results are varied. The main advantage of printing is the reduced waste as well as a decreased working time for mass produced restorations [23].

The printed prosthetic restorations must go through the post-processing protocol which includes washing in isopropyl alcohol/ethyl alcohol for 5 minutes OR 3 minutes in an ultrasonic bath with ethyl alcohol. This affects the entire surface of the restoration including the intaglio surface. If certain areas of the surface show more residual resin, these areas will be washed to a different extent as other areas that do not contain excess residual resin, areas where the alcohol may begin to dissolve the surface of the printed restoration microscopically. Any change in the washing protocol may result in varying degrees of microscopic alteration of the restoration surface (e.g., shorter or longer washing/soaking time in alcohol). It is almost impossible to ensure a perfectly uniform microscopic wash over the entire printed restoration because the excess unpolymerized resin will not be perfectly uniform on the restoration when it is removed from the printer and placed in the wash tank. After washing in alcohol, the printed restorations go through a drying process and then UV curing for a minimum of 4 minutes. This must also be carried out on the intaglio surface of the restoration to ensure that no toxic monomer resin remains

machine was used. Also, the wear of the milling tools was not evaluated in the present study. Therefore, the authors advise experimenting with various additive manufacturing methods and evaluating additional brands of resin used for 3D printed crowns. Additionally, using different milling machines can lead to more comprehensive results regarding the overall trueness comparison between milled and printed restorations.

printed restorations (11 microns difference), thus promising a better internal fit.

2. The smallest mean discrepancy was observed for the Brilliant Crios (Coltene) milled occlusal veneers
3. There were no statistically significant differences in the intaglio surface trueness of the two different groups of milled materials.
4. Both milled and printed restorations showed mean values of the intaglio surface trueness within the accepted limit of <50 microns, indicating a clinically acceptable fit.

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clinically observable differences in the internal fit of the restorations can be expected based on the approximately 11 microns differences observed between the printed and milled restorations.

Among the limitations of the study the following aspects are worth mentioning. The printed crowns were manufactured using only one brand of printing resin and only one printer. Moreover, for the subtractive manufacturing, only one milling

CONCLUSIONS

The discrepancy values of the three investigated groups showed statistically significant differences in terms of trueness of the intaglio surface between milled and printed crowns, milling procedure being able to manufacture prosthetic restorations with better internal fit.

The following conclusions can be drawn within the limitations of this in-vitro investigation:

1. The milled occlusal veneers showed slightly better results in terms of mean intaglio surface trueness compared to

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