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Dimensional accuracy of provisional complete crown made by the 3D printing method

Acuidade dimensional de coroas totais provisórias confeccionadas pelo método de impressão 3D

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ABSTRACT

Objective: This study evaluated the dimensional accuracy of provisional complete crowns printed with photopolymerizable resin using an LCD-type 3D printer through optical metrology, varying the printing angle and the number of complete crowns printed at once on a single-build platform. **Material and Methods:** The complete crowns were printed with temporary crown resin, A2 temporary (Wilcos do Brasil), divided into four groups with n=12: Group A - 3 complete crowns positioned at 150° on the x-axis; Group B - 4 complete crowns positioned at 150° on the x-axis; Group C - 3 complete crowns positioned at 180° on the x-axis; and Group D - 4 complete crowns positioned at 180° on the x-axis. Dimensional accuracy was assessed by overlaying images in the Gom Inspect measurement software, where the STL of each complete crown was aligned and compared to the master model. For statistical analysis, one-way ANOVA and Shapiro-Wilk tests were used. **Results:** No significant statistical difference was observed between the different angles, or the number of complete crowns printed at once. **Conclusion:** Based on dimensional accuracy, the printing of provisional complete crowns with an LCD-type 3D printer shows no significant statistical difference with either the 150 or 180-degree angle variations, and there is also no difference when printing 3 or 4 complete crowns at once.

KEYWORDS

CAD-CAM; Dental crowns; Dental prosthesis; Prosthodontics; 3D printing.

RESUMO

Objetivo: Este estudo avaliou a acuidade dimensional de coroas totais provisórias impressas com resina fotopolimerizável por uma impressora 3D tipo LCD por meio da metrologia optica, variando angulação de impressão e número de coroas impressas por vez em uma única plataforma de construção. **Material e Métodos:** As coroas foram impressas com resina para coroa provisória, A2 temporário (Wilcos do Brasil), divididas em quatro grupos com n=12: Grupo A - 3 coroas posicionadas a 150° no eixo x; Grupo B - 4 coroas posicionadas a 150° no eixo x; Grupo C - 3 coroas posicionadas a 180° no eixo x e Grupo D - 4 coroas posicionadas a 180° no eixo x. A acuidade dimensional foi feita com a sobreposição de imagens no programa de aferição Gom Inspect, em que o STL de cada coroa foi alinhado e comparado ao modelo mestre. Para análise estatística, foram utilizados os testes ANOVA um fator e Shapiro-Wilk. **Resultados:** Não foi verificada diferença estatística significativa entre as diferentes angulações ou quantitadade de coroas impressas em uma única vez. **Conclusão:** Com base na acuidade dimensional, a impressão de coroas provisórias com impressora 3D tipo LCD não apresenta diferença estatística significative com nenhuma das duas variações angulação de 150 ou 180 graus e não há diferença também ao fazer a impressão de 3 ou 4 coroas de uma única vez.

PALAVRAS-CHAVE

CAD-CAM; Coroa dental; Prótese dental; Odontologia protética; Impressão 3D.

INTRODUCTION

The making of high-precision dental crowns became possible in dentistry through the wax elimination technique, introduced by Taggart in 1907 [1], however, because it depends on a high level of skill in casting by the dental prosthesis technician, this technique is subject to a multitude of errors during obtaining the piece.

The introduction of the automated CAD/CAM system, computer-aided design/computer-aided manufacturing (GPT-9 2017) in 1970 aimed to simplify the manufacturing processes in dentistry, reducing the dependence on the manual skill of the technician, reducing the chances of errors during obtaining the part [2] reducing clinical and laboratory time, increasing productivity and ensuring quality of the final part with predictability in the treatment, without changing patients' perception of satisfaction [3,4]. CAD/CAM technology facilitates the daily life of the clinician, performing direct teeth scans of a patient using an intraoral scanner is quicker and facilitates simple digital bite registration, for example, in the manufacture of provisional complete crowns, in which there is a need for gingival conditioning by adding material to the provisional crowns [5]. This increase can be made by producing temporary complete crowns with a progressive increase in height so that these cases can be rehabilitated faster than the conventional method [6]. For example, we can also mention the manufacture of prostheses on unitary provisional implants in cases performed with guided surgery for immediate dental implant installation, in which it is possible to plan the exact position of the dental implant through virtual space analysis and, consequently, this information allows the provisional prosthesis to be made before the implant installation surgery. In the conventional method, it is necessary to perform the surgery for implant installation before preparing the provisional prosthesis. In summary, the integration of CAD/CAM for designing dental prostheses, facilitated by the development of rapid prototyping (RP), allows the efficient production of frameworks. This approach offers advantages such as precise fit, simplified fabrication, reduced costs, shortened treatment times, and the potential for mass production, thereby saving materials, time, and effort [7].

The elements of the CAD/CAM system are divided into (1) acquisition of informative data, which consists of image capture through scanning and obtaining the digital file; (2) design (CAD), in which the data obtained in the previous phase in design software, or digital design program, will be processed to plan the design of the definitive prosthesis; and (3) manufacturing process of the prosthesis (CAM), at this stage, automatic machines follow information from a digital design program to manufacture the project of the previous phase [2].

Within the part manufacturing process (CAM) is included, the means of subtractive fabrication or CNC (computer numerical control) (GPT-9 2017), which uses milling machines, and also additive manufacturing, which uses 3D printers.

3D printing was classified in 2017 by Tahayeri et al. [6] according to their manufacturing process, which divides the methods into 4 categories: (1) Fused-deposition modeling, (2) Inkjet printing, (3) Selective laser sintering and (4) lithographic printing. Light or lithographic printing uses photopolymers kept in a vat; direct exposure of the polymer to light builds the 3D object as the sample support moves up or down.

Inserted in light printing, are printers by stereolithography (SLA), printers by digital light processing (DLP) and printers by liquid crystal display (LCD), which are the most used in dentistry.

The applications of 3D printing in dentistry are variable, such as the making of surgical guides, models, occlusal splints, oral and maxillofacial prostheses, fixed partial dentures, removable partial dentures, complete dentures and provisional prostheses. 3D printing allows many customized products to be produced at relatively low costs [8].

3D printing of complex geometries, such as complete crowns, becomes more precise by adjusting the printing parameters, which vary according to the object to be built and the material made. Processing by 3D printing goes through the curing process, in which the construction of the layers is done, and the process of post-curing, in which the final polymerization of the object is done. The printing angle is one of the parameters that, when appropriate, increases the volumetric accuracy of the final result, and reduces printing time and production cost. In the processing, the printing angle makes it possible to support the material during its manufacture.

This support, similar to the sprue in the wax elimination technique, is made through supports of the material itself that will be made. The ideal is that as few supports as possible be placed, to reduce the polymerization contraction of the material during the manufacture, before the post-curing process. In addition, a smaller amount of support reduces the amount of material used. In the post-curing process, these supports will also undergo polymerization contraction, if they are in excessive quantity they can interfere with the volumetric accuracy of the result. The programs used for the 3D printing processing step, called slicing software, offer the operator the automatic option to make these supports or the operator's option to manually insert each support, varying in the number of supports, position and diameter of each support. In the literature, the proposed angles for 3D printing concerning the X-axis of the slicing software platform are 150° and 180° for complete crowns. However, there is no standardization related to the anatomy of the object, so more studies should be conducted for a clinically acceptable adaptation [9].

Another relevant parameter is the amount of high-complexity objects that can be made in the same print, that is, the reproducibility of printed materials. The precision of the final piece is influenced by the light intensity that the material receives on the construction platform [10].

Although there is research that considers the parameters of angle of inclination and reproducibility in 3D prints, the lack of standardization of these parameters is still a recurring problem and there are no studies that relate these two variables together. Inappropriate printing angles can result in a lack of material and failures in the morphology of the object.

The reproducibility and angulation of printing complete crowns can be tested using optical metrology, more specifically dimensional accuracy, because it evaluates in a three-dimensional way a complex geometry, being relatively simpler and faster than conventional techniques such as the silicone replica technique or the technique of direct visualization in microscopy. About the silicone replica, optical metrology allows evaluation without the destruction of the part, in addition, it is not necessary to make cuts in axes pre-defined by the work, reducing the possibilities of manipulation errors, which can be the result of the choice of favorable plans for evaluation. Concerning the technique of direct visualization in microscopy, optical metrology makes it easier to obtain the measurement points, since they are precisely defined by the software [10].

Thus, to analyze the dimensional accuracy of provisional complete crowns printed, the present study made this analysis utilizing optical metrology, varying printing angles and the number of complete crowns printed at the same time on a single construction platform, to indicate an appropriate methodology for 3D printing of provisional complete crowns, since there is still no standard established by the literature.

MATERIAL AND METHODS

In a resin mannequin tooth (MOM© - Manequins Odontológicos Marília, Marília, São Paulo, Brazil), corresponding to the dimensions of a first right upper molar, a prepare was made for a unitary complete crown with a bevel end, occlusal reduction of 1.5 mm and convergence angle of six to ten degrees, about the long axis of the tooth, for the manufacture of the master model. For the preparation, diamond tips mounted in high-speed handpiece under constant irrigation were used, respecting the axial inclinations - spherical tip for wear orientation grooves, thin conical-trunk tip for removal of interproximal contacts, ogival end tip for axial and occlusal wear and rounded end tip for delimitation of the marginal groove. The finish was made with the same diamond tips mounted on a micromotor and low-speed drill, to remove irregularities that may have remained in the region of the cervical termination and round the preparation. The aspect of the finalized preparation is shown in Figure 1.

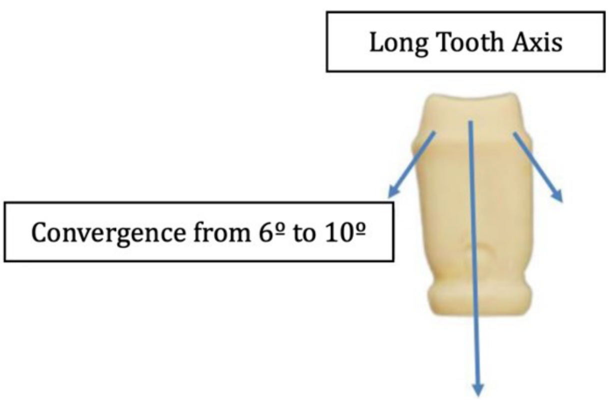

Figure 1 - Preparation of complete crown for making the master model.

The image acquisition was made by scanning the master model with a contact scanner CS3700 (Carestream Dental LLC, Atlanta, USA), to obtain a digital file (Figure 2). After scanning, the image acquisition is transferred to the digital language in the form of a mesh in STL (Standard Triangle Language) format, which is a digital mesh built by triangles. The scanning file was exported to the design software EXOCAD Dental DB 2.4 Plovid 7290 (Exocad GmbH©, Darmstadt, Germany), in which the design of the complete crown was made (Figure 3).

Next, the design file was exported to the W3D Printer Slicer V1.0 printing program (Wilcos do Brasil Indústria e Comércio Ltda, Petrópolis, Rio de Janeiro, Brazil).

The W3D Printer Slicer V1.0 (Wilcos do Brasil Indústria e Comércio Ltda, Petrópolis, Rio de Janeiro, Brazil) program features a support table that makes it possible to plan the print. The printing parameters, described in Figure 4, include a print layer thickness of 0.03mm and an exposure time of 12s per layer. These parameters are important because they influence the accuracy of the object to be created. The groups were divided as follows: Group A - 3 crowns positioned at 150° on the x-axis; Group B - 4 crowns positioned at 150° on the x-axis; Group C - 3 crowns positioned at 180° on the x-axis and Group D - 4 crowns positioned at 180° on the x-axis, with a sample number equal to 12. To reach the sample number, groups A and C were printed four times and groups B and D were printed three times (Figure 5).

The printing of the complete crowns was made of photopolymerizable resin Resilab 3d Premium Temporary color A2 (Wilcos do Brasil Indústria e Comércio Ltda, Petrópolis, RJ, Brazil) (Figure 6A) in a SLA type printer W3D Print (Wilcos do Brasil Indústria e Comércio Ltda, Petrópolis, RJ, Brazil) (Figure 6B).

Figure 2 - Scanner CS 3700, Carestream.

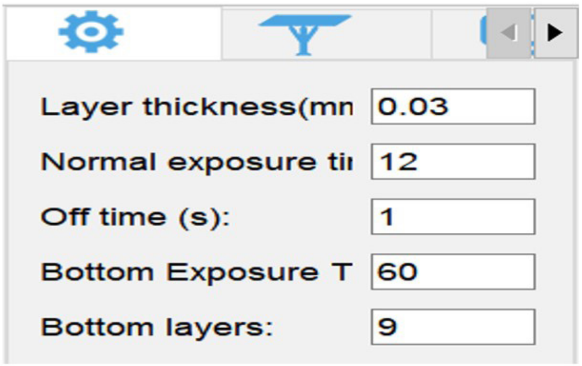

Figure 4 - Print parameters in W3D Printer Slicer V1.0 software.

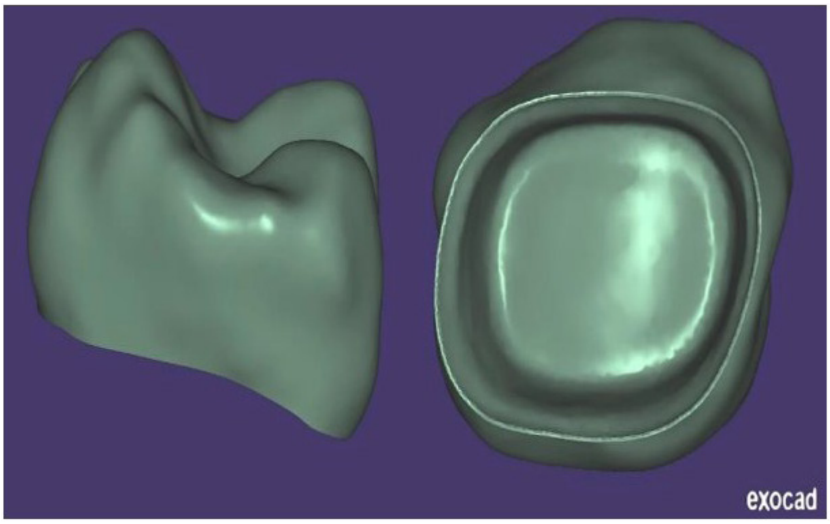

Figure 3 - Design of the complete crown in Exocad software.

The prints were removed from the 3D printer and washed with isopropyl alcohol, then submerged in an ultrasonic tub Anycubic Wash & Cure Machine 2.0 (Anycubic©, Shenzhen, China), (Figure 6C) with isopropyl alcohol for 5 minutes. The post-cure Anycubic Wash & Cure Machine 2.0 (Anycubic©, Shenzhen, China) was done for 45 minutes, according to the manufacturer's instructions. The complete crowns were detached from the printing table with clinical tweezers, the excess material was removed and finished and polished the outside of the complete crown was with polishing drills mounted on a straight piece. All processes were done following the manufacturer's recommendations, without compromising the internal or marginal area.

All printed complete crowns were scanned and the STL file obtained was exported to the GOM Inspect inspection program (GOM© Braunschweig, Germany) for dimensional accuracy analysis by means of overlapping images, a procedure that allows you to evaluate point-to-point any discrepancy in the characteristics of the complete crown. In the program, the CAD file is the reference (the design of the complete crown made by the design software). MESH is the file of the scanned complete crown. Both CAD and MESH were imported into the program in STL format and first underwent a pre-alignment, based on the global best-fit algorithm, with an additional point of aid in the center of the pulp wall of the complete crown. In the MESH file, the internal region of the crown, which includes marginal, axial, and occlusal parts, was selected for the main alignment, best-fit-local, and maximum search distance at 1mm (Figure 7A, B, C). With the meshes properly aligned, the surface comparison between them was performed, with a maximum search distance of 1mm and closed color legend for color histogram, at 120 μm (Figure 7D).

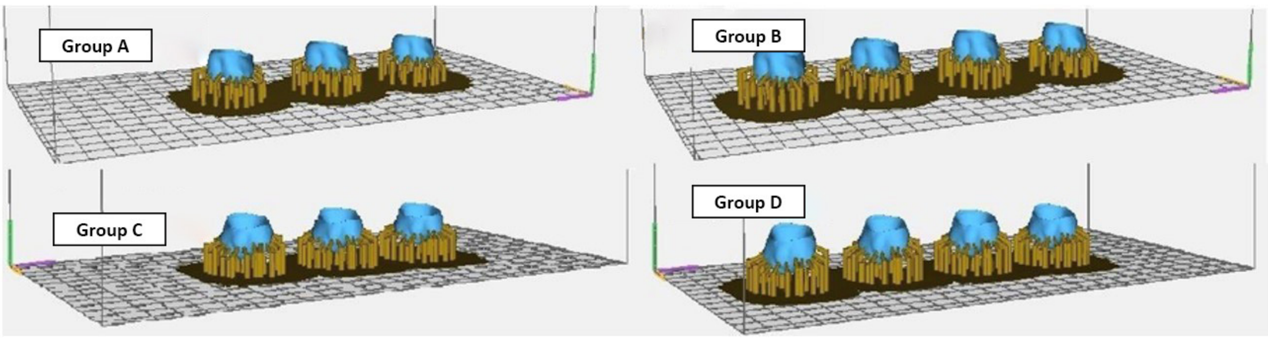

Figure 5 - Print of the software print table, representing each group. Group A, with 3 complete crowns positioned at 150° on the x-axis, totaling 4 impressions to make 12 complete crowns: group B, with 4 complete crowns positioned at 150° on the x-axis, totaling 3 impressions to make 12 complete crowns; group C with 3 complete crowns positioned at 180° on the x-axis, totaling 4 impressions to make 12 complete crowns and group D, with 3 complete crowns positioned at 180° on the x-axis, totaling 3 impressions to make 12 complete crowns).

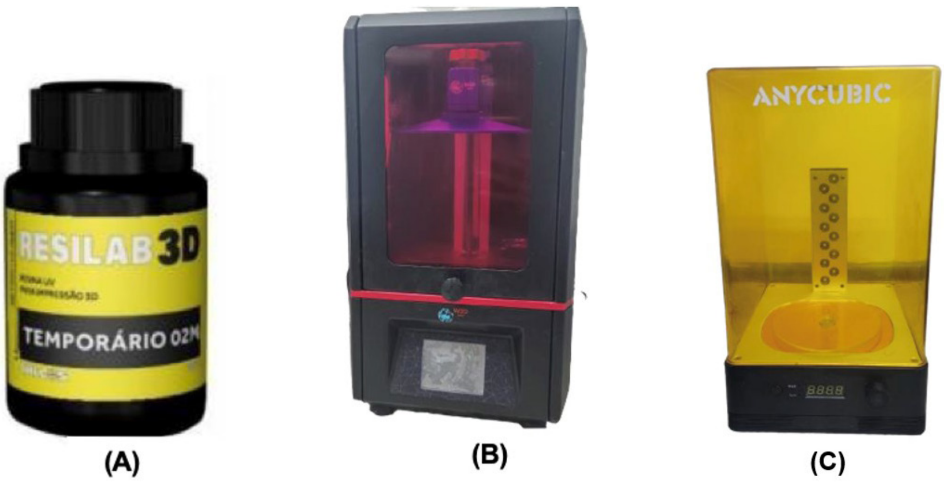

Figure 6 - Representation of materials and methods. (A) Resin resilab 3d Premium Temporary color A2 from Wilcos; (B) Wilcos W3D Print LCD Printer; (C) Utrasonic Cuba Anycubic Wash & Cure Machine 2.0.

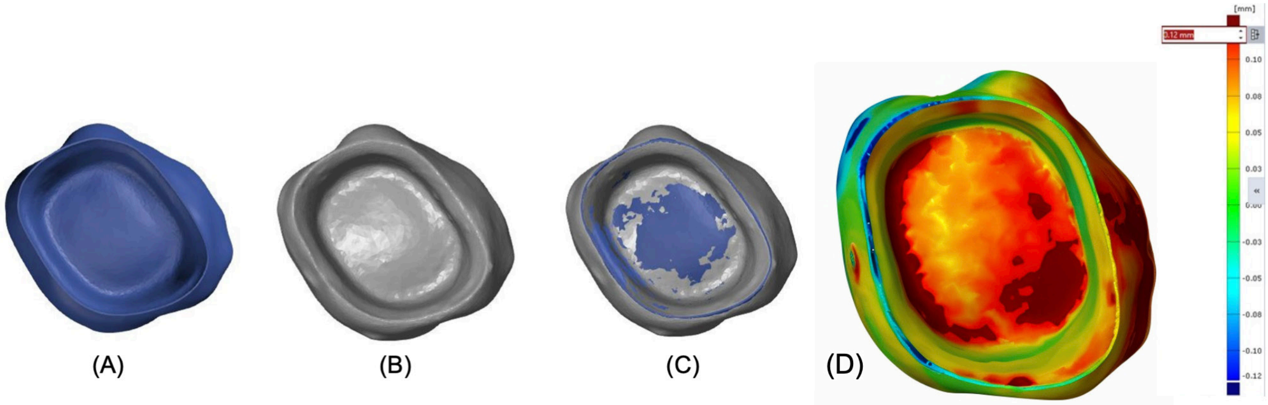

Figure 7 - Alignment of STL files. (A) CAD file; (B) the Mesh file; (C) alignment between the two files; (D) Surface comparison with closed color legend for color histogram, at 120 µm.

Deviation labels were distributed in the internal area of each complete crown, totaling 129 points of deviation, 1mm equidistant (Figure 8). To ascertain the clinical acceptability of the complete crowns, the deviation values were compared to the reference values for marginal adaptation suggested by the literature ≤ 1 μm McLean and von Fraunhofer, 1971 [11]. The values of these deviations were exported to Excel software (Microsoft©, 30 Washington, USA) to calculate the root mean square (RMS), or effective value, of the 129 measured deviation labels of each of the complete crowns.

The mean RMS values were evaluated in the Bioestat 5.0 statistical program. The results of the deviations were used for the root mean square (RMS) of each complete crown, in which the square root of the arithmetic mean of the squares of the deviations of each crown will be made. As for normality, the distribution of the data was analyzed using the Dwass-Steel-Critchlow-Fligner and Shapiro-Wilk tests. The ANOVA one-factor test was used to compare average values. The significance level was established at $P \leq 0.05$ and a 95% confidence interval. To ascertain the clinical acceptability of complete crowns, reference values for marginal adaptation suggested by the literature ≤ 120 μm were used [11].

A comparison of the volume deviations in mm³ was made between the design of the complete crown made in the EXOCAD Dental DB 2.4 Plovid 7290 (Exocad GmbH©, Darmstadt, Germany) and the scanning of each printed complete crown, using the Gom Inspect program (GOM© Braunschweig, Germany). Initially, the volume of the design complete crown (325.45 mm³) was calculated; this value was used as a reference

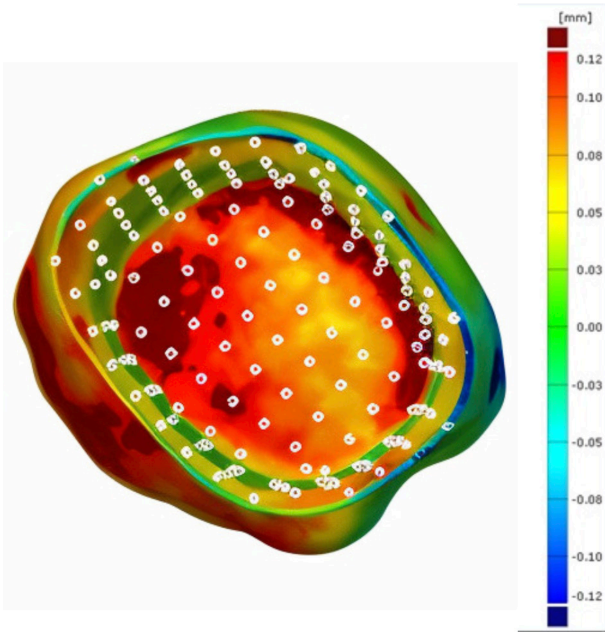

Figure 8 - Visualization of the distribution of equidistant deviation labels.

to compare the volume deviations between the design (nominal value) and the printed complete crowns (current value) (Figure 9).

Since there is no methodology for 3D printing of provisional complete crowns supported by the literature to date, a pilot study has been made to calibrate the main 3D printing parameters used in this study, which are: the thickness of the printing layer (layer thickness); normal exposure time; shutdown time (off time); lower exposure time (bottom exposure time) and amount of lower layers (bottom layers). These parameters were used to establish the most appropriate printing angle and the ideal quantity of complete crowns per print. The density and quantity of supports also influenced the accuracy of the printing.

The thickness of the layer is related to the precision or final resolution of the piece, in an inversely proportional way, because the smaller the thickness of the layer, the greater the resolution, due to the formation of a greater number of layers to compose the final piece, which will present well-defined details and high surface smoothness. In the same way, the bigger the thickness of the layers, the lower the final resolution of the final piece. The normal exposure time is related to the thickness of the layer; the thicker, the longer the exposure time of the layer to light. This parameter is defined according to the thickness of each layer, the complexity of model details, and the resin material. The shutdown time is the interval that UV light is turned off between the formation of each layer. The lower exposure time is the time of exposure to light of the first layers formed, which are called lower layers or "bottom". These layers ensure the adhesion of the resin to the platform and, to perform their function, they must receive a large dose of energy in their formation. To receive the necessary amount of light, the lower layers must be exposed to light for at least 30s. The number of lower layers is also related to the adhesion of the resin to the 3D printer platform.

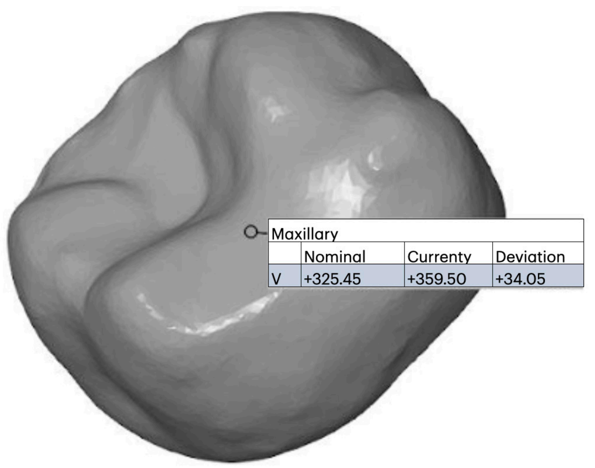

Figure 9 - Volume deviation between design and printed complete crown.

Initially, a print of 9 complete crowns was made: 3 complete crowns positioned at 90 degrees concerning the X-axis, 3 complete crowns positioned at 180 degrees concerning the X-axis, and 3 complete crowns positioned at 150 degrees concerning the X-axis (Figure 10). The following printing parameters were used: print layer thickness 0.05mm; normal exposure time 60s; shutdown time 1s; lower exposure time 60s, 8 lower layers, and light density for the construction supports. The 3D printer was unable to print the complete crowns properly with this configuration, because, at the end of printing, the material was adhered to the platform and at the bottom of the resin tank, indicating that there was insufficient light exposure. A second impression was made with these same settings, changing the exposure time to 12s and support density to medium. This time, there was the 3D construction of the complete crowns, but there was a visible misadaptation of the crown to the master model, mainly of the complete crowns printed at 90 degrees, that is, there was a lower resolution than necessary. As discussed in this section, the 90-degree construction angle produced support fixation in the complete crown margin, resulting in the complete crown with margin misadaptation. A third print was then made, adjusting the layer thickness to 0.03mm and 9 lower layers, moreover reducing the number of complete crowns to 3 complete crowns per print and increasing the number of supports per complete crown (Figure 11). The 90-degree printing angle was discarded, using a 150-degree angle concerning the X-axis. This last impression obtained complete crowns with visible marginal

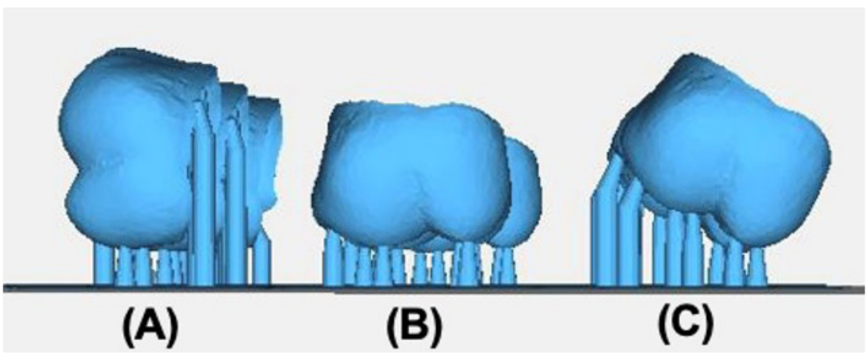

Figure 10 - Printing platform of the pilot study. Pilot study with printing of complete crowns positioned at 90 degrees (A); 180 degrees (B); and 150 degrees (C) concerning the X-axis.

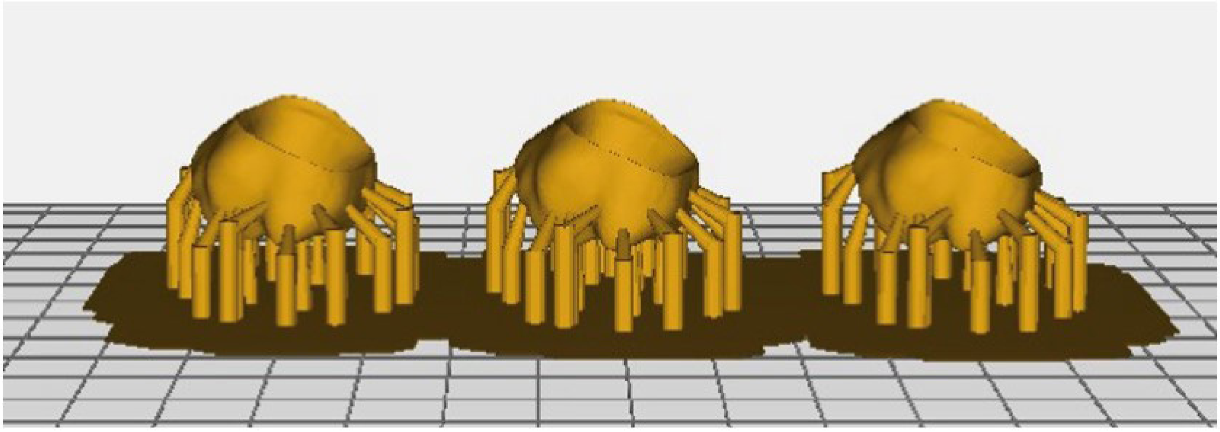

Figure 11 - Printing of 3 complete crowns with an angle of 150° degrees concerning the X-axis.

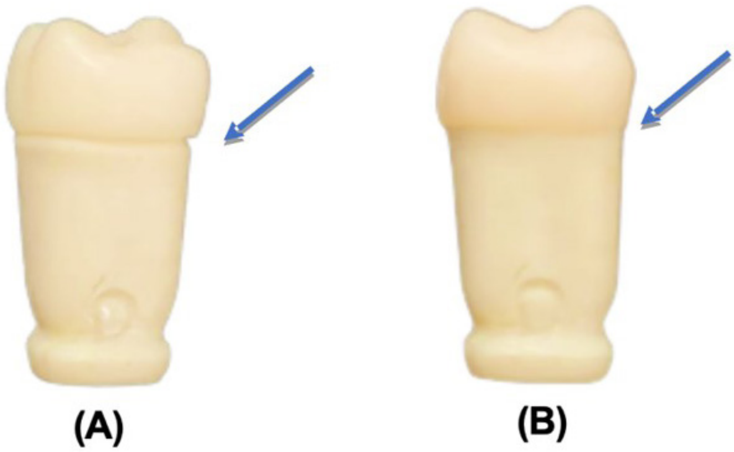

Figure 12 - Marginal adaptation of complete crowns printed in the pilot study. Provisional complete crowns printed without marginal adaptation to the master model (A) and printed complete crowns adapted to the master model (B).

adaptation to the master model (Figure 12), so the same printing parameters were used to make the samples and, later, evaluate dimensional accuracy.

RESULTS

The data were explored for normality by checking the distribution of the data and using the Dwass-Steel-Critchlow-Fligner and Shapiro-Wilk tests. The ANOVA one-factor test was used to compare average values. The significance level was established at $p \leq 0.05$ and a 95% confidence interval. Table I presents RMS data for the crowns of each group. Even the groups presenting homogeneity according to the Levene test ($p=0.728$), except for the 180° group with four samples, the other groups did not follow normal distribution, because their values according to the Shapiro- Wilk test, were below the significance level $\alpha=0.05$.

Table II shows the multiple comparisons for dimensional accuracy between the groups studied, showing that there was no a statistically significant difference ($p \leq 0.05$).

Table III presents the results from the Kruskal-Wallis test between the groups studied, the test reveals that there is no statistically significant difference between the groups for dimensional accuracy (p value= 0.340), that is, p-value above the significance level $\alpha=0.05$. Table IV presents volume values for the crowns of each group. Table V presents the results from the Kruskal-Wallis test between the groups studied, the test reveals that there is no statistically significant difference between the groups for volume (p value= 0.084), that is, p-value above the significance level $\alpha=0.05$. Finally, Table VI presents multiple comparisons between the groups for volume value analyses.

Table I - Nominal values of RMS per crown

Grup A (150 - 3)	Grup B (150 - 4)	Grup C (180 - 3)	Grup D (180 - 4)
0.149297874	0.079381668	0.099005929	0.096150546
0.051898731	0.128141679	0.114629207	0.102345677
0.095500209	0.105658734	0.142159841	0.072176314
0.059180298	0.077464344	0.060585003	0.126465324
0.06366378	0.090750531	0.040985912	0.031364326
0.128652783	0.034763877	0.042270814	0.042307475
0.072446427	0.04668881	0.032397722	0.048119683
0.04668881	0.039854386	0.037695228	0.059337427
0.077464344	0.032943456	0.032943456	0.040280028
0.04668881	0.040985912	0.033154559	0.066478416
0.048086461	0.04	0.034450279	0.052095619
0.031364326	0.035535766	0.031364326	0.060585003

Table II - Multiple comparisons Dwass-Steel-Critchlow-Fligner – Dimensional accuracy

Multiple comparisons - RMS (mm)			
		W	p
150° - 03 Impressions at a time	150° - 04 Impressions at a time	-1.430	0.743
150° - 03 Impressions at a time	180° - 03 Impressions at a time	-2.246	0.386
150° - 03 Impressions at a time	180° - 04 Impressions at a time	-0.368	0.994
150° - 04 Impressions at a time	180° - 03 Impressions at a time	-1.225	0.822
150° - 04 Impressions at a time	180° - 04 Impressions at a time	0.980	0.900
180° - 03 Impressions at a time	180° - 04 Impressions at a time	1.879	0.545

Table III - ANOVA one factor (non-parametric Kruskal-Wallis) - Dimensional accuracy

Kruskal-Wallis			
	χ^2	gl	P
RMS (mm)	3.35	3	0.340

Table IV -. Volume values per crown, in mm^3

Grup A (150 - 3)	Grup B (150 - 4)	Grup C (180 - 3)	Grup D (180 - 4)
343.35	344.26	368.31	375.77
319.82	362.35	363.72	358.18
351.88	359.5	368.56	352.74
365.04	314.89	343.36	376.19
373.98	379.23	350.52	357.14
380.2	364.84	351.46	347.13
368.1	375.29	348.85	340.02
373.52	373.5	345.44	364.43
357.99	378.23	336.26	337.02
353.77	361.53	350.42	363.48
374.08	371.45	339.48	339.65
363.2	351.58	329.68	352.42

CAD reference value= 325.45 mm^3.

Table V - ANOVA one factor (non-parametric Kruskal-Wallis) - Volume

	Kruskal-Wallis		
	χ^2	gl	P
Volume (mm^3)	6.66	3	0.084

Table VI - Dwass-Steel-Critchlow-Fligner multiple comparisons - Volume

Multiple comparisons - Volume (mm^3)			
		W	p
150° - 03 Impressions at a time	150° - 04 Impressions at a time	0.163	0.999
150° - 03 Impressions at a time	180° - 03 Impressions at a time	- 2.858	0.180
150° - 03 Impressions at a time	180° - 04 Impressions at a time	- 1.470	0.726
150° - 04 Impressions at a time	180° - 03 Impressions at a time	- 3.103	0.125
150° - 04 Impressions at a time	180° - 04 Impressions at a time	- 1.878	0.545
180° - 03 Impressions at a time	180° - 04 Impressions at a time	1.633	0.656

DISCUSSION

It is important to emphasize that the evolution of printed materials has been taking place without a consensus in the literature on the ideal standards for 3D printing. Thus, in addition to analyzing the properties of printed materials, it is important to specify the methodology used to establish the ideal parameters for printing materials for dental purposes.

The image overlay method used in the present study proved to be a suitable method and followed the study by Chaturvedi et al. in 2020 [12]. To evaluate the adaptation of the complete crowns, the authors of this study used direct visualization measurement tools in the SEM (scanning electron microscopy). They cited adaptation evaluation techniques, such as the triple scanning technique and the silicone replica (SRT) technique. The SRT has as a disadvantage the difficulty in locating the margins, rupture of the silicone layer, presence of defects in the surface of the silicone (for example the incorporation of bubbles), and errors in the cutting planes. Thus, in addition to studying the properties of materials developed by CAD/CAM technology, it is interesting to study more effective methods for the accuracy of the adaptation of these materials, such as, for example, optical metrology through the overlapping of images, which is an example of a digital method of measurement.

LCD (liquid crystal display) printers are the most used in dentistry because they have a good cost-benefit [13-15]. In general, these printers have high precision and are suitable for fine details and functional printing [15], however, the DLP-type printers are less accurate and have slower processing [13,14]. DLP-type printers have minor disadvantages precision in larger parts of the 3D object, so they are not suitable for work with larger pieces that require high precision, for example, printing of working models [15]. The LCD printer, on the other hand, can print working models with high precision. For the printing of temporary prostheses, LCD-type printers have similar performance to DLP printers about the accuracy, provided that a powerful post-polymerization unit is used or a long post-curing time. In addition, they are printers with a lower cost of obtaining compared to DLP-type printers, facilitating their acquisition in dental clinics [13]. Thus, the present study used an SLA-type printer for printing provisional crowns, respecting the appropriate polymerization unit and post-curing time, since it is the type of printer most used in dental clinics, due to the cost benefit.

It is supported by the literature that the orientation of printing, the angle of construction, and the position influence not only the accuracy of the printing but also other properties, such as compressive strength, surface morphology, and the bacterial response of printed provisional complete crowns [16]. Regarding the mechanical properties, the 90° angle about the X-axis of the construction platform produces a more resistant piece to compression [6] compared to a piece printed at 180° due to the orientation of the layers [15]. However, concerning the accuracy of complete crowns, the angle of 90° is not indicated, because perpendicular angles to the construction platform can result in support fixation close to the edge of the complete crown and, consequently, complete crowns with unsatisfactory adaptation [9,16].

The best marginal adjustment of complete crowns was obtained with construction angles of 120° and 135° about the X-axis of the construction platform and 150° and 180° [9,16]. The present study used angulations of 150° and 180°, following the guidelines of the study by Ryu et al. [9], because it deals with the printing of provisional complete crowns, as was done in this study.

The literature shows that the accuracy of the final piece is influenced by the number of specimens printed on the same construction platform [10] and by the printing angle concerning the X-axis of the platform [9]. The degree of light energy applied when there is only one specimen can be excessively high, which may result in a larger piece than that provided for in the digital file and a lack of precision in the finer details. Similarly, with six specimens on the printing platform, the light is distributed very widely to provide the necessary light energy, and the transference to the target is inefficient, which may result in smaller parts than predicted in the digital file, partial or total printing failure and parts with impaired resistance. The printing of three specimens at a time on the same construction platform results in complete crowns with adequate precision for clinical use, as there is adequate light distribution [10]. However, until the present study, there has been no research that evaluated the accuracy of complete crowns printed by a construction platform with four and five complete crowns at the same time, since there is a gap between the ideal number of complete crowns printed at the same time (three) and the number that results in complete crowns without adequate precision (six). Thus, the present study evaluated whether the precision pattern of complete crowns printed with three specimens on the same construction platform is maintained with four specimens. The results showed that there were no statistical differences in the dimensional accuracy of complete crowns printed with three and four specimens at the same time, indicating that printing with four specimens brings greater cost benefit compared to printing with three specimens, in addition to reducing the time of making the piece.

The choice of print material is associated with the application and the type of printer that will be used. In the studies of Tahayeri et al. [6] and Ryu et al. [9], a micro-hybrid 3D printing photoactivated resin was used, indicated for long-lasting provisional prostheses (NextDent C&B), which has flexural strength and polishing capacity suitable for provisional prostheses. The study of de Tahayeri et al. [6] used a 3D printer of the SLA type and the study of Ryu et al. [9] used a 3D printer of the DLP type, both use a light source for the polymerization of the material. In the present study, the photoactivated resin Resilab 3D (Wilcos do Brasil Indústria e Comércio Ltda - Brasil, Petrópolis, RJ) was used, which can be used in printers that use light processing and this material has properties of resistance to flexion and polishing capacity suitable for provisional prostheses, as in previous studies. Already, the study of Mukai et al. [17], presented that the photoactivated resin E-Guide Tint (EnvisionTEC) was used to evaluate the accuracy of printed materials through the overlapping of images, as was done in the present study. This resin has properties of resistance to flexion and polishing capacity similar to the resin used in the present study and the resins used in the studies cited in this paragraph, however, it has greater biocompatibility, because its indication is for the manufacture of surgical guides [17].

A pilot study was made to delimit the sample number of the present study. In the pilot study, n=3 was used for groups A and C, because they are groups that were printed 3 crowns on the same construction platform, varying the angulation. Following this reasoning, n=4 was used for groups B and D. According to the results of the pilot study, n=12 was used because it is the lowest common denominator between 3 and 4.

The absolute values for RMS of the printed complete crowns obtained through the distance deviations between the CAD and MESH files corroborate the absolute cementation line evaluation values, in which the reference values for marginal adaptation are less than 120 μm [11]. The overlap of images made possible an analysis qualitative comparison of the surface with color histogram between the CAD and MESH files. The patterns of distortion in the pulp walls have a predominance of red and yellow colors, indicating an excess of material, while in the axial walls, green colors are predominant, indicating deviations close to zero, and blue, indicating a lack of material in this region.

The present study showed results that follow the study by Ryu et al. [9], because the complete crowns showed clinically adequate dimensional acuity with printing angles of 150° and 180°. According to Siqueira et al. [18] variables such as build orientation and printing angle have an impact on material properties, product accuracy, and even biocompatibility. Although analyzing the results for RMS and volume deviation objectively, there were no statistical differences between the construction angulation variables (150° and 180°) and the number of specimens printed on the same platform (three or four crowns at a time). Although they did not present statistical differences in the present study, the crowns printed at 150° obtained distance values closer to 120 micrometers (reference value for clinical acceptability), about the complete crowns printed at 180°. The justification for this may be related to the flow of the resin, since the complete crown is parallel to the platform when positioned at a 180° angle, resulting in an accumulation of resin in the lower region. In a complete crown positioned at 150° about the construction platform, there is less chance of resin accumulation, because there is a flow area for it.

The results for dimensional accuracy and volume deviation showed no statistical differences between the groups with three complete crowns (A and C) and the groups with four complete crowns (B and D) printed on the same printing platform. This shows that the printing of four complete crowns at a time has a greater cost-benefit compared to the printing of three complete crowns because it can maintain an adequate precision standard and a greater number of complete crowns can be produced in less time.

In general, the dimensional acuity values of the complete crowns found in this study show that 3D printing processing is suitable for dentistry and follows previous studies presented above in the discussion. 3D printing is certainly promising in dentistry, so much so that Yildirim's study [19] even recommends printed complete crowns rather than milled or heat-pressed complete crowns by the conventional method, which corroborates the results for the dimensional accuracy of the present study. The number of complete crowns printed with a stereolithographic printer interferes with the final resolution of the piece as much as the printing parameters, because the material can receive an excessive or inefficient amount of light [13,14,20-22]. It is supported by the literature that the printing of 3 crowns at a time obtains complete crowns with better resolution than the printing of 9 complete crowns at the same time [10]. This information follows the results of the present study because there was no statistical difference in the dimensional acuity of complete crowns printed with 3 or 4 complete crowns at a time on the same construction platform. The printing angles of 150 degrees and 180 degrees about the x-axis produced satisfactory results for dimensional acuity in the present study, agreeing with the angulation of 150 degrees and 180 degrees indicated in the previous study [9].

Moreover, a significant clinical implication supporting the preference for printed complete crowns over conventional ones could be self-polymerizable resins pose a significant challenge in this regard, relying on a chemical activator rather than heat to establish numerous chemical bonds, which can lead to higher levels of uncured material. These levels may vary depending on the specific composition of each product and the processing techniques employed. Additionally, utilizing the fastest digital scanning and printing processes helps mitigate potential issues associated with provisional elements, such as minimizing their impact, for example, mitigating allergies related to these components [23].

The present study presents as a limitation the use of only one type of resin for printing and one type of 3D printer, since it would be interesting to compare these results with other types of resins and 3D printers, given the diversity currently available for dental use.

In addition to the issues of printing angulation and the number of complete crowns printed at the same time, the present study contributes to the definition of a methodology for 3D printing in dentistry, because it is a factor that is not yet clear in previous studies, due to the great diversity of printers and materials available for printing. Thus, it is important to emphasize that more studies are needed to compose this methodology in a sedimented way in the literature, to make this knowledge more accessible to dentists in the daily life of the clinic.

CONCLUSION

Considering the results obtained, the present study concludes that, based on dimensional accuracy and volume deviation, the printing of provisional complete crowns with an LCD-type 3D printer has adequate accuracy both with an angle of 150 degrees about the X-axis, and with an angle of 180 degrees about the X-axis of the construction platform. There is no difference between printing three or four complete crowns printed at the same time on the same construction platform. Thus, the printing of four complete crowns on the same construction platform has a greater cost-benefit compared to the printing of three complete crowns, as it offers similar precision and shorter manufacturing time. Additionally, this type of manufacturing facilitates obtaining the part, reduces allergenic risks to the patient, and mitigates potential human errors during the conventional manufacturing process.

Author's Contributions

ERP: Investigation, Data Curation and Writing – Original Draft Preparation. LGBS: Data Curation, Formal analysis. MSC: Writing – Review & Editing. GCL: Writing – Review & Editing. RMA: Supervision and Project Administration.

Conflict of Interest

No conflicts of interest declared concerning the publication of this article.

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Regulatory Statement

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