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Dimensional stability and fidelity in the details of resins used in the printing of prototyped surgical guides

Marcus Fernandes dos Santos de Jesus

Dissertação conducente ao Grau de Mestre em

Medicina Dentária (Ciclo Integrado)

Gandra, 27 de Setembro de 2020

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Trabalho realizado sob a Orientação de Juliana de Sá

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Eu, "**Juliana de Sá",** com a categoria profissional de **"Monitor Clínico"** do Instituto Universitário de Ciências da Saúde, tendo assumido o papel de Orientador da Dissertação intitulado ***"Dimensional stability and fidelity in the details of resins used in the printing of prototyped surgical guides"***, do Aluno do Mestrado Integrado em Medicina Dentária, **"Marcus Fernandes dos Santos de Jesus"**, declaro que sou de parecer favorável para que a Dissertação possa ser depositada para análise do Arguente do Júri nomeado para o efeito para Admissão a provas públicas conducentes à obtenção do Grau de Mestre.

Gandra, 27 de Setembro de 2020

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O Orientador

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Resumo:

Objetivos: O objetivo deste trabalho foi avaliar a fiabilidade de um modelo impresso com uma resina para guia cirúrgico utilizada em dois modelos de impressoras diferentes.

Materiais e Métodos: Após criação de um modelo mestre em STL com medidas padronizadas em formato digital (Grupo Controle) que foi utlizado para a produção de 20 modelos simulando guias cirúrgicos impressos e divididos em dois grupos (10 modelos em cada grupo) de acordo com a impressora utilizada (FDM ou DLP). Os modelos foram medidos relativamente a sua espessura, largura, comprimento e no diâmetro da abertura do guia cirúrgico, com paquímetro manual e os dados forma analisados estatisticamente.

Resultados: Na largura e na espessura não forma encontradas diferenças estatisticamente significantes entre os grupos, porem a espessura apresentou diferença significativa do grupo FDM para os demais e o diâmetro teve diferença significativa entre todos os grupos com o grupo DLP apresentando mais desvio do planeado que o grupo FDM.

Conclusão: Com base nos resultados obtidos, pode-se afirmar que a impressora DLP é mais precisa com relação ao modelo digital do que a impressora do tipo FDM. Resultando em um modelo com dimensões próximas aos valores planejados no software de manipulação de imagens 3D, porém, as medidas dos furos simulando as aberturas de uma guia cirúrgica foram muito pequenas em relação ao diâmetro planejado, o que pode dificultar o uso do instrumental cirúrgicos ou mesmo a instalação de arruelas metálicas, que podem ocasionar alterações no posicionamento final do implante em relação ao planejado virtualmente.

Palavras Chave: Implante Dental; Guia cirúrgico; Estereolitografia, Prototipagem rápida; Acurácia.

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Abstract:

Goals: The objective of this work was to evaluate the reliability of a model printed with a surgical guide resin used in two different printer models.

Materials and methods: After creating a master model in STL with standardized measures in digital format (Control Group) that was used for the production of 20 models simulating printed surgical guides and divided into two groups (10 models in each group) according to the printer used (FDM or DLP). The models were measured in relation to their thickness, width, length and the diameter of the opening of the surgical guide, with a manual caliper and the data were analyzed statistically.

Results: There were no statistically significant differences in width and thickness between the groups, but the thickness showed a significant difference from the FDM group to the others, and the diameter had a significant difference between all groups with the DLP group showing more deviation from the plan than the FDM group.

Conclusion: Based on the results obtained, it can be said that the DLP printer is more accurate with respect to the digital model than the FDM type printer. Resulting in a model with dimensions close to the values planned in the 3D image manipulation software, however, the hole measurements simulating the openings of a surgical guide were very small in relation to the planned diameter, which can make it difficult to use surgical instruments or even the installation of metal washers, which can cause changes in the final positioning of the implant in relation to virtually planned.

Key words: Dental implant; Surgical guide; Stereolithography, Rapid prototyping; Accuracy.

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ABBREVIATION INDEX

DICOM	Digital Imaging and Communications in Medicine
DLP	Digital light processing
DMDs	Digital micro-mirror devices'
FDM	Fusion deposition modeling
LED	light-emitting diode
SLA	Stereolithography
STL	Standard Triangle Language
UV	Ultraviolet light

1 -Introduction

The treatment with dental implants has grown a lot in recent years and the search for a better three-dimensional positioning of the implant in relation to the future prosthesis has been the great challenge of modern implantology. (1) With the advancement of technology and the increasing use of computed tomography (DICOM) and three-dimensional images of oral structures (STL) in surgical planning, (1–4) the big challenge has become how to get this planning into the patient's mouth, with minimal deviation. (4) In this context, we have the use of prototyped surgical guides, which is also due to technological advances related to 3D printers and the creation of software and hardware capable of manipulating these images and generating a guide capable of being printed on these printers. (5–7) The prototyped surgical guides allow the surgeon to transfer the planning performed on the computer to the patient's mouth, thus allowing the implants to be installed in the previously planned location, with minimal deviation from their planned position virtually. (8)

There are several techniques and materials available for making surgical guides. (9) In recent years, we have seen an increase in the type of printer for making guides and in the variety of resins available on the market. These factors allowed greater access to this technology in dental offices. (3,10) Although the prototyped surgical guides have high precision, which is defined with the relationship between the final position of the implant and the planned position, (5,11) there are still deviations from the planned one, which are influenced by several factors, (7,12,13) including the type of guide support tissue, where the guides supported only on the mucosa, tend to be more inaccurate than the guides supported on the teeth or directly on bone tissue, other factors such as type and height the washer of the drilling guide, size of the used surgical cutter, distance of the guide and the surgical cutter to the bone bed and material from which the guide is made. (14,15)

Much attention has been given to factors related to the supporting tissue and the surgical equipment used for milling and installing the implants, however the materials used in making the surgical guide, as well as the printing techniques and printers used in this process have had little attention by researchers. (16–18)

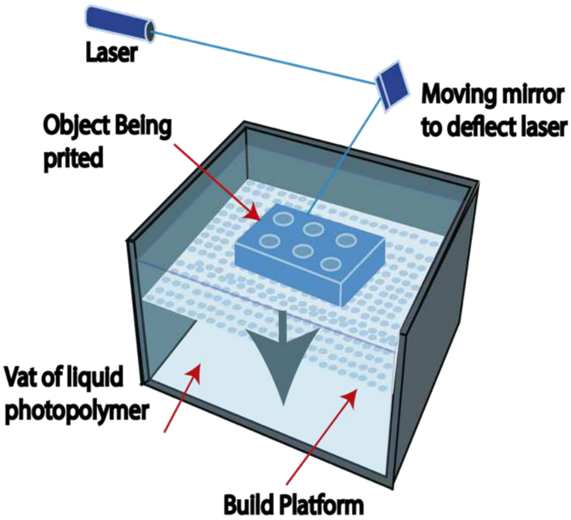
There are several types of 3D printers, which can be classified according to printing technology, and for use in making surgical guides we have mainly stereolithography (SLA), digital light processing (DLP) and fusion deposition modeling (FDM), as described in *Table 1*. (19–21)

Table 1: Comparative table of rapid prototyping techniques

Techniques	Advantages	Disadvantages
Stereolithography (SLA) Polymerization using a laser in a vat containing a light-sensitive liquid polymer.	Fast manufacturing. Able to create complex shapes with high resource resolution. Lower cost materials.	• Available only with light curable liquid polymers. • The resin can cause skin sensitization and can be irritating for contact and inhalation. Limited shelf life and shelf life. • It cannot be sterilized while hot. High-cost technology
Digital light processing (DLP) Polymerizable resin using an LED screen or UV light.	Good accuracy, smooth surfaces, relatively fast. Lower cost technology.	• Light-curable liquid polymers. • Resin can cause skin sensitization and can be irritating by contact. • Higher cost materials.
Fusion deposition modeling (FDM) Heated plastic filament.	Low cost, cheaper equipment, ease of use.	• Distortion. • Low print resolution.

Stereolithography printing (SLA) was the first commercial 3D printing process, these printers were manufactured by 3D Systems and were referred to as a stereolithography device or SLA. This process uses a computer-controlled laser beam to build a 3D object inside a liquid photopolymer vat (*Figure 1*). (20–22).

Figure 1: Stereolithographic 3D printing method. note that the object is formed from the surface of the print tank.



The DLP (Digital Light Processing) printing method consists of a DLP panel, formed by a small image chip that contains a variety of microscopic mirrors or 'digital micro-mirror devices' (DMDs).

This DLP projector replaces the laser of SLA printers, being positioned under the printing platform, where the images of the contour of each layer of the object are projected to solidify the resin (*Figure 2*, *Figure 3*). (21,22) In *Figure 4* it is possible to see the packaging of the Resilab 3D printing resin model Skin (Wilcos Brazil, Petropolis, Brazil).

Figure 2: Projector of a DLP printer, note that the image of the object to be printed is projected at the bottom of the printing tray.

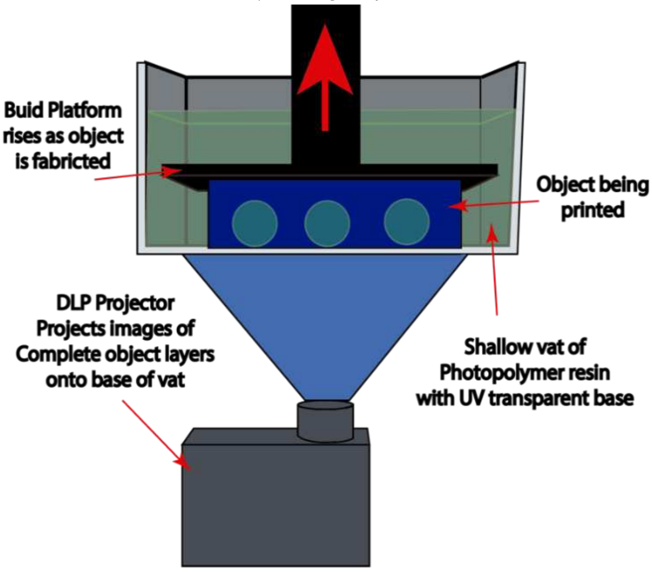


Figure 3: DLP type printer. (W3D Print, Wilcos Brazil, Petropolis, RJ)

Figure 4: Packaging of the Resilab 3D printing resin model Skin (Wilcos Brazil, Petropolis, Brazil).

The FDM (Fusion deposition modeling) printing process consists of heating a thermoplastic filament, which merges into the printer's extruder nozzle, which will deposit this material layer by layer on the blade; the printing form thus forming the three-dimensional object (*Figure 5*). The filament used can be of several different types of materials, the most used are ABS, nylon and PBS, in *Figure 6* it is possible to observe a filament used for 3D printing.

Figure 5: Material extrusion 3D printing (FDM).

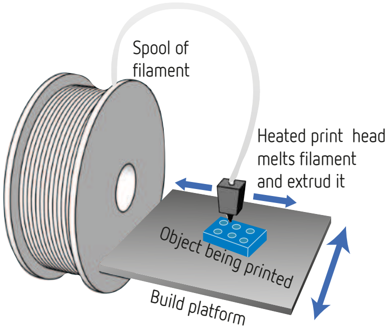
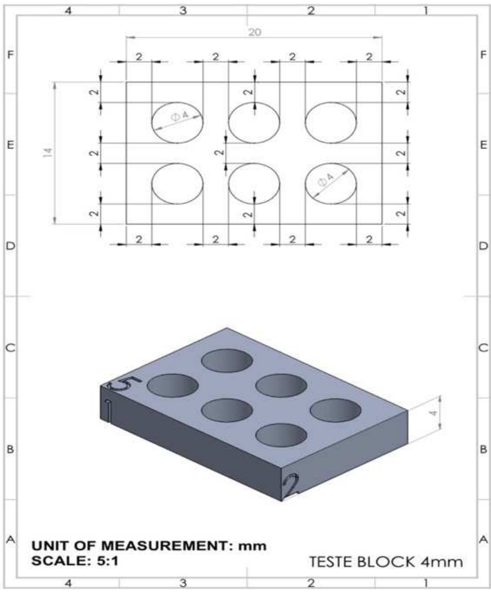


Figure 6: Dimensions of the three-dimensional model used as a control group for the actual measurements performed on the printed test models.



2 -Objectives and Hypotheses

The aim of this work is to perform an in vitro experiment will be carried out to analyze comparatively two 3D desktop printers, with respect to the precision of the printed guide in relation to the planned digital model, followed by a correlation of these data with the data obtained from the literature.

The null hypothesis (H_0) was that no difference would be found in the veracity of the different types of 3D printing methods.

The alternative hypothesis (H_a) was that there is a significant difference between the printers and between the different printing materials.

3 -Materials and Method

3.1 -The experimental model

3.1.1 -Group control

A STL (Standard Triangle Language) model simulating a surgical guide measuring 20 x 14 x 4 mm, with 6 perforations of 4 mm in diameter each, with a distance of 2 mm between them. The measures were standardized in the STL model in order to facilitate the conduct of the study based on the middle opening of a surgical guide for implant installation (diameter of 4.0 mm), and the distance of 2.00 mm between the implants. As shown in *Figure 7*, was made in the software Solid Works 3D (Dassault Systèmes, Massachusetts, USA). The STL model will be used as a control group in the analysis of printing accuracy. The models printed in a single print are paired according to *Figure 8*.

Figure 7: Layout of the models for printing. Screenshot of printing software.

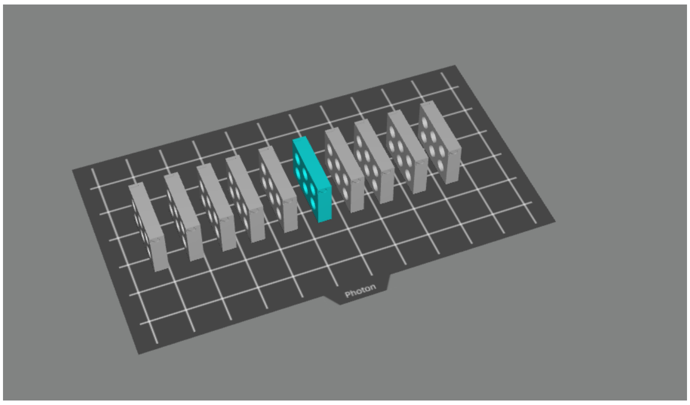
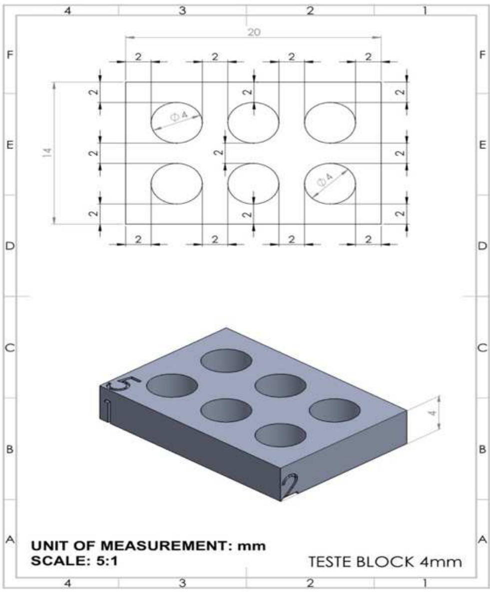


Figure 8: Dimensions of the three-dimensional model used as a control group for the actual measurements performed on the printed test models.



3.1.2 -Test groups

The study had two test groups:

- FDM Group: Using the Sethi3d S2 printer (Sethi3d Printing, Campinas, Brazil) (*Figure 9*) and using ABS filament (Frisotec®, São Paulo, Brazil) (*Figure 10*) for printing the test models. 10 models were printed in this group, all at once.

- Group DLP: Using the W3D Print (Wilcos Brazil, Petropolis, RJ) (*Figure 3*) and using Skin model resin (Wilcos do Brazil, Petropolis, Brazil) (*Figure 4*) for printing the models test. 10 models were printed in this group, all at once.

Figure 9: ABS filament used for printing on FDM printers. ABS filament (Frisotec®, São Paulo, Brazil)

Figure 10: FDM printer Sethi3d S2 printer (Sethi3d printing, Campinas, Brazil) used to print the FDM group test models.

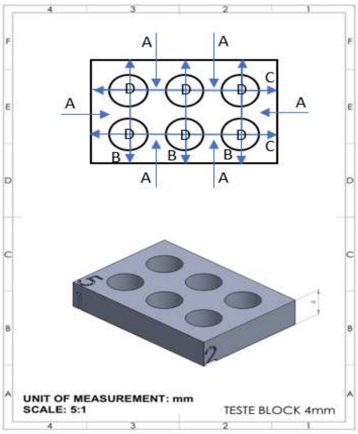
Each group will consist of 10 specimens that will be printed at once, evenly distributed on the printing tray, as shown in Figure 7.

3.2 -Printing and analysis of models

After printing, the models will be cleaned in alcohol isopropyl for 2 minute immersed in an ultrasonic vat, followed by washing in isopropyl alcohol and although in the study by Unkovskiy, *et al.,* (18) no relevant effect was found between printed models that underwent curing and those that were not cured with respect to accuracy, all models DLP in this study were cured following the recommendations of the resin manufacturer (Skin model resin, Wilcos do Brazil, Petropolis, Brazil) in a UV chamber of at least 36W for 10 minutes.

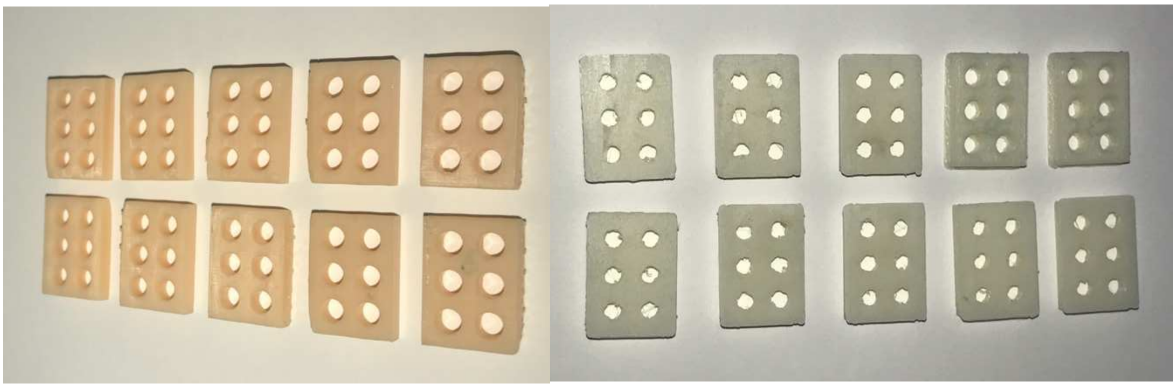
Measures were taken with a vernier caliper (MTX Matrix Tools for Existence, China), with 0.02 mm resolution. In each model 6 measurements of thickness (A), 3 measurements of width and 2 of height (B and C) were carried out in addition to 6 measurements of diameter (D), one in each hole of the test model, as shown in *Figure 11*.

Figure 11: Marking measurement areas with calipter on the test model. According to the diagram, measurements were taken on the diameter of the model opening, on the width, thickness and height of the test models.



After printing, the visual analysis of the models showed some irregularities on the surface, especially in the FDM group, the irregularities were mainly associated with the contact face of the model with the printing tray. Visually the appearance of the models of the DLP group was better than that of the test models of the FMD group. Visually, DLP printing features greater detail fidelity. In *Figure 12* we can see the models printed in the DLP and FDM groups respectively.

Figure 12: Printed proof models, DLP Group and FDM Group respectively.



3.2.1 -Comparison Groups

The description of the accuracy of a measurement method is used the terms "trueness" and "precision" for the International Standards Organization, the trueness is defined as the closeness of agreement between the arithmetic mean of many test results and the true or accepted reference value. Precision refers to the closeness of agreement between test results.

The measurements obtained were inserted in the statistical analysis software IBM SPSS Statistic (IBM Corporation ©) and analyzed according to the statistical tests described below.

3.2.2 -Statistical analysis

The dimensional accuracy data were tested for normal distribution and the statistical significance of the differences between the experimental groups was examined at an alpha level of 5%.

The data were analyzed within and between groups and compared with the values of the master model. The analyzes were performed considering the height, width, and thickness of the test model, as well as the diameter of the openings, as printing variables. Data were tabulated, and mean, median and standard deviations were calculated from measurements. The samples were analyzed using Independent-Samples Kruskal-Wallis Test, for comparison between the test groups and the control group. Independent analysis was performed for each measurement group performed on the test models.

4 -Results

4.1 -Experimental results

The Kruskal-Wallis Test of Independent Samples showed a statistically significant difference between groups ($P < 0.05$) (Table 2; Table 3; Table 4), in the intra-group analysis it did not show significant difference between the DLP group and the measures of the standard model ($p > 0.05$), but there is a statistically significant difference between the DLP group and the FDM group and between the FDM group and the control group ($p < 0.05$) showed in the *Table 2*.

Table 2: Pairwise Comparisons of Group

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
FDM-DLP	54.276	11.182	4.854	.000	.000
FDM-CONTROL	-97.303	26.224	-3.710	.000	.001
DLP-CONTROL	-43.026	26.224	-1.641	.101	.303

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same. Asymptotic significances (2-sided tests) are displayed. The significance level is .050.

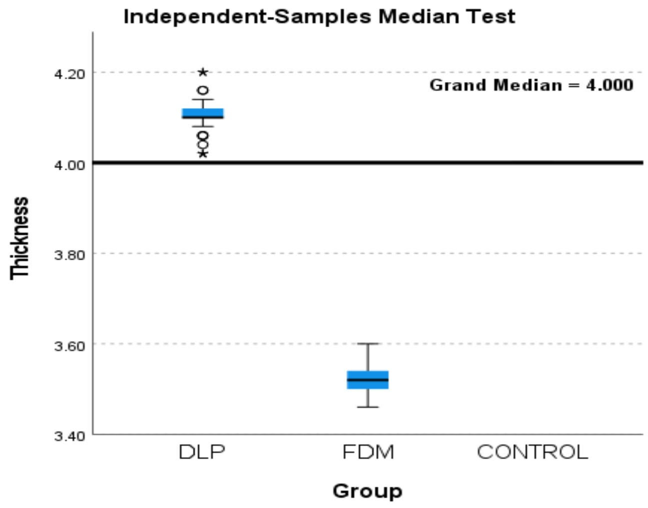
a. Significance values have been adjusted by the Bonferroni correction for multiple tests.

The analysis of the thickness of the models revealed a statistically significant difference between the values of the control group and the values of thickness for the FDM group ($p < 0.05$) and between the FDM and DLP test groups ($p < 0.05$), however there was no difference statistically significant between the DLP group and the control values (p> 0.05), as shown in *Table 3* and *Figure 13*.

Tab*le 3: Pairwise Comparisons of Group for thickness Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same. The significance level is .050.*

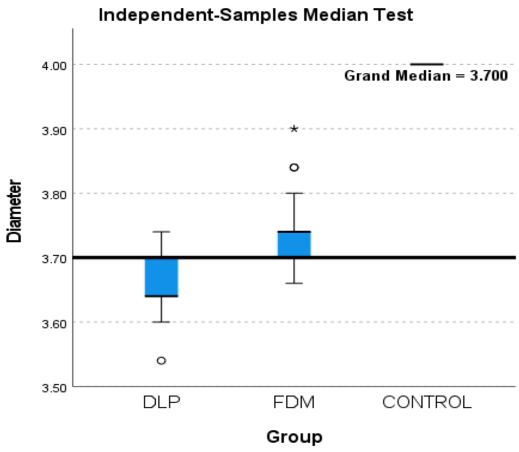
Sample 1-Sample 2	Test Statistic	Sig.	Adj. Sig.[a]
FDM-CONTROL	7.013	.008	.024
FDM-DLP	120.000	.000	.000
CONTROL-DLP	3.771	.052	.156
a. Significance values have been adjusted by the Bonferroni			

Figure 13: Correlation between the thickness measurements of the test and control groups.



The diameter analysis showed a statistically significant difference between the test groups and the control group (p <0.05), (*Figure 14*). The diameter of the guide opening averaged 3,656 mm (SD 0.041) and 3,727 (SD 0.560) for the DLP and FDM groups, respectively.

Figure 14: Correlation between the Diameter measurements of the test and control groups.



The analysis of the groups of measures revealed that there was no significant difference between the groups when the height and width were compared ($p > 0.05$), *Figures 15* and *Figure 16*.

Figure 15: Correlation between the Height measurements of the test and control groups.

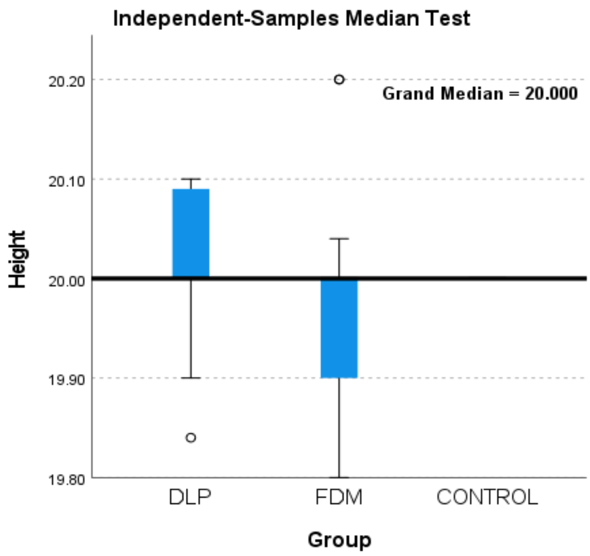
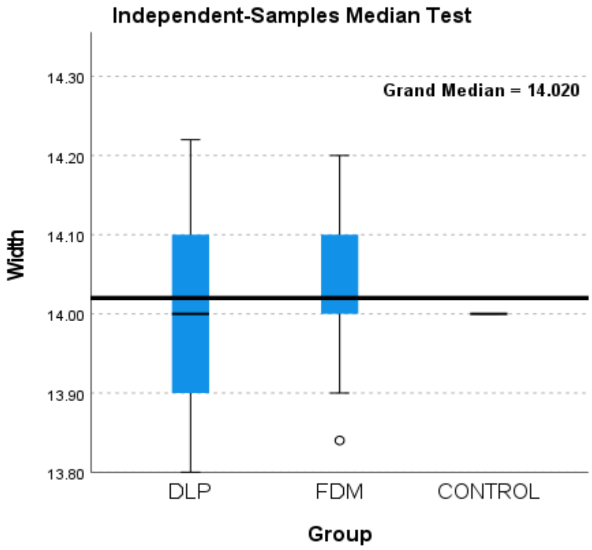


Figure 16: Correlation between the width measurements of the test and control groups.



5 -Discussion

Several studies have studied the factors that influence the precision in guided surgery, showing that the type of guide support (bone, teeth or mucosa), as well as the height of the guide, the presence or not of a metal washer, distance from the guide up bone tissue, surgical cutters, as well as the manufacturing and storage process of the guide until its use. (3,6,11,13,15,23–27) The deviations between the planned and the placed implant are the sum of the cumulative errors in the entire cascade of implant placement aided by computer and the errors can occur in different stages. (28) The errors when a template is used for computer- guided surgery are cumulative and interactive and include those for image acquisition, registration between the image data and the physical space, surgical template production, and the human error that occurs after the application of the template to the patient. (29)

Among the studies, much attention has been given to the imprecision factors related to the supporting tissues, as well as to the surgical technique and instruments used, however little has been studied about the possible distortions related to the printing material.(16)

This study is perhaps one of the first to assess the reliability of printing city guides on 3D printers, comparing two low-cost printers, a DLP and an FDM, assessing the accuracy of the guide print and not the precision in the placement of the implant, in however, the precision of the guide will have a direct influence on the accuracy of the implant placement, as shown by other authors. (3,6,11,13,15,23–27)

In the study by Dalal, *et al.*, it was observed that the impression of the surgical guide using 50 µm layers was observed less discrepancy and less variation when compared to impressions made with 100 µm layers. (16)

In the studies of Dalal, *et al.*, and Unkovskiy, *et al.*, it was observed thar the impression using 45° object was observed less discrepancy and less variation. (16,18)

The study has some limitations that should be discussed. First, guides can have different thicknesses and irregularities that can influence the dimensional discrepancy and consistency of the guide. In this study, the printed guides were limited to a single guide with constant thickness and tube positioning at a constant distance and inclinations also constant, without inclination between them, for simplicity and homogeneity of the study. In real life, the surgical guides for the implants may vary, and the deviations in the notch and tube may become more exaggerated than the simplified guides in this study. Second, only two 3D printers and two printing materials were used here. Currently, there are several 3D printers and countless resins for printing the guides, which are available on the market.

6 -Conclusions

These results demonstrate that the DLP printer is able to have greater accuracy in relation to the digital model when compared to a FDM type printer, which will result in a model with dimensions close to the values planned in the 3D image manipulation software. however, this accuracy is limited since, even with external dimensions awfully close to the planned values, the holes in the surgical guide showed a significant difference to the planned values. This difference may have been caused by several factors, among them an excess of unpolymerized resin in the printer and not removed in the alcohol bath, which may have been deposited in these areas during post curing or even factors related to polymerization during printing due to scattering of light during the process, which may have generated extra layers of resin not foreseen in the digital project during the slicing of the model for printing. It becomes necessary to study this phenomenon so that it can be avoided.

Based on these results, it is possible to state that the DLP printer is more accurate than the digital model than the FDM type printer. Resulting in a model with dimensions close to the values planned in the 3D image manipulation software, however, the measurements of the holes simulating the openings of a surgical guide were very small in relation to the planned diameter, which may result in difficulty in using the surgical apparatuses or even the installation of metal washers, which can cause changes in the final positioning of the implant in relation to what was planned virtually.

Further studies are needed to determine the influence of different resins and printers on the final precision of the prototyped surgical guides, as well as to determine a way to reduce the lack of precision related to the printing technique.

7 -Clinical Implications

Dentists can use several types of printers to print their surgical guides, it is important to know that there are differences between printers that can significantly impact the final result of the printed guide.

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Appendix

Table 4: measurements performed on the test models.

Group	Thickness	Diameter	Height	Width
1	4.10	3.60	19.84	13.80
1	4.08	3.64	20.00	13.84
1	4.06	3.64	20.00	13.90
1	4.08	3.66	20.00	13.94
1	4.08	3.64	20.00	14.00
1	4.10	3.66	19.90	14.12
1	4.06	3.64	20.00	13.94
1	4.06	3.64	20.02	14.00
1	4.02	3.66	20.00	14.02
1	4.08	3.70	20.00	13.84
1	4.08	3.64	20.10	13.94
1	4.04	3.64	20.10	13.90
1	4.10	3.68	20.10	14.04
1	4.12	3.70	20.08	14.02
1	4.12	3.66	20.10	14.20
1	4.12	3.60	20.00	14.10
1	4.08	3.70	20.00	14.12
1	4.10	3.70	20.00	14.02
1	4.02	3.66	20.10	14.00
1	4.02	3.66		14.02
1	4.10	3.64		13.90
1	4.10	3.64		14.22
1	4.10	3.74		14.12
1	4.10	3.64		13.80
1	4.10	3.64		13.84
1	4.12	3.64		14.12
1	4.10	3.74		14.10
1	4.10	3.60		13.90
1	4.12	3.70		14.12
1	4.10	3.60		14.00
1	4.10	3.74		
1	4.16	3.70		
1	4.10	3.70		
1	4.10	3.60		
1	4.12	3.70		
1	4.14	3.60		
1	4.10	3.70		
1	4.12	3.66		
1	4.12	3.64		
1	4.12	3.60		
1	4.12	3.64		
1	4.12	3.62		

1	4.10	3.64		
1	4.12	3.62		
1	4.12	3.54		
1	4.10	3.60		
1	4.12	3.64		
1	4.10	3.70		
1	4.12	3.66		
1	4.12	3.64		
1	4.20	3.74		
1	4.16	3.64		
1	4.14	3.64		
1	4.20	3.66		
1	4.10	3.66		
1	4.10	3.70		
1	4.12	3.70		
1	4.10	3.60		
1	4.10	3.66		
1	4.12	3.70		
2	3.54	3.70	20.00	14.06
2	3.58	3.84	19.82	14.02
2	3.60	3.80	19.82	14.00
2	3.60	3.74	19.82	14.20
2	3.60	3.80	20.00	14.02
2	3.60	3.84	20.04	14.02
2	3.54	3.74	20.20	14.10
2	3.54	3.76	20.20	14.10
2	3.50	3.80	20.00	14.02
2	3.54	3.80	20.00	14.02
2	3.52	3.80	19.80	14.12
2	3.50	3.90	20.00	14.10
2	3.50	3.74	19.90	14.10
2	3.48	3.74	19.90	14.12
2	3.44	3.64	20.00	14.00
2	3.50	3.76	20.00	14.04
2	3.44	3.80	19.92	14.02
2	3.44	3.74	19.92	14.00
2	3.48	3.64	20.00	14.02
2	3.46	3.68	20.00	14.00
2	3.52	3.70		14.00
2	3.52	3.70		14.00
2	3.52	3.74		14.12
2	3.52	3.80		14.20
2	3.52	3.70		14.20
2	3.52	3.64		13.90
2	3.54	3.74		14.10
2	3.54	3.68		14.12
2	3.50	3.70		13.84
2	3.54	3.70		13.90

2	3.54	3.66		
2	3.50	3.70		
2	3.50	3.74		
2	3.50	3.74		
2	3.50	3.74		
2	3.50	3.74		
2	3.54	3.74		
2	3.52	3.74		
2	3.52	3.74		
2	3.52	3.74		
2	3.52	3.74		
2	3.52	3.72		
2	3.52	3.64		
2	3.50	3.64		
2	3.54	3.70		
2	3.54	3.74		
2	3.54	3.64		
2	3.54	3.64		
2	3.54	3.66		
2	3.54	3.66		
2	3.54	3.70		
2	3.54	3.70		
2	3.50	3.70		
2	3.50	3.70		
2	3.50	3.70		
2	3.50	3.70		
2	3.60	3.72		
2	3.60	3.74		
2	3.60	3.74		
2	3.60	3.80		
3	4.00	4.00	20.00	14.00
3	4.00	4.00	20.00	14.00
3	4.00	4.00		14.00
3	4.00	4.00		
3	4.00	4.00		
3	4.00	4.00		