ARTIGO ORIGINAL

ACCURACY OF DIFFERENT RESINS USED IN 3D PRINTING OF DENTAL MODELS: IN VITRO STUDY

Precisão de diferentes resinas utilizadas na impressão 3D de modelos dentários: estudo in vitro

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ABSTRACT

In this study, 3D printing resins were evaluated, using digital light processing technology, verifying their accuracy. For this, a plaster model was produced from a prefabricated synthetic resin model, which was scanned by a SHINING bench scanner, generating an STL file. This file was used as reference measurements, from which they were printed by a 3D printer, DLP Anycubic Photon, thirty models (N=30) with 3 different 3D printing resins (n=10), namely: Low Smell Skin, Prizma 3D - Model - DM-300 and Smart Print LCD Model. After printing the resin models were also scanned. The reproduction accuracy was evaluated using Geomagic software. These image files were superimposed on the reference file, and linear measurements were analyzed between 4 dental points, marked on the original model. The transverse distance between the reference points and the Pythagorean Theorem calculation was measured. The resin used significantly influenced the area discrepancies ($p < 0.001$), without significant difference between Prizma and Smart Print resins, which presented significantly smaller area discrepancies compared to Low Smell Skin resin. However, the linear measurements measured in the model printed with Prizma resin were 0.02 mm short of those obtained in the reference model in type IV plaster. In the impressions made with the Low Smell Skin and Smart Print resins, the linear measurements were above those measured in the type IV plaster reference model. It was concluded that the resin used influences reproduction discrepancies, but 3D printing resins can be used safely to produce dental models.

Keywords: 3D printing, precision, dental models.

RESUMO

Neste estudo foram avaliadas resinas de impressão 3D, utilizando tecnologia de processamento digital de luz, verificando sua precisão. Para isso, foi produzido um modelo de gesso a partir de um modelo pré-fabricado em resina sintética, que foi digitalizado por um scanner de bancada SHINING, gerando um arquivo STL. Este arquivo foi utilizado como medidas de referência, a partir das quais foram impressos por uma impressora 3D, DLP Anycubic Photon, trinta modelos (N=30) com 3 resinas de impressão 3D diferentes (n=10), a saber: Low Smell Skin, Prizma 3D - Modelo - DM-300 e Smart Print LCD Model. Após a impressão os modelos em resina também foram digitalizados. A precisão da reprodução foi avaliada utilizando o software Geomagic. Esses arquivos de imagens foram sobrepostos ao arquivo de referência e foram analisadas medidas lineares entre 4 pontos dentários, marcados no modelo original. Foi medida a distância transversal entre os pontos de referência e o cálculo do Teorema de Pitágoras. A resina utilizada influenciou significativamente nas discrepâncias de área ($p < 0,001$), sem diferença significativa entre as resinas Prizma e Smart Print, que apresentaram discrepâncias de área significativamente menores em comparação à resina Low Smell Skin. Porém, as medidas lineares medidas no modelo impresso com resina Prizma ficaram 0,02 mm aquém daquelas obtidas no modelo de referência em gesso tipo IV. Nas impressões realizadas com as resinas Low Smell Skin e Smart Print, as medidas lineares ficaram acima daquelas medidas no modelo de referência do gesso tipo IV. Concluiu-se que a resina utilizada influencia nas discrepâncias de reprodução, mas as resinas de impressão 3D podem ser utilizadas com segurança para produzir modelos dentários.

Palavras-chave: Impressão 3D, precisão, modelos odontológicos.

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INTRODUCTION

The technological advances resulting from research involving dental machinery and materials, together with the exploration of durable aesthetic treatments, have facilitated the acquisition of prostheses, reducing the time involved in the process and archiving the physical space for models of these prosthetic works. There are several improvements offered by digital practice, such as the direct scanning of teeth in the patient's mouth, which can already be considered a reality in contemporary dentistry. In the late 1970s and early 1980s, CAD/CAM technology was introduced in dentistry. The main propositions of technology, such as automation of manual processes, minimization of variation or human error and reduction of production costs, stimulated investment in research to advance further in technology[1].

The digital manufacturing process begins with the development of a CAD model that will be transferred to a machine where, for example, a restoration will be machined, cut, and polished before being fixed to the mouth. The methods of using this technique of manufacturing computer-aided objects can be divided into subtractive (removal of material by milling to obtain an object) or additives (adding material per 3D printing to obtain an object)[2].

It can be said that intraoral moldings using conventional materials (e.g., elastomers) and the making of plaster casts have several disadvantages, such as: deformation of the molding material or model, contamination of saliva or blood, patient discomfort such as pain, nausea, taste discomfort and operator ability that greatly affects the accuracy of the printing. These deficiencies are compensated in digital printing, where intraoral scanners generate three-dimensional (3D) images, in which data can be transferred digitally to a laboratory for permanent storage, using very little storage space. From this, the physical models necessary for diagnosis, removable restorations, preparation of appliances, more complex treatments, among others are manufactured[3].

In some situations, not even the models are produced, the 3D modeling of a patient's tooth using intraoral scanners is known as an oral fingerprint, this allows the manufacture of a prosthesis without a working model, being faster and more efficient. However, the most important requirement for prosthesis stability is adjustment, and this should be determined and corrected by producing a work model[4].

Different techniques have been developed to build scanning devices, each with its own advantages and disadvantages. Therefore, it is necessary to compare the data obtained from gypsum models by traditional methods with digital 3D models to evaluate the reliability of the measurements of length and differences in arc dimensions[5]. The plaster has been used in successful rehabilitations for many years, has greater accuracy than the models of the additive technique and is the reference model in several studies[6].

Few published studies have applied 3D evaluation to the accuracy of 3D moldings of complete dental arches. The data acquisition process for the reconstruction of 3D-printed dental models is a nonlinear spatial process, so the evaluation method must also be three-dimensional[7].

More research on digital technologies is needed, since few studies evaluate the accuracy of 3D molds made with additive technology. These come mainly from molds produced with additive stereolithography (SLA) technology. Dimensional inaccuracies in these templates can affect the final fit of the final restore. The information is limited, and the results of these studies are inconclusive[8].

3D printing still presents few comparative studies of accuracy among the various types of printers and resins. Therefore, more information about these technologies still needs be obtained. In this study, an evaluation of 3D printing resins was performed, using DLP technology to evaluate their accuracy through software.

The aim of this study was to compare three three-dimensional printing resins: Low Smell Skin (Quanton 3D, Belo Horizonte-MG, Brazil), Prizma 3D - Model - DM-300 (Makertech Labs, Tatuí-SP, Brazil) and Smart Print LCD Model (Mmtech, São Carlos-SP, Brazil), and a DLP printer Anycubic Photon (Anycubic, Shenzhen, Guangdong, China), having as reference a model of plaster generated through a synthetic resin denture (A3, Frasaco, Tettnang, Germany), evaluating its accuracy.

The null hypothesis postulates that the resins do not influence the results of print reproduction.

METHODOLOGY

The present study was provided by the Research Ethics Committee, under the protocol: 2020/0762, because it is not research involving human beings.

Experimental design

A model of synthetic resin denture was used (Modelo Dentário AG-3, Frasaco, GmbH, Tettnang, Germany)9, molded with silicone to obtain the gypsum model, which was used as reference.

This model was scanned by a desktop scanner, generating a 3D reference STL file. Based on this file, 30 models were printed on a single printer using three different resin types, forming three groups, being eland s: LS group with 10 models of Low Smell Skin resin (Quanton 3D, Belo Horizonte-MG , Brazil), PR group with 10 models of Prizma 3D resin - Model - DM-300 (Makertech Labs, Tatuí-SP, Brazil) and SP group with 10 models of resin Smart Print Lcd Model (Mmtech, São Carlos-SP, Brazil).

Table 1. Nomenclature and quantity referring to the name of the resins used.

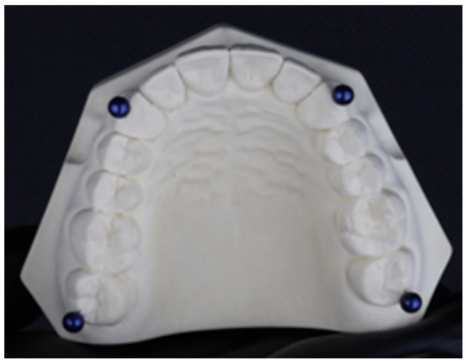
Group	Material	Number of models
A (control)	Type IV plaster	1
LS	Low Smell Skin - Quanton 3D	10
PR	Prizma Resin - Model	10
SP	Resina Smart Print - Mmtech	10

Legend: Name of the groups referring to the name of the resins used, as well as the number of models per group. The name used in the group section refers to the acronym of the initials of the resins, while group A refers to the control group. In the sequencua, you have the material used and the quantity used.

Obtaining the plaster model

For the manufacture of the matrix, we used a gypsum model obtained through a complete model of lower dentures in synthetic resin (A3, Frasaco, Tettnang, Germany) that was molded with an Express XT addition silicone (3M, Sumaré-SP, Brazil), following the manufacturer's instructions. After the period of one hour, the special stone plaster FujiRock EP Type IV was released, following the ideal proportions of powder (100 g) and distilled water (20 ml), also according to the manufacturer's recommendations. A vacuum trowel (Wamix-Classic; Wassermann Dental-Maschinen GmbH) and vibrator (KV-16; Wassermann Dental-Maschinen GmbH) were used. The mold was maintained for 45 minutes before removal and inspection. In the obtained model, ball head pins with Superbonder quick-drying glue (Henkel Lta Itapeni/SP Brazil) were placed on the distal vestibule cusps of the teeth 17 (second right upper molar), 27 (second left upper molar), in the incisal of teeth 13 (right upper canine), 23 (upper left canine), as shown in Figure 1.

Figure 1. Reference plaster model.



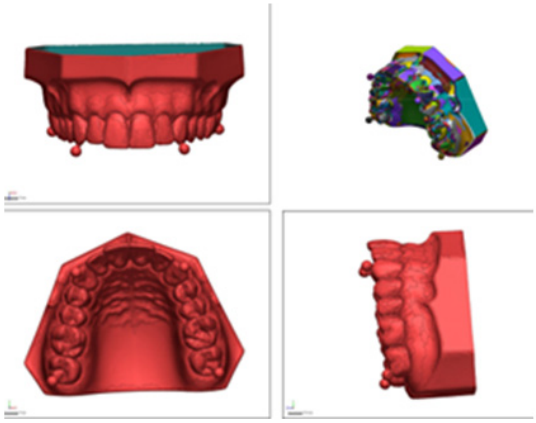
Source: Own authorship.

Scan

With a SHINING 3D table scanner (Talmax, Curitiba-PR, Brazil), the reference plaster model described above was digitized. And the resulting read data was designated as the CAD reference model.

In addition, a complete scan was performed, creating a 3D reference STL file of the plaster model (Figure 2).

Figure 2. STL file.



Source: Own Authorship.

Printing

As a basis in the SLT file, obtained by scan the model made by the scanner mentioned above, a total of 30 models were printed using three different types of resins, forming three groups, being eland s: LS group with 10 models of Low Smell Skin resin (Quanton 3D, Belo Horizonte-MG, Brazil), PR group with 10 models of Prizma 3D - Model - DM-300 resin (Makertech Labs, Tatuí-SP, Brazil) and SP group with 10 models of Smart Print Model LCD resin (Mmtech, São Carlos-SP, Brazil).

For printing these models, we used a 3D printer Anycubic Photon (Anycubic, Shenzhen, Guangdong, China), which is considered a high performance 3D printer for various reasons, such as its versatility, its fine features and impeccable details.

And soon after the print was done the process of post curing in a UV chamber (Anycubic, Shenzhen, Guangdong, China), for five minutes.

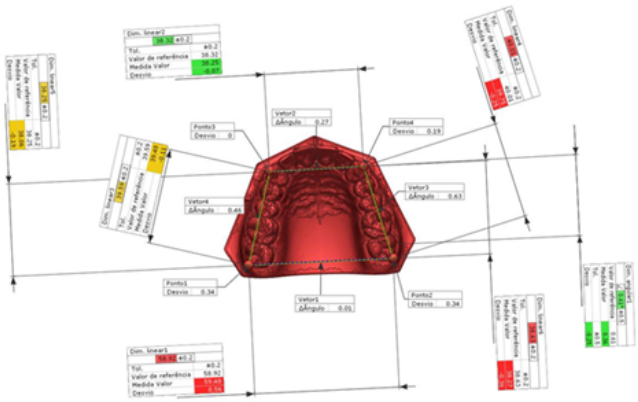
Acting

The 30 models manufactured by 3D printing already mentioned, were scanned using the same flatbed scanner (SHINING 3D), which was also mentioned above, and the data scanned models were saved as STL file.

When the analysis was completed, the reference STL file designated itself as the control group, while the STL files test as the test group. Each Test STL file was overpostedover the reference STL file, using specialized software (Geomagic Control X, 2017.0.3, 3D Systems, Cary, NC, USA). For overlay, the STL test file has been converted to cloud point data. Then, the CAD-reference-model (CRM), surface date, CAD-model test (CTM), and the data from the cloud point, were initially aligned and subsequently rearranged for better alignment and adjustment. Finally, cloud point data projected onto the surface of CRM data. To evaluate the accuracy, the cross-sectional distance between reference points 13-23, 17-27

and anteroposterior 13-17 and 23-27 was used as reference, and the trapezoid area obtained through the connection between the reference points (Figure 3), which was calculated using the calculation of Pythagoras theorem, where the obtained data were sent for statistical analysis.

Figure 3. Image representing linear lines and the shape of the trapezoid.



Source: Own authorship.

Statistical Analysis

To investigate the ability of resin-printed models to replicate the reference model in type IV gypsum, the measurements obtained in the four locations in the samples of each group were evaluated using intraclass correlation coefficients (ICC). Then, the discrepancies (errors) between each resin model and the reference model in gypsum type IV were calculated. For the statistical approaches, the programs SPSS 23 (SPSS INC., Chicago, IL, USA) and BioEstat 5.0 (Fundação Mamirauá, Belém, PA, Brazil) were used, setting the significance level at 5%.

RESULTS

Considering the four linear measurements obtained in each of the ten models printed with the resins Prizma (CCI: 0.9996), Low Smell Skin (CCI: 0.9182) and Smart Print (CCI: 0.9994), it was found that the resins resulted in excellent replicability in relation to the reference model in type IV plaster.

Although all resins for 3D printing have been shown to be excellent, the Kruskal-Wallis test indicated that there was a significant difference between them ($p < 0.001$). As identified by the Student-Newman-Keuls test, Prizma and Smart Print resins provided significantly smaller discrepancies than those found for Low Smell Skin resin (Table 2 and Graph 1). Specifically, on average, the linear measurements measured in the model printed with Prizma resin were 0.02 mm below those obtained in the reference model in type IV plaster and Graph 1).

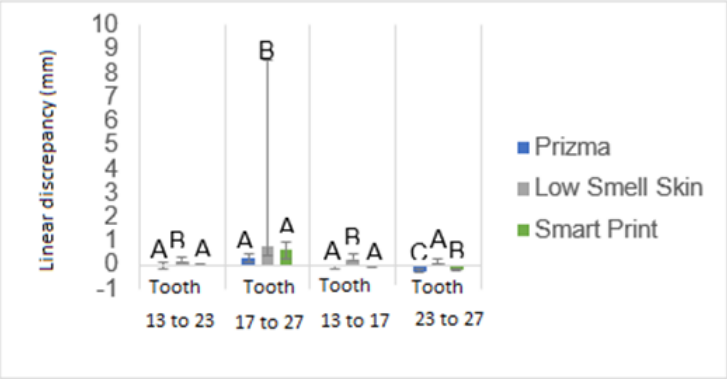
Also, regarding the linear discrepancy, in the line formed between the teeth 23 to 27, it was verified that the Low Smell Skin resin showed significantly lower value in relation to the Smart Print resin and this, in turn, presented linear discrepancy significantly lower than that of prizma resin.

Table 2. Arithmetic means, standard deviations, medians and minimum and maximum values of linear discrepancies (mm) between models obtained by 3D printing and the reference model in type IV plaster, according to the resin used and straight.

Resin	Straight			
	Teeth 13-23	Teeth 17-27	Teeth 13-17	Teeth 23-27
Prizma	-0,01 (0,13) A -0,07 [-0,12; +0,24]	+0,28 (0,19) A +0,28 [0,00; +0,58]	-0,09 (0,07) A -0,11 [-0,17; +0,02]	-0,26 (0,07) C -0,26 [-0,36; -0,14]
Low Smell Skin	+0,16 (0,17) B +0,16 [-0,18; +0,42]	+0,75 (7,79) B +2,72 [-21,09; +6,27]	+0,24 (0,20) B +0,21 [-0,08; +0,49]	+0,08 (0,15) A +0,07 [-0,21; +0,32]
Smart Print	0,00 (0,02) A -0,02 [-0,03; +0,04]	+0,61 (0,37) A +0,57 [+0,16; +1,26]	-0,06 (0,06) A -0,05 [-0,15; +0,07]	-0,17 (0,03) B -0,17 [-0,21; -0,12]

Legend: Arithmetic means and standard deviations (in parentheses) are in the first line. Medians and minimum and maximum values (in brackets) are in the second row. Negative and positive values indicate that the measure in the model printed in resin were, respectively, smaller and higher than in the plaster model. Considering each line (comparisons within each column individually), resins identified by distinct capital letters differ significantly from each other. Letters comparing resins are departing from the Student-Newman-Keuls test based on the averages of the orders, but are indicated along side arithmetic means.

Graph 1. Column diagram of the mean values of linear discrepancies between models obtained by 3D printing and the reference model in type IV plaster, according to the resin used and the line.



Legend: Vertical lines above and below the columns indicate standard deviation. Negative and positive values indicate that the measurement in the resin-printed model was respectively smaller and larger than in the plaster model. Considering each line (comparisons within each individual column), resins identified by different uppercase letters differ significantly from each other. Letters comparing resins are derived from the Student-Newman-Keuls test based on rank means but are presented alongside arithmetic means.
Source: Own Authorship.

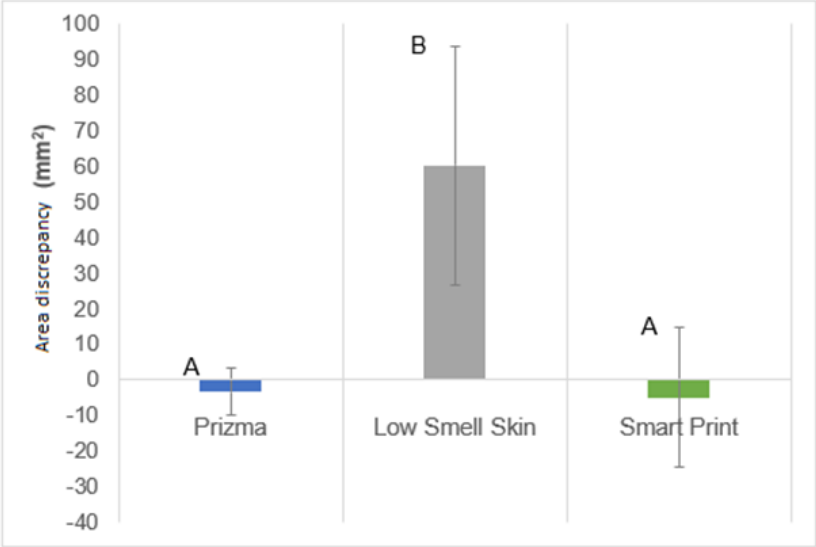
When considering the area measured in the models (Table 3 and Graph 2), it was found that in those printed on Prizma resins, the area obtained was 3.59 mm below that calculated in the type IV plaster model. On the other hand, on average, in the printing using low smell skin resin, the measurements were 60.13 mm higher than those measured in the type IV plaster model. Print, which showed significantly smaller area discrepancies compared to Low Smell Skin resin.

Table 3. Arithmetic means, standard deviations, medians and minimum and maximum values of area discrepancies (mm^2) between models obtained by 3D printing and the reference model in type IV plaster, according to the resin used.

Resin	Discrepancy (error) in relation to the plaster model
Prizma	-3,59 (6,58) A -5,45 [-12,00; +7,00]
Low Smell Skin	+60,13 (33,40) B +51,80 [+18,00; +106,70]
Smart Print	-5,03 (19,54) A 2,65 [-40,50; +14,50]

Legend: Arithmetic means and standard deviations (in parentheses) found for each resin are in the first line. Medians and minimum and maximum values (in brackets) found for each resin are in the second line. Negative and positive values indicate that the measure/area in the model printed in resin were, respectively, smaller and higher than in the plaster model. Resins whose means are followed by distinct capital letters differ significantly from each other. Letters comparing resins are departing from the Student-Newman-Keuls test based on the averages of the orders, but are indicated along side arithmetic means.

Graph 2. Column diagram of the mean values of area discrepancies between models obtained by 3D printing and the reference model in type IV plaster, according to the resin used.



Legend: Vertical lines above and below the columns indicate standard deviation. Negative and positive values indicate that the measurement in the resin-printed model was respectively smaller and larger than in the plaster model. Resins identified by different uppercase letters differ significantly from each other. Letters comparing resins are derived from the Student-Newman-Keuls test based on rank means but are presented alongside arithmetic means.

Source: Own authourship.

DISCUSSION

In this study, three differences brands of printing resins were tested for their accuracy to be used in the daily dental clinic. In the context of the fidelity of reproduction of the printed models, some considerations are necessary, in addition to the resin mark, object of study of this research, we can mention the choice of the printing method and the speed of light curing reaction.

SLA technology (stereolithography) focuses the laser beam on the surface of the liquid photosensitive resin, so that it heals from one point of a line and then to a surface, polymerizing layer by layer to form a 3D physical object. Like this we have digital light processing (DLP) presenting obvious advantages in printing on higher velocity due to its high-fixing projector, which can and cure an entire layer at once[10]. The choice of printer interferes significantly in obtaining the results[11]. For this reason, digital light processing technology (DLP) was chosen in this study, and it presented satisfactory results of reproduction of models.

Computer algorithm-based 3D assessment considers the 3D spatial structure of the dental complex anatomy, provides more clinically relevant information, and can minimize human error[7]. As an option for measuring teeth, there are digital calipers, but it can lead to measurement errors, as it is difficult to fix a reference point on the tooth surface. Comparing accuracy between models printed by different printers is also an option, but it can leave gaps. The reference points should then be established in the area of the tooth and gum, and the 3D software applied to verify the accuracy and accuracy of the dental model made in the 3D printer[12]. Comparative studies have evaluated the accuracy of measurements made in digital models obtained with a flatbed laser scanner. For these measurements, a digital caliper can be used, directly on the plaster models, conventionally or through digital means such as the Ortho Analyser program. Measurements can be obtained by analyzing several points such as: diameter and dental height, overjet, overbite, intercanine and intermolar distances, and bilateral sagittal relationship. The measures that are too varied in points and methodology for obtaining these may present discrepancies in the results, even if they are not clinically significant[13]. Therefore, we used only the software as a measurement method and in addition to the cross-sectional measurements, this study also chose to measure the trapezoid area, acquired through the connection of the reference points, in order to reduce the variables of discrepancies, obtaining a result more accurate and reliable, and no significant differences were found between linear and trapezium area measurements.

3D printed models compared for their accuracy in three types of DLP printers, through Geomagic software, obtained good print accuracy[10]. The compration of3D models of dental resin created by casting modeling, SLA and Polyjet prototype technologies, with traditional plaster models showed a clinically significant difference between the models defined as a measurement discrepancy greater than 0.5 mm.14 Using a single DLP printer this study showed that resin significantly influences printing accuracy.

Three 3D printing resins with different commercial market values were printed on a single 3D printer and compared for veracity and accuracy, there was a significant discrepancy of the cross-sectional distance measurements between the 3D polymeric resins, being the most accurate product

of value respectively, but the mean precision did not vary much between these three resins, therefore, the veracity and precision required of the clinical purpose of the model should be decisive factors in the scan of 3D printing materials.15 This study used resins of similar commercial values and still found a greater discrepancy in accuracy between one of them.

The new patent experimental resin was evaluated for accuracy, volumetric contraction, and bending and traction properties for 3 other existing resins: Die and Model Tan (SprintRay), Formlabs Gray (FormLabs) and LCD Gray (Roxel 3D), all of which are printed on a single DLP printer. It was shown that the experimental resin presented significantly higher precision than the other commercially available resins ($p < 0.001$), besides lower volumetric contraction and adequate mechanical properties[16]. The accuracy of dental models manufactured by conventional methods, grinding and printing methods, were scanted and evaluated by a software, concluding that plaster models have better accuracy than other milled and printed models[17]. The present study used a gypsum model as the reference standard for having the best accuracy and found good precision results of the resins, disagreeing with the other study that compared the new patented resin to three other resins already existing on the market instead of buying the gypsum model that is our reference standard.

Conventional plaster molds have had better results when adjusting to printed molds, additional improvements of the 3D printer are needed for its application in prosthesis, but still the impress o molds have an acceptable accuracy for clinical applicability[18]. Even with limited3D printing p-split of the chosen printing system, a 3D printable temporary restorative material allows sufficient mechanical properties for intraoral use[19]. Although one of our resins presented a discrepant result, this study showed that prints in 3D resins are a viable option in dental clinical practice.

Given this, it can be evidenced that 3D printing already has a variety of applications in dentistry and is a great promise to make many other treatments and interesting ways of doing dental restorations. For this reason, more research in this area is needed.

CONCLUSION

From this study, it is concluded that additive manufacturing technology proved to be efficient. Despite the differences found in the results, the printed models present themselves as a reliable method of reproduction of models.

The null hypothesis was rejected because there were significant differences between the resins used.

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