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Evaluation of Accuracy of Different Print Angulations for 3D Printed Dental Crowns

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Additive manufacturing (AM), also known as additive printing, is increasing its importance in every field of dentistry. There are different methods of AM, one of these being digital light processing (DLP). Several factors can influence the accuracy of printed crowns, and one of them is the building or printing orientation. Therefore, the aim of this study is to evaluate the trueness and precision of temporary crowns produced via DLP with different printing angles. An artificial molar prepared to receive a full crown was scanned. A total of 15 resin crowns were printed through DLP and divided into three groups considering 3 different printing angulations: 90°, 45° or a custom angulation. Trueness and precision were evaluated considering the Root Mean Square Error (RMSE). Regarding the internal fit, the 90° printing angulation showed a higher accuracy compared to the other angulations, whereas regarding the occlusal aspect, Custom angulation crowns were better. Custom Crowns showed a higher precision when considering the internal aspect, being equal to the 90° printing angulation regarding the occlusal aspect. 135° printing angulation value performed equal or worse precision and accuracy in all zones. In terms of trueness and precision, custom angulation crowns showed acceptable internal and occlusal results for 3D printed provisional crowns.

Keywords: 3D printing, provisional crowns, print orientation.

1. INTRODUCTION

Computer-aided design and computer-assisted manufacturing (CAD-CAM) have quickly caught on in the field of dentistry and are currently widely used. CAD-CAM workflow involves the acquisition of data, their digital elaboration, and finally the manufacturing process of the restoration through different techniques [1].

There are two main digital production ways in the field of the manufacturing process: Additive Manufacturing (AM) and Subtractive manufacturing (SM). Subtractive Manufacturing (SM) involves milling the object from a disk or a cube made of resin or ceramic. This is a high accuracy process since the material, already in a solid state, is not subjected to polymerization shrinkage; on the other hand, there is a high waste of material and the burs used to mill the restorations may create micro-cracks in the milled restoration; this method is also fairly slow and burs need to be replaced often [2]. Additive Manufacturing (AM), also known as 3D printing, is defined as the “process of joining materials to make objects from 3D model data, usually layer by layer, as opposed to subtractive manufacturing methods” [3]. This method facilitates the manufacturing of complex geometries, while guaranteeing less waste of material and faster production [4]. The ISO 17296-2:2015 [5] distinguishes seven categories of AM processes: vat-polymerization (VPP), material extrusion (MEX), material jetting (MJT), binder jetting (BJT), powder-based fusion (PBF), sheet lamination (SHL), and directed energy deposition (DED).

The Vat polymerization technology is capable of producing highly complex structures with a layer-by-layer method, in which consecutive microscopic layers of a photosensitive resin are exposed to light irradiation [6]. Depending on the type of light source employed to trigger polymerization, VPP can be further divided in the following subcategories: Stereolithography (SLA), Direct Light Processing (DLP), Continuous Direct Light Processing (CDLP), and Direct UV Printing (DUP) [7]. In the dental field, Digital Light Processing (DLP) is increasing its popularity in dentistry, allowing the production of high-precision manufacts rapidly and economically while providing an excellent aesthetic [8]. It involves a Digital Micromirror Device (DMD) made up of hundreds of thousands of micromirrors that can be moved by software to an on/off state [9].

Recently, 3D printing technologies have been used to produce temporary restorations. In fixed prosthodontics, the temporary phase is extremely important, both functionally and esthetically. Among the various advantages of using 3D printing to produce temporary crowns, there is the possibility of producing a new one based on the digitally scanned data, considering the frequent breakage of temporary restorations [10]. Additionally, the 3D model of

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the temporary crown can also be used for the design of the final crown.

3D printing temporaries, however, poses some challenges regarding the accuracy of the product, which is described by trueness and precision, according to ISO 5725 [11]. Trueness is defined as the closeness of agreement between the arithmetic mean of a large number of test results and the true or accepted reference value, whereas precision is the closeness of agreement between test results [11, 12]. The accuracy of 3D printed products depends on laboratory factors (such as devices, materials, 3D printing technology used) and on operator-dependent factors, one them being the building or printing orientation [12], which is the angulation of the STL file to the building platform applied during the nesting process [12], which influences the manufacturing time process, the shrinkage between the layers, and the mechanical properties of the printed materials [13], which are affected by anisotropy, since the object is produced along a preferential direction [14].

Despite of the large number of research for the best build orientation [14 – 16] the effects of different orientation on accuracy remains an open issue: the primary objective of this study is to evaluate the trueness and precision of temporary crowns produced via DLP with three printing angles, considering the fit (internal aspect) and the occlusal aspect of the printed crowns.

The secondary objective of this study is the macroscopic evaluation of the samples' marginal fit using a periodontal probe used as a reference with no measurement, and the evaluation of qualitative aesthetic criteria (eg. details of the occlusal anatomy) to understand if the printing orientation might also affect these aspects.

2. EXPERIMENTAL DETAILS

Using a training dummy, tooth number 4.6 (FDI numbering system) was prepared to receive a dental crown and it was scanned using an optical scanner (Primescan, Dentsply) to obtain surface data. A dental crown for the prepared tooth was designed using dental CAD software (DentalCad, Exocad): the margins of the crown were determined digitally on the scanned model of the prepared tooth; the contralateral tooth of the training dummy was also scanned and mirrored to obtain adequate anatomy of the crown, then adapted to the crown margins previously determined. Digital occlusal checks were performed, and the occlusal anatomy was modeled to remove excessive occlusal contacts and provide adequate adaptation of the digital crown to the training dummy's occlusion. The model obtained was exported and saved as an .stl file (master file).

Using slicing software (Chitubox 1.8.1) the main axis of the crown was orientated in three different printing angles:

- 90°: perpendicular to the printing platform;
- 45°: at a 45° angle to the printing platform;
- custom angle: oriented to minimize the number of supports on the occlusal surface.

While the first two angles involve a rotation limited to only one axis, the custom orientation comprises the rotation of the tooth along two different axes: considering the morphology of the crown in an exam, a rotation of about 35° on the X-axis and 50° on the Y-axis was necessary to obtain the minimum amount of supports without compromising printing reliability (according to simulations run on Chitubox). The support used for the prints was a combination of different thicknesses and was placed manually supporting overhanging sections of the model (also called "islands") [17]. Layer height was set to 0.3 mm; support settings can be seen in Table 1, Table 2 and Fig. 1.

Table 1. Settings for light supports

Top section		Middle section		Bottom section	
Setting	Value	Setting	Value	Setting	Value
Contact shape	None	Shape	Cylinder	Platform touch shape	Skate
Contact diameter, mm	0.20	Diameter, mm	1.00	Touch diameter, mm	10.00
Contact depth, mm	0.20	Angle, °	70.00	Thickness	0.80
Connection shape	Cone	Small pillar shape	Cone	Model contact shape	None
Upper diameter, mm	0.20	Diameter, mm	0.40	Contact diameter, mm	0.40
Lower diameter, mm	1.00	Upper depth, mm	0.25	Contact depth, mm	0.20
Connection length, mm	1.00	Lower depth, mm	0.25	Contact point	3
Auto support					
Cross width, mm	4.00	Cross width, mm	4.00	Cross width, mm	4.00
Cross start height, mm	1.00	Cross start height, mm	1.00	Cross start height, mm	1.00
Density, %	50.00	Density, %	50.00	Density, %	50.00
Angle, °	45.00	Angle, °	45.00	Angle, °	45.00

Table 2. Settings for medium supports

Top section		Middle section		Bottom section	
Setting	Value	Setting	Value	Setting	Value
Contact shape	None	Shape	Cylinder	Platform touch shape	Skate
Contact diameter, mm	0.40	Diameter, mm	1.50	Touch diameter, mm	12.00
Contact depth, mm	0.15	Angle, °	70.00	Thickness	1.00
Connection shape	Cone	Small pillar shape	Cone	Model contact shape	None
Upper diameter, mm	0.40	Diameter, mm	0.50	Contact diameter, mm	0.60
Lower diameter, mm	1.50	Upper depth, mm	0.30	Contact depth, mm	0.20
Connection length, mm	3.00	Lower depth, mm	0.30	Contact point	3
Auto support					
Cross width, mm	4.00	Cross width, mm	4.00	Cross width, mm	4.00
Cross start height, mm	3.00	Cross start height, mm	3.00	Cross start height, mm	3.00
Density, %	50.00	Density, %	50.00	Density, %	50.00
Angle, °	45.00	Angle, °	45.00	Angle, °	45.00

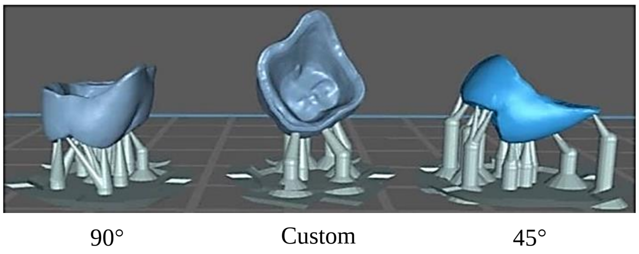

Fig. 1. Crown orientations

A total of 15 provisional crowns were printed using a Sonic Mini 4K (Phrozen) using the DSI 3d Crown & Bridge Resin (Dental Solutions Israel), divided into groups of 5 specimens based on the printing angle:

- D90 group (*n*=5): DSI 3D C&B resin was used, printing layers at a 90° angle compared to the main axis of the tooth. Models were labeled as D 90-a, D 90-b, D 90-c, D 90-d, D 90-e;
- D45° group (*n*=5): DSI 3D C&B resin was used, printing layers at a 45° angle compared to the main axis of the tooth. Models of this group were labeled as D 45°-a, D 45°-b, D 45°-c, D 45°-d, D 45°-e;
- DCu group (*n*=5): DSI 3D C&B resin was used, printing layers at a custom angle compared to the main axis of the tooth. Models of this group were labeled as D cu-a, D cu-b, D cu-c, D cu-d, D cu-e.

Optimal printing settings were derived from the printing of multiple resin exposure tests (xp2 Validation Matrix, Photonsters) and following the instructions provided by the manufacturer (Table 3).

Table 3. Printer settings for DSI 3d Crown & Bridge Resin (Dental Solutions Israel)

3D printer settings	
Layer height, mm	0.03
Bottom layer count	4
Transition layer count	0
Transition type	linear
Exposure time, s	2.3
Bottom exposure time, s	13.8
Light-off delay, s	11.6
Bottom light-off delay, s	11.6
Bottom lift distance, mm	6
Lifting distance, mm	6
Bottom lift speed, mm/s	50
Lifting speed, mm/s	50
Retract speed, mm/s	150

All the prints were subdivided into 2 printing plates and saved as a .ctb file. The files were saved on a USB flash drive and transferred to the 3D printer (Sonic Mini 4K, Phrozen). The printer was kept in a thermostat-controlled temperature environment to match the temperature of 37 °C during the whole printing process. The resins containers were vigorously shaken and then poured into the printer vat. The printing process was then started. Following the manufacturer's instructions, prints from groups D90, D45°, Dcu underwent two cycles of isopropyl alcohol washing of 3 minutes each in a cleaning station (Wash&Cure, Anycubic), and then dried with compressed air (Fig. 2). After printing, all the models were further polymerized in the Anycubic Wash&Cure station for 30 minutes total: all the areas of the print were equally exposed to the light thanks to the 360° positioning of the blue LED lights of the Anycubic Wash & Cure station.

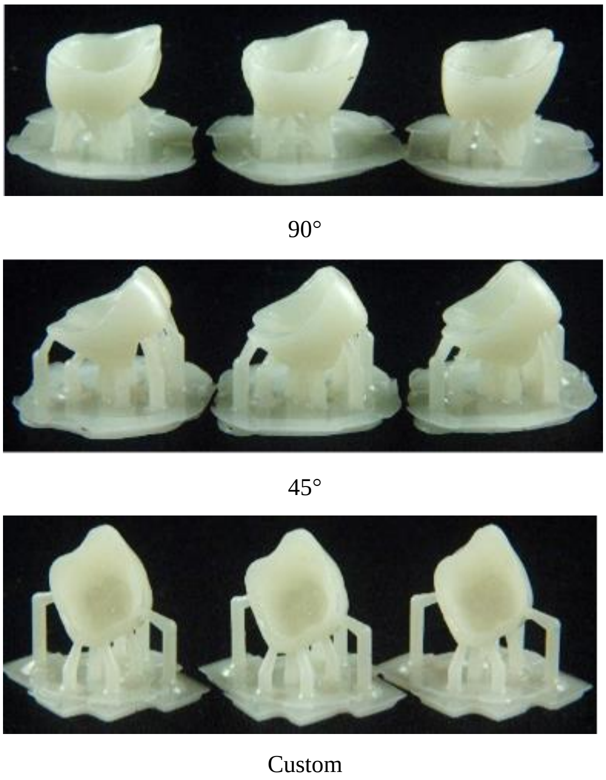

Fig. 2. Print results of different printing orientations

The supports were then gently removed from the prints using a combination of manual and rotatory tools to remove exclusively the flash left by the supports. Polishing was not performed in order to avoid removing material, which could influence the measurements.

The prints were then coated with a scanning powder (Powder Scan Spray, VITA) and scanned with a laboratory scanner (InEos X5, Sirona) to generate .stl files (called test files from now on) for occlusal surfaces and internal surfaces. Test files were imported into the software used for measuring and comparing the crowns through a digital subtraction technique: CloudCompare V2.12. An error of 8 µm was considered to compensate for the thickness of the scan spray (based on indications of average coat thickness provided by the manufacturer). The way the software works is the following: it allows the comparison of two digital models, in this case the master model (the one designed through exocad and exported as an .stl file) and the scanned crown: this is done by aligning the models manually by picking 4 equivalent point pairs (one on the master model, one on the scanned crown model) to create the same coordinate system. The excess surface of the scanning platform acquired with the scanning of the printed crowns was segmented out with the appropriate tool.

The models were then finely aligned with an automatic software function and distances between mesh points were computed. Each printed crown surface is subdivided by the algorithm of the program into several points, creating a cloud of points. The same happens for the surface of the master model. The distance between each pair of corresponding points is then calculated. Data was exported as an Excel file. The files were one by one to the master file (Fig. 3). For each model, the data consists of a set of distance values and the number of points of the printed crown that find themselves at that specific distance from the master model. In the case of Fig. 4, a green color suggests that the points of the scanned crown correspond to those of the master model: a red or blue color indicates an excess or defect of material, respectively. This procedure was repeated for every printed crown, separating the inner and the outer surface (since scanning the whole printed crown in one single file was not possible due to the scanner's software limitations).

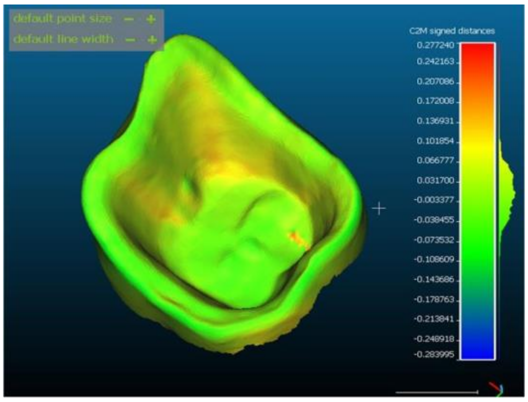

Fig. 3. Example of the results of the comparison of the master 3D model and a printed crown using Cloudcompare software

Fig. 4. Macroscopic analysis of the marginal fit of Custom orientation crowns. The "frosty" look of the surface is caused by the scanning powder used

The comparison made by the software then provides the Root Mean Square Error (RMSE), which is the numeric value expressing the difference between two compared volumes. For trueness, each scanned specimen was compared to the reference STL (master 3D model) and a mean RMSE was obtained for each group, for both internal and external surfaces. For Precision, in each group every scanned specimen was compared to the other specimens, and a mean RMSE was obtained for each group for both internal and external surfaces (Table 4).

The sample size calculation was performed on the primary outcome, the trueness and the precision of printed temporary crowns measured as the Root Mean Square Error (RMSE). Based on the work of Hada and co-workers (2020) [2] who compared 0°, 45° and 90° printing angles, the minimum samples size required was 4 crowns per group, considering a power of 90 % and $\alpha = 0.05$.

It was decided to print and analyze 5 crowns per group to overcome the risk of possible non-readable crowns. Statistical analyses were performed using the statistical analysis software XLSTAT from Addinsoft (2022). (citazione: XLSTAT statistical and data analysis solution. New York, USA. https://www.xlstat.com/en). Descriptive statistics were reported as means, standard deviations, and percentages. Shapiro-Wilk test was performed to verify the normality of the distributions. According to the distribution of the variables, parametric (One-way ANOVA and Tukey's test for multiple comparisons) or non-parametric (Kruskall-Wallis) tests were used to analyze the sample.

3. RESULTS

3.1. Trueness and precision evaluation

To evaluate the trueness and the precision for both internal and external surfaces, the RMSE between the models was used. This value is given by the Cloudcompare software through the digital subtraction technique and expresses the difference in volume between the master model and the scanned print: the smaller the RMSE is, the more similar two models will be.

Regarding internal trueness, the 90° orientation is the most accurate in a statistically significant manner ($p < 0.05$), followed by the custom orientation and 45° orientation, which show no statistically significant differences between each other.

Regarding external trueness, the custom orientation is the most accurate in a statistically significant manner ($p < 0.05$), followed by the 45° and the 90° orientation, which show no statistically significant differences between each other.

Regarding internal precision, the custom orientation is more precise than the 90° orientation in a statistically significant manner ($p < 0.05$) but shows no statistically significant differences compared to the 45° orientation. The 90° orientation is less precise than both the custom and 45° orientation in a statistically significant manner ($p < 0.05$)

Regarding external precision, the custom and 90° are more precise than the 45° orientation in a statistically significant manner ($p < 0.05$) but have no statistically significant differences between them.

In addition to digital analysis, all the models were fitted on the tooth abutment to observe the precision and trueness of the crowns at a macroscopical level. Photographs were taken of the occlusal portion of the models to observe and compare the occlusal topography and aesthetics (Fig. 4, Fig. 5, Fig. 6, Fig. 7).

Fig. 5. Macroscopic analysis of the marginal fit of 90° orientation crowns. The "frosty" look of the surface is caused by the scanning powder used

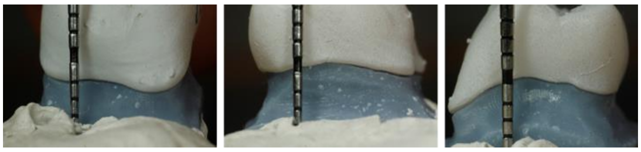

Fig. 6. Macroscopic analysis of the marginal fit of 45° orientation crowns. The "frosty" look of the surface is caused by the scanning powder used

As seen in the Fig. 4 to Fig. 7, a periodontal probe was positioned vertically next to the crown in order to provide a way to evaluate macroscopically the fit of the restoration.

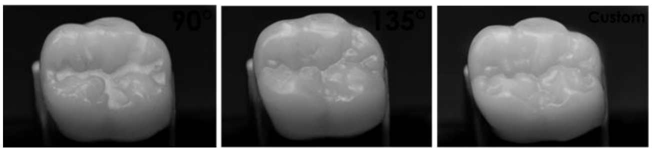

Fig. 7. Macroscopic analysis of the occlusal surfaces. From left to right: 90° orientation, 45° orientation and custom orientation

No numerical measurements were made using the probe, and only the presence of an “acceptable” or “unacceptable” fit was registered. The different angles of the photographs allowed inspection from all sides. An “acceptable fit” was registered if there was no macroscopical gap between the crown and the finishing line of the preparation: if a gap was present the fit was deemed “unacceptable”. As seen in Fig. 7, the occlusal surface examination consisted of a macroscopical observation of the pits and grooves of the surface: it was considered “acceptable” if the anatomy of the tooth was well marked and pleasant to the eye, while it was deemed “unacceptable” if markings, resin-filled pits and fissures or distortions were present.

4. DISCUSSION

The conflicting nature of studies regarding the printing orientation of 3D printed objects is mainly caused by the diversity of materials and 3D printers available. Most of the studies available, however, do not evaluate the possibility of rotating a 3D model in three dimensions, and limit rotation of a to-be-printed model on only one axis: the custom orientation of a model based on the need to apply as little supports as possible in order to minimize post-processing has been scarcely investigated in literature.

In addition, it is important to highlight the difference between the occlusal and internal surfaces of a print: the internal surface obviously needs to be highly accurate to guarantee the best fit, but the occlusal surface also needs to be accurate, for both functional and aesthetic reasons: the latter is influenced by the presence of printing supports that need to be cut, grainded and polished after polymerization.

The trueness and precision of a print (similarity to the master model and repeatability of the process, respectively) defines the accuracy of a process and are determined by the RMSE between the master model and the printed object and between printed objects: this number needs to be as close to zero as possible; the higher the number, the less accurate a print is [18].

Thus, accuracy is a combination of the trueness and precision of a certain data set, and both need to be considered.

Previous studies have explored the effect of different print orientations: some used simple geometric shapes [18 – 20] while others used dentures [2] and single crowns [21 – 23]: results from these studies are conflicting due to the diversity in the light source, printer and resins used; most of the studies on print orientation evaluate rotation of the model on only one axis, while rotation on the remaining two axes has been neglected.

Many studies have used different methods of comparing STL files from master models and scanned crowns [22]: one of the most used is the digital subtraction technique, using software such as Geomagic Studio (3D Systems). The techniques used in this in-vitro study have been based on previous work which, however, only observed occlusal trueness and precision and did not analyze internal trueness and precision for full crowns.

To examine statistically significant data, the mean RMSE of each group with its standard deviation was considered, similar to other studies found in literature [22]. This value allows us to compare different groups in a statistical manner and determine which orientation is the best regarding external and internal trueness and precision. One of the drawbacks of this technique is that preventive measures need to be taken to not introduce errors in the measurement: excess scanned surface (i.e. supporting structures, other teeth etc) should be cut from the digital model; recognizable points need to be present to correctly choose them and thus reliably couple the models to allow the program to analyze their volumes. However, with care, this technique has proven to be reliable to compare digital volumes [16, 22].

A small RMSE for a group of prints indicates that all the parts of the model are practically identical to each other and to the master 3D model.

In the present study, it was observed that the 90° orientation is the most accurate only regarding internal trueness, with the custom orientation as a close second, while the latter excels in both external trueness, internal precision and external precision. The worst performing, overall, is the 45° orientation.

The reason for this is probably due to the nature of the printing process, which is essentially a successive apposition of slices: the difference in model orientation produces different sets of slices, and makes it necessary for different sets of supports to be positioned and designed; some degree of distortion may be present even with correctly designed and positioned supports, and it might be related to the orientation of the model. The superior internal accuracy of 90° prints might be related to the regular aspect of the internal surfaces of the crowns, while for the external accuracy, the custom orientation has better results because of the irregular nature of the external surface (with cusps, curves, pits and fissures); Any degree of orientation usually provides good results for curved surfaces in VAT 3D printing.

For the macroscopic analysis of marginal fit and surface detail, if the marginal fit is considered, the 90° orientation crowns seemed to have the best all-around marginal fit, followed by the custom oriented crowns and the 45° orientation crowns: all crowns, however, seemed to have minimal marginal inaccuracies.

If occlusal anatomy is considered, the custom orientation shows the best-looking occlusal surface among all the groups; the worst occlusal aspect is found in 90° orientation crowns.

This may be because the number of layers with which the morphology of the sulcus is "described" changes according to the orientation. A 90° orientation places the apex of the groove perpendicular to the print surface using far fewer layers than would be used by placing the apex of the groove angled to the surface. Moreover, there is a critical distance under which two points are recognized as a single point. This threshold is exceeded much closer to the point of maximum depression of the sulcus in the 90° inclination compared to that at 45° or custom. Those two factors combined with the fact that the cusps are not self-supported for the most part in the 90 orientation lends to more rough occlusal morphology. The present study has some flaws that need to be addressed: first of all, a bigger sample size is desirable. Secondly, potential deformations introduced by the position in different areas of the plate during the printing process were not taken into account. Finally, regarding the supports, it is currently not possible to establish a standard workflow that allows any operator to position them in the same manner, especially on surfaces as complex as the occlusal surfaces of dental elements. A different support asset or slicing software could introduce different distortions from those that emerged in this study.

Table 4. RMSE values for the internal and external precision and trueness

Orientation	Internal trueness	External trueness	Internal precision	External precision
D90	0.050±0.005	0.083±0.007	0.020±0.003	0.038±0.004
DCu	0.032±0.0026	0.090±0.005	0.022±0.003	0.030±0.004
D45	0.053±0.003	0.071±0.004	0.019±0.002	0.027±0.003

5. CONCLUSIONS

In this study, a quantitative accuracy analysis and a qualitative aesthetical evaluation were conducted. From the results of the accuracy analysis, the 90° orientation has been reported as the most accurate only regarding internal trueness, with the custom orientation as a close second, while regarding external trueness, internal precision and external precision the custom orientation is the most accurate. The worst performing, overall, is the 45° orientation. Regarding the macroscopical evaluation of marginal fit, the worst performing crowns were the 45° orientation ones, while 90° and custom orientation crowns showed the best performances.

For the macroscopical evaluation of occlusal surface and marginal fit, unfortunately, no numerical data is available, but through objective observation the custom orientation crowns seem to be the best performing while the 90° orientation showed the poorest performance. The absence of numerical data for the macroscopical observation of occlusal surface esthetics and the marginal fit is one of the drawbacks of this study, and the observations made by the authors should be interpreted with care: one of the future objectives of the authors is to use an adequate method of measuring the real marginal fit and to evaluate the occlusal surface numerically in order to provide statistical observations on the matter. Based on the results of the present study, it can be concluded that the Custom orientation seems to be the one that excelled in both accuracy and aesthetical tests. This result highlights the importance of exploiting both rotational axes when placing a model on the build plate in the digital design phase. Future objectives are to increase the number of samples to obtain more statistically relevant data and, as already stated, to evaluate the marginal fit numerically. It would also be desirable to develop a program capable of recognizing and autonomously adding supports in the most congenial way to the morphology of the type of printed restoration.

It would then be useful to evaluate the repercussions of these different orientations on the resistance to load cycles of the printed products. Furthermore, a careful analysis of the surface color with the spectrophotometer could highlight other aesthetically relevant data such as possible changes in the color rendering of the layer overlap in different angles. A comparison with other resins and a quantitative evaluation of the marginal fit would also be desirable in future studies.

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REFERENCES

1. **Piedra-Cascon, W., Krishnamurthy, V.R, Att, W., Revilla-León, M.** 3D Printing Parameters, Supporting Structures, Slicing, and Post-Processing Procedures of Vat-Polymerization Additive Manufacturing Technologies: A Narrative Review *Journal of Dentistry* 109 2021: pp. 103630. https://doi.org/10.1016/j.jdent.2021.103630
2. **Hada, T., Kanazawa, M., Iwaki, M., Arakida, T., Soeda, Y., Katheng, A., Otake, R., Minakuchi, S.** Effect of Printing Direction on the Accuracy of 3D-Printed Dentures Using Stereolithography Technology *Materials* (Basel) 13 (15) 2020: pp. 3405. http://doi.org/10.3390/ma13153405
3. **ISO/ASTM** Additive Manufacturing – General Principles – Terminology. *Beuth* 2017, 52900.
4. **Van Noort, R.** The Future of Dental Devices Is Digital . *Dental Materials* 28 (1) 2012: p. 3 – 12.
5. **ISO/ASTM** Additive Manufacturing – General Principles – Part 2: Overview of Process Categories and Feedstock. *Beuth* 2016 17296-2.
6. **Unkovskiy, A., Schmidt, F., Beuer, F., Li, P., Spintzyk, S., Kraemer Fernandez, P.** Stereolithography vs. Direct Light Processing for Rapid Manufacturing of Complete Denture Bases: An in Vitro Accuracy Analysis *Journal of Clinical Medicine* 10 2021: pp. 1070 – xx. http://doi.org/10.3390/jcm10051070
7. **Schweiger, J., Edelhoff, D., Güth, J.F.** 3D Printing in Digital Prosthetic Dentistry: An Overview of Recent Developments in Additive Manufacturing *Journal of Clinical Medicine* 10 2021: pp. 2010. http://doi.org/10.3390/jcm10092010
8. **Lee, H.E., Alauddin, M.S., Mohd Ghazali, M.I., Said, Z., Mohamad Zol, S.** Effect of Different Vat Polymerization Techniques on Mechanical and Biological Properties of 3D-Printed Denture Base *Polymers* 15 2023: pp. 1463. http://doi.org/10.3390/polym15061463
9. **Dudley, D., Duncan, W., Slaughter, J.** Emerging Digital Micromirror Device (DMD) Applications *Micromachining and Microfabrication* 4985 2003: pp. 1 – 25.
10. **Xiangjia, L., Xie, B., Jin, J., Chai, Y., Chen, Y.** 3D Printing Temporary Crown and Bridge by Temperature Controlled Mask Image Projection Stereolithography *Procedia Manufacturing* 26 2018: pp. 1023 – 1033.

https://doi.org/10.1016/j.promfg.2018.07.134

11. **ISO/ASTM** Accuracy (Trueness and Precision) of Measurement Methods and Results – Part 1: General Principles and Definitions, I.O.F. Standardization, Geneva, CH, 1994.
12. **Herpel, C., Tasaka, A., Higuchi, S., Finke, D., Kühle, R., Odaka, K., Rues, S., Lux, C.J., Yamashita, S., Rammelsberg, P., Schwindling, F.S.** Accuracy of 3D Printing Compared With Milling – A Multi-Center Analysis of Try-in Dentures *Journal of Dentistry* 110 2021: pp. 103681. http://doi.org/10.1016/j.jdent.2021.103681
13. **Alharbi, N, Osman, R., Wismeijer, D.** Effects of Build Direction on the Mechanical Properties of 3D-Printed Complete Coverage Interim Dental Restorations *Journal of Prosthetic Dentistry* 115 (6) 2016: pp. 760 – 767. http://doi.org/10.1016/j.prosdent.2015.12.002
14. **Di Angelo, L., Di Stefano, P., Guardiani, E.** Search for the Optimal Build Direction in Additive Manufacturing Technologies: A Review *Journal of Manufacturing and Materials* 4 2020: pp. 71. https://doi.org/10.3390/jmmp4030071
15. **Yu, B.Y, Son, K., Lee, K.B.** Evaluation of Intaglio Surface Trueness And Margin Quality of Interim Crowns in Accordance with the Build Angle of Stereolithography Apparatus 3-Dimensional Printing *Journal of Prosthetic Dentistry* 126 (2) 2021: pp. 231 – 237. http://doi.org/10.1016/j.prosdent.2020.04.028
16. **Osman, R., Alharbi, N., Wismeijer, D.** Build Angle: Does ot Influence the Accuracy of 3D-Printed Dental Restorations Using Digital Light-Processing Technology? *The Internatonal Journal of Prosthodontics* 30 (2) 2017: p. 182 – 188. http://doi.org/10.11607/ijp.5117
17. **Shi, K., Cai, C., Wu, Z., Yong, J.** Slicing and Support Structure Generation for 3D Printing Directly on B-rep Models *Visual Computing for Industry, Biomedicine, and Art* 2 (1) 2019: p. 3. http://doi.org/10.1186/s42492-019-0013-x
18. **Shim, J.S., Kim, J.E., Jeong, S.H., Choi, Y.J., Ryu, J.J.** Printing Accuracy, Mechanical Properties, Surface Characteristics, and Microbial Adhesion of 3D-Printed Resins with Various Printing Orientations *Journal of Prosthetic Dentistry* 124 (4) 2020: p.468 – 475. http://doi.org/10.1016/j.prosdent.2019.05.034
19. **Unkovskiy, A., Bui, P.H., Schille, C., Geis-Gerstorfer, J., Huettig, F., Spintzyk, S.** Objects Build Orientation, Positioning, and Curing Influence Dimensional Accuracy and Flexural Properties of Stereolithographically Printed Resin *Dental Materials* 34 (12) 2018: p. e324 – e333. http://doi.org/10.1016/j.dental.2017.10.003
20. **Tahayeri, A., Morgan, M., Fugolin, A.P., Bompolaki, D., Athirasala, A., Pfeifer, C.S., Ferracane, J.L.** 3D Printed Versus Conventionally Cured Provisional Crown and Bridge Dental Materials *Dental Materials* 34 (2) 2018: p. 192 – 200. http://doi.org/10.1016/j.dental.2017.10.003
21. **Alharbi, N., Osman, R.B., Wismeijer, D.** Factors Influencing The Dimensional Accuracy of 3D-Printed Full-Coverage Dental Restorations Using Stereolithography Technology *The Internatonal Journal of Prosthodontics* 29 (5) 2016: pp. 503 – 510. http://doi.org/10.11607/ijp.4835
22. **Park, G.S., Kim, S.K., Heo, S.J., Koak, J.Y., Seo, D.G.** Effects of Printing Parameters on the Fit of Implant-Supported 3D Printing Resin Prosthetics *Materials (Basel)* 12 (16) 2019: pp. 2533. http://doi.org/10.3390/ma12162533