THE JOURNAL OF PROSTHETIC DENTISTRY

RESEARCH AND EDUCATION

Influence of print orientation on the intaglio surface accuracy (trueness and precision) of tilting stereolithography definitive resin-ceramic crowns

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ABSTRACT

Statement of problem. Vat-polymerization tilting stereolithography (TSLA) technology can be selected for fabricating definitive crowns; however, how the printing variables, including print orientation, influence its manufacturing accuracy remains unclear.

Purpose. The purpose of this in vitro study was to assess the influence of different print orientations (0, 45, 75, or 90 degrees) on the intaglio surface accuracy (trueness and precision) of TSLA definitive resin-ceramic crowns.

Material and methods. The virtual design of an anatomic contour molar crown was obtained in standard tessellation language (STL) file format and used to manufacture all the specimens by using a TSLA printer (DFAB Chairside) and a resin-ceramic material (Irix Max Photoshade single-use cartridges). Four groups were created depending on the print orientation used to manufacture the specimens: 0- (Group 0), 45- (Group 45), 70- (Group 75), and 90-degree (Group 90) print orientation (n=30). Each specimen was digitized by using a laboratory scanner (T710) according to the manufacturer's scanning protocol. The reference STL file was used as a control to measure the volumetric discrepancies of the intaglio surface with the digitized specimens by using the root mean square (RMS) error calculation. The trueness data were analyzed by using 1-way ANOVA followed by post hoc pairwise multiple comparison Tukey tests, and precision data were analyzed using the Levene test (α=.05).

Results. Significant mean trueness (P<.001) and precision (P<.001) value discrepancies were found among the groups tested. Additionally, all the groups were significantly different from each other (P<.001), except for the 45- and 90-degree groups (P=.868). Group 0 showed the best mean trueness and precision values, while the Group 90 demonstrated the lowest mean trueness and precision values.

Conclusions. The print orientations tested influenced the intaglio surface trueness and precision values of the TSLA definitive resin-ceramic crowns. (J Prosthet Dent 2023;■:■-■)

Polymer, metal, and ceramic additive manufacturing (AM) technologies provide a new fabricating method for producing interim and definitive prostheses.[1-5] With the development of these technologies and the increasing variety of available dental materials, definitive resin-ceramic restorations can be fabricated by using vat-polymerization 3-dimensional (3D) printers.[6-9]

When using vat-polymerization printers, different printing parameters such as print orientation,[10-25] layer thickness,[13,24] position on the build platform,[14,23] and

Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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Clinical Implications

To maximize the manufacturing accuracy, 0-degree print orientation is recommended for fabricating definitive resin-ceramic crowns by using the selected TSLA (DFAB Chairside) and a resin-ceramic material (Irix Max Photoshade).

postprocessing procedures[25-27] can influence the mechanical properties,[10,12,14-16,18,20,22-24] surface roughness,[12] manufacturing accuracy,[12,17,18,20,21,23,28] and marginal and internal discrepancies[11-13,19] of vat-polymerized surgical implant guides,[17] denture bases,[12] and interim dental materials.[10,11,13-16,18-30] However, the influence of these printing parameters when processing these new definitive resin-ceramic materials using vat-polymerization 3D printers remains unknown. The understanding of how the outcome of printed restorations can be affected by operator decisions when handling a vat-polymerization printer is fundamental to standardizing the printing procedures and optimizing the additive fabricating procedures.

The 3 main vat-polymerization categories based on the light source for polymerizing the material in the vat-polymerization 3D printer[3,30,31] are stereolithography (SLA), which uses a laser[31,32]; digital light processing (DLP), which has a projector or a digital micromirror device (DMD)[31,33]; and liquid crystal display (LCD) based printers, also called daylight polymer printing (DPP), which use an LCD screen to polymerize the photosensitive resin.[31,34] Tilting stereolithography (TSLA) technology is an SLA printer in which the build platform is positioned at a 45-degree orientation for manufacturing a device. This provides several advantages such as shorter printing time, higher viscosity of the photosensitivity resin, and manufacturing of restorations with graded color.[3,30,31]

The purpose of the present in vitro study was to assess the influence of different print orientations (0, 45, 75, or 90 degrees) on the intaglio surface accuracy (trueness and precision) of vat-polymerized TSLA definitive resin-ceramic crowns. The null hypothesis was that no difference would be found in the intaglio surface accuracy (trueness and precision) of the vat-polymerized TSLA definitive resin-ceramic crowns fabricated with different print orientations.

MATERIAL AND METHODS

The virtual design of an anatomic contour molar crown was obtained in standard tessellation language (STL) file format. The design had an overall minimum thickness of 1 mm without any internal sharp angles.[35] The reference STL file was used to manufacture all the specimens by using a TSLA printer (DFAB Chairside; DWS) and a resin-ceramic material (Irix Max Photoshade A1-A3,5, single-use cartridges; DWS).

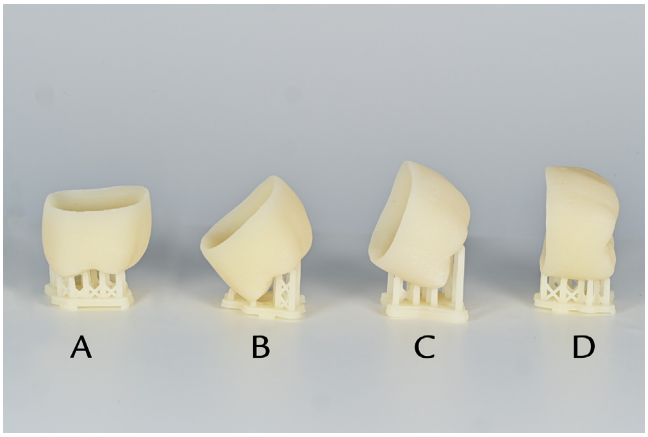

Figure 1. Representative specimen of each group tested. A, Group 0. B, Group 45. C, Group 70. D, Group 90.

The manufacturing accuracy of the printer selected was 3 μm on the x-, y-, and z-axis as reported by the manufacturer.

Four groups were created depending on the print orientation used to manufacture the specimens: 0- (Group 0), 45- (Group 45), 70- (Group 75), and 90-degree (Group 90) print orientation (n=30). The 0-degree print orientation represented the occlusal surface of the crown positioned toward the build platform; therefore, the printing layer would be parallel to the occlusal surface of the crown specimen. The manufacturer's recommended layer thickness of 60 μm was selected. All the remaining printing parameters were identical among the groups tested. Because of the restricted size of the build platform (20×50 mm), only 3 specimens of the same group were printed at a time. After printing, the specimens were rinsed in a bath of 95% pure ethyl alcohol (96% Ethyl Alcohol; Innovating Science) for 2 minutes.[25-27] Then, the specimens were dried using compressed air to remove any residue, followed by an additional 3 minutes drying in a paper towel at 24 °C ambient temperature. Lastly, the polymerization of the specimens was completed in a UV-polymerization unit (DCure; DWS) for 9 minutes. No additional postprocessing procedure was completed (Fig. 1).[25-27]

Each specimen was digitized by using a laboratory scanner (T710; Medit) by following the manufacturer's scanning protocol. The digitalization procedure did not require scanning powder. The manufacturer of the scanner reports a scanning accuracy of 4 μm. Each scan was exported in an STL file format.

The reference STL file was used as a control to measure the volumetric discrepancies of the digitized specimens by using a computer-aided design (CAD) software program (Medit Link, Medit Design App, v.3.0.3; Medit). The reference STL file and the experimental file were defined and aligned by using the best fit technique.[36] After the alignment, the intaglio of the specimen was selected, followed by the inversion of the selection, which allowed the elimination of all the scans

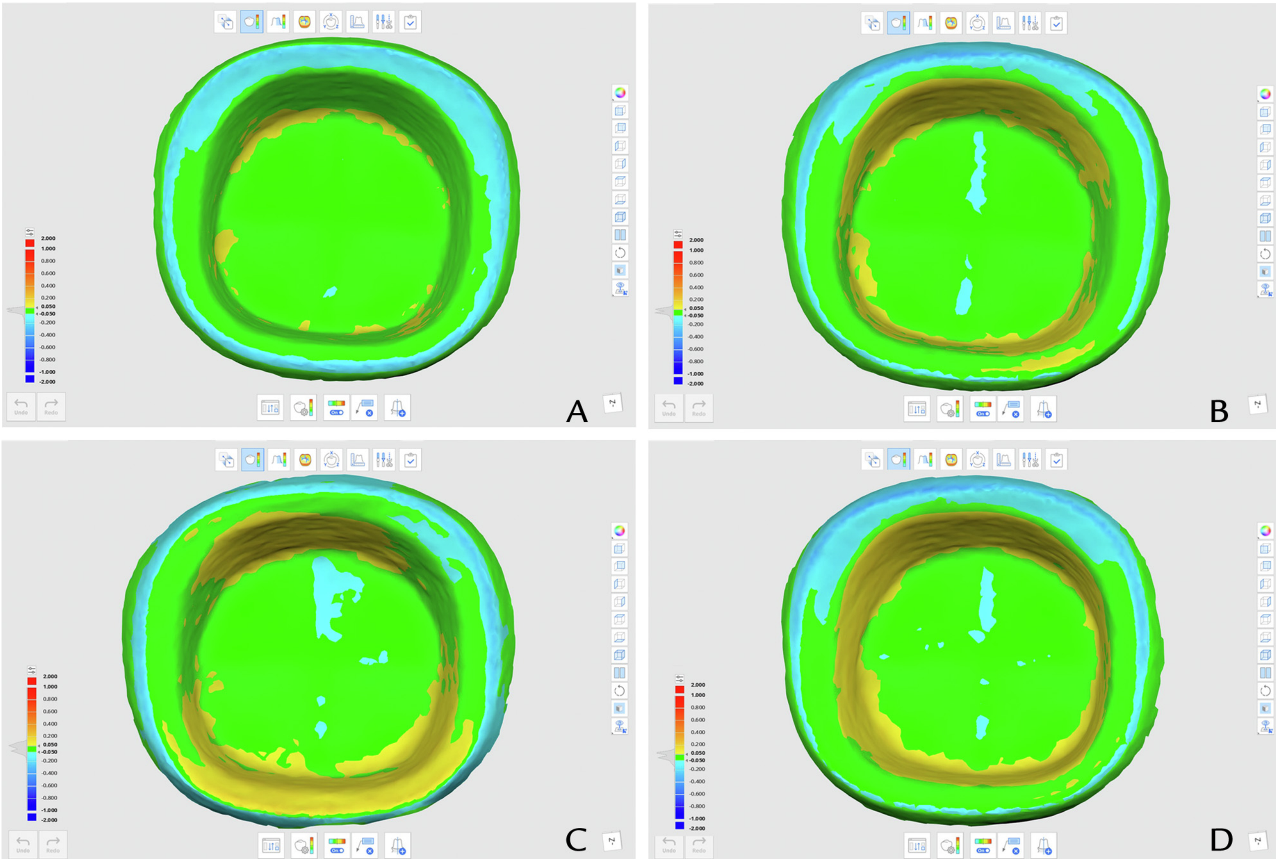

Figure 2. Representative color map discrepancy of each group tested. A, Group 0. B, Group 45. C, Group 70. D, Group 90.

except the intaglio surface. The volumetric discrepancy of the intaglio surface between both meshes was measured using the root mean square (RMS) error calculation: $RMS = \sqrt{\frac{\sum_{i=1}^{n}(X_{1,i}-X_{2,i})^2}{n}}$, where X1,i are the reference data and X2,i are the scan data, and where n indicates the total number of points measured in each analysis (Fig. 2).

The RMS error measurements for each group were used to analyze the data. Trueness was defined as the average RMS error discrepancies between the reference file and the digitized specimens, while precision was described as the RMS error variations per each group or standard deviation (SD).[37,38] The Shapiro-Wilk test showed that the data were normally distributed. The trueness data were analyzed using 1-way ANOVA followed by post hoc pairwise multiple comparison Tukey tests (α=.05). The precision data were analyzed by using the Levene test (α=.05). A statistical software program (IBM SPSS Statistics, v25 for Windows; IBM Corp) was used to analyze the data.

RESULTS

The overall mean ±standard deviation RMS error discrepancies (trueness ±precision) are presented in Table 1. One-way ANOVA showed significant mean trueness value discrepancies among the groups tested (df=3, MS=0.001353, F=14.05, P<.001). Additionally, all the groups were significantly different from each other (P<.001), except for the 45- and 90-degree groups (P=.868). Group 0 showed the best mean trueness value, while Group 90 demonstrated the worst mean trueness value (Fig. 3A, B).

Regarding the precision evaluation, the Levene test showed significant precision value discrepancies among the groups tested (P<.001). All the groups were significantly different from each other (P<.001), except for the 45- and 90-degree groups (P=.951). Group 0 showed the best mean precision value, while Group 90 demonstrated the worst mean precision value (Fig. 3B).

DISCUSSION

The results of the present study demonstrated that the print orientations tested influenced the intaglio surface trueness and precision values of the definitive resin-ceramic crowns fabricated by using the selected TSLA printer (DFAB; DWS) and resin-ceramic material (Irix Max Photoshade; DWS). The 0-degree print orientation showed the best manufacturing accuracy values, while the 90-degree print orientation showed the lowest

Table 1. Descriptive trueness and precision values obtained among groups tested

Group	Mean ±SD RMS Error (μm) Trueness ±Precision
Group 0	54 ±5
Group 45	62 ±9
Group 70	70 ±15
Group 90	61 ±7

SD, standard deviation; RMS, root mean square.

manufacturing accuracy values. Therefore, the null hypothesis was rejected.

The authors are unaware of a previous study that assessed the influence of different print orientations on the intaglio surface accuracy of TSLA definitive resin-ceramic crowns; consequently, comparisons with previous published studies are not feasible. Based on the results obtained in this study, 0-degree print orientation should be selected for maximizing the intaglio surface accuracy of the crowns fabricated with the selected TSLA printer and resin-ceramic material. Previous studies have demonstrated that restorations fabricated with the layer oriented perpendicular to the load direction would maximize the flexural strength of the restoration.[10,39] Therefore, when using the selected printer and material, the 0-degree print orientation may not only maximize the manufacturing accuracy of the intaglio surface of the crowns but also the flexural strength characteristics of the TSLA AM restorations.

Different investigations have analyzed the influence of the print orientation on manufacturing accuracy when processing interim dental materials[16,18,20,21,28] using vat-polymerization 3D polymer printers. Additionally, in these previous studies, either a bar-[16,20] or crown-shaped[18,21,28] specimen and a different manufacturing trinomial were used to fabricate the specimens (technology, printer, and interim dental material). Moreover, this is the first in vitro study assessing the influence of print orientation on the manufacturing accuracy of the intaglio surface of definitive resin-ceramic crowns fabricated by using a TSLA printer. The optimization of the printing parameters, including print orientation, should be based on the manufacturing trinomial and clinical application of the printed device.[18] As a result, when a different printer and material are used or an alternative printing protocol is selected, comparisons of the results among studies are difficult.

De Castro et al[16] evaluated the influence of different print orientations (0, 45, and 90 degrees) on the manufacturing accuracy of bar-shaped specimens fabricated by using 3 different materials and 4 printers (1 SLA, 2 DLP, and 1 LCD). The results showed manufacturing accuracy among the materials and printers tested, in which the 90-degree print orientation of the SLA group obtained the highest manufacturing accuracy in length and thickness.[16] The manufacturing accuracy for width did not show significant differences among the groups tested.[16] Similarly, Tahayeri et al[20] assessed the influence of different print orientations (0, 15, 45, and 90 degrees) on the manufacturing accuracy of the bar specimens fabricated by using an SLA printer (FormLabs1+; Formlabs) and an interim dental material (Nexdent C&B; 3D Systems). The authors reported that specimens printed at a 90-degree orientation had the lowest average percentage error.[20] However, comparisons with the results of the present investigation are not feasible because of the differences in the manufacturing trinomial and geometry of the specimens.

Yu et al[21] compared the manufacturing accuracy on the intaglio surface of the crowns manufactured with different print orientations (90, 120, 135, 150, 180, 210, 225, 240, and 270 degrees) by using an SLA printer (ZENITH U; ZENITH) and an interim dental material (ZMD-1000B Temporary; Dentis), measuring manufacturing accuracy from the RMS error. The results demonstrated that the manufacturing protocol tested accurately reproduced the intaglio surface of the interim crowns at between 150 and 210 degrees print orientation.[21] The results of the present study are not comparable because of differences in the printer, interim material processed, and geometry of the specimens.

An in vitro study also assessed the impact of varying print orientations (90, 120, 135, 150, 180, 210, 225, 240, and 270 degrees) on the manufacturing accuracy of printed interim crowns.[18] The specimens were fabricated by using a DLP printer (D30; Rapidshape) and an interim dental material (Nexdent C&B; 3D Systems).[18] The RMS error calculations revealed the lowest manufacturing discrepancies on the 135- and 210-degree print orientation groups.[18] Comparisons with the results of the present study are challenging because of disparities in the AM technology, printer, interim material processed, and geometry of the specimens.

Alharbi et al[28] also tested the effect of different print orientations (90, 120, 135, 150, 180, 210, 225, 240, and 270 degrees) and supportive material configuration (thick and thin) on the manufacturing accuracy of printed interim crowns. The 120-degree print orientation with either thick or thin support designs showed the lowest manufacturing discrepancy.[28] Comparisons with the results of the present study are challenging because of disparities in the AM technology, printer, interim material processed, and geometry of the specimens.

A previous review concluded that the optimization of the printing protocols should be based on the manufacturing trinomial selected (AM technology, printer, and material) and the clinical application of the printed dental device.[30] The different results among the studies that assessed the influence of print orientations on the manufacturing accuracy of printed interim crowns may confirm the previous suggested conclusion.[30] The manufacturing protocol for fabricating definitive resin-ceramic restorations should be based on the technology, printer, and material selected.

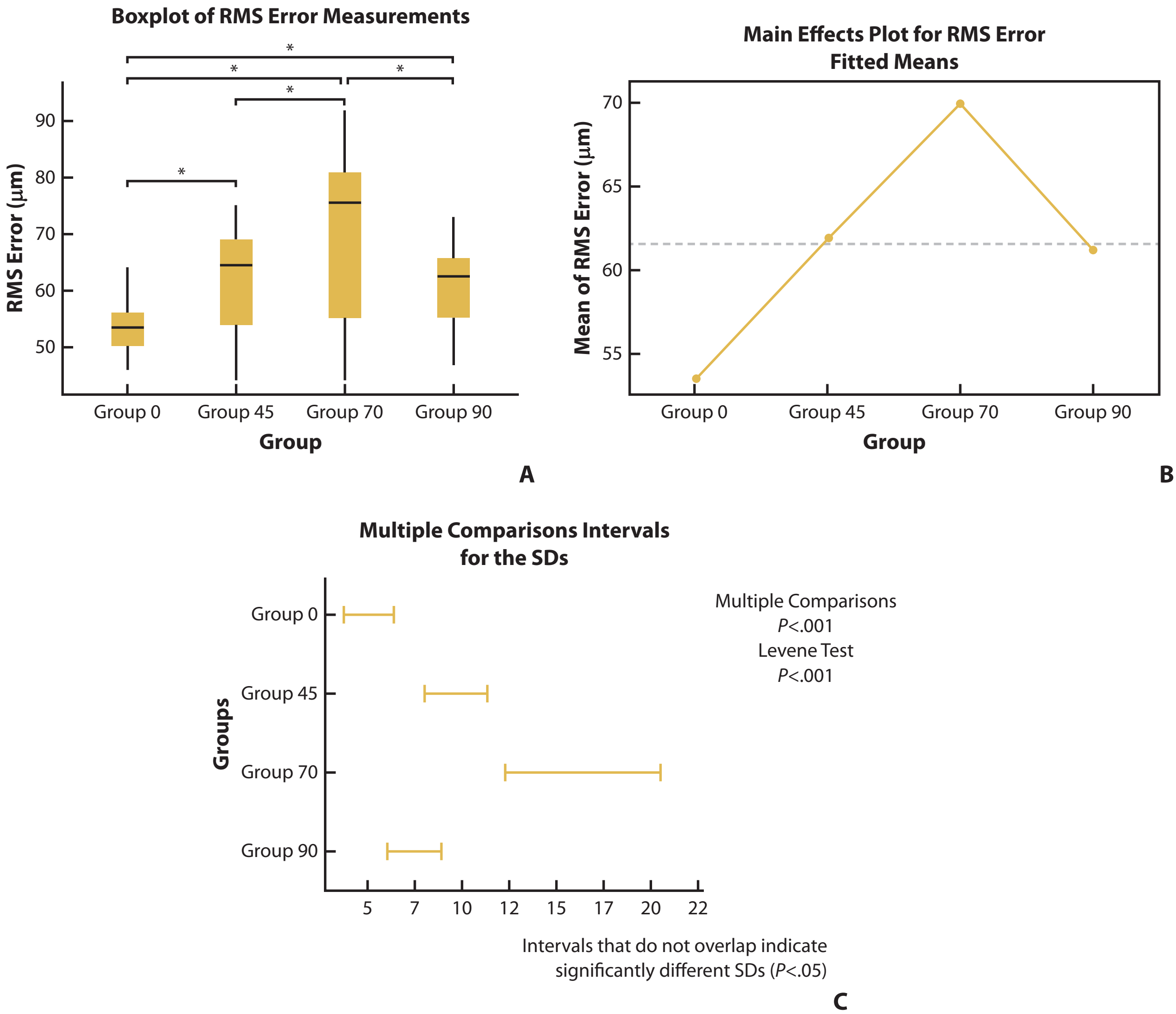

Figure 3. A, Boxplot of RMS error measurements (trueness). B, Main effects plot for RMS error (trueness). C, Multiple comparisons intervals for the SDs (precision). Data in µm. RMS, root mean square; SD, standard deviation.

Additionally, the printing parameters and postprocessing procedures should be standardized to optimizing the outcome of the printed restoration.[25-27,30] Additionally, the different results from the present study may be explained by the different manufacturing trinomial used to fabricate the crown specimens.

In the present investigation, because of size limitations of the build platform, the specimens were manufactured in multiple printing procedures. However, except for print orientation, the same printing parameters and postprocessing protocol were used to standardize the manufacturing protocol. Additionally, only the intaglio surface of the specimens was assessed, as the supportive material was positioned on the occlusal, buccal, lingual, or proximal surfaces depending on the print orientation tested; this prevented an evaluation of the manufacturing accuracy of the entire specimen.

Limitations of the present study included the use of a single TSLA printer and material, as well as a single best fit algorithm selected to align the reference and the experimental files. Additionally, the manufacturing accuracy of the specimen was only assessed on the intaglio surface of the crowns. Additional studies are required to assess the influence of different printing parameters on the accuracy, mechanical properties, and marginal and internal discrepancies of the TSLA definitive resin-ceramic crowns.

CONCLUSIONS

Based on the results of the present in vitro study, the following conclusions were drawn:

1. The print orientations tested (0, 45, 70, and 90 degrees) influenced the manufacturing trueness and

precision values of the intaglio surface of the TSLA definitive resin-ceramic crowns.

2. The 0-degree print orientation showed the best manufacturing trueness and precision values on the intaglio surface of the specimens among the print orientations tested.
3. The 90-degree print orientation showed the lowest manufacturing trueness and precision values on the intaglio surface of the specimens among the print orientations tested.

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https://doi.org/10.1016/j.prosdent.2023.03.020