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Original Article

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Performance of conventional acrylic resin vs. 3D printed resin in surface roughness, hardness, and mechanical resistance

Desempenho de resina acrílica convencional vs. resina impressa em 3D em rugosidade superficial, dureza e resistência mecânica

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Resumo

Introdução: Próteses provisórias protegem os preparos dentários durante o tratamento, com métodos convencionais e digitais disponíveis para sua fabricação. Embora as resinas impressas em 3D apresentem potencial para durabilidade e propriedades mecânicas, mais pesquisas são necessárias para esclarecer suas vantagens em relação às resinas acrílicas convencionais, especificamente quanto à rugosidade de superfície, dureza e resistência em coroas provisórias. **Objetivo:** Comparar a resina acrílica convencional e a resina impressa 3D para confecção de próteses provisórias, através de um estudo *in vitro* sobre rugosidade superficial, dureza e resistência mecânica. **Material e método:** Barras (25 x 12 x 2 mm) em resina acrílica termopolimerizável (RAT=05) e autopolimerizável (RAA=05), além de resina Impressa 3D (R3D=05) foram confeccionadas para a realização dos testes de rugosidade superficial média (Ra), Dureza Vickers e resistência à flexão três pontos, em seguida os espécimes foram avaliados após a fratura. Também foi realizada a caracterização superficial com espécimes significativos por grupo experimental (N=1), por meio de estereomicroscópio, microscópio eletrônico de varredura e perfilômetro. **Resultado:** Os dados de rugosidade superficial, dureza e resistência mecânica foram submetidos ao teste estatístico ANOVA 1 Fator ($p < 0{,}05$), seguido pelo Teste de Tukey quando tenha sido identificada diferença estatisticamente significativa. Os achados da análise superficial e da fractografia foram apresentados de forma qualitativa. O grupo R3D apresentou uma superfície com camadas sucessivas e distinta das demais resinas. Não houve diferença estatística entre grupos para a rugosidade superficial (p=0,220). Para dureza e resistência mecânica (p=0,000) foi identificada diferença estatística entre grupos experimentais. Destacando o grupo R3D com maior média de dureza (19,50 VD) e menor média de resistência mecânica (54,08 Mpa). Os espécimes do grupo R3D apresentam dois ou mais fragmentos após a fratura, já nos demais grupos havia apenas dois fragmentos. Identificou-se semelhança quanto à rugosidade superficial entre as resinas acrílicas convencionais e a resina impressa 3D. **Conclusão:** A resina impressa 3D apresentou desempenho superior e inferior, quando comparada com as resinas acrílicas convencionais, em relação a dureza e a resistência mecânica.

Descritores: Prótese dentária; impressão 3D; polímeros; resistência à flexão.

Abstract

Introduction: Provisional prostheses protect dental preparations during treatment, with conventional and digital methods available for fabrication. While 3D-printed resins show promise for durability and mechanical properties, further research is needed to clarify their advantages over conventional acrylic

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resins, specifically in terms of surface roughness, hardness, and resistance in provisional crowns. **Objective:** To compare conventional acrylic resin and 3D printed resin for fabrication of provisional prostheses through an in vitro study on surface roughness, hardness, and mechanical resistance. **Material and method:** Bars (25 x 12 x 2 mm) of heat-polymerized acrylic resin (RAT=05) and self-polymerized acrylic resin (RAA=05), as well as 3D printed resin (R3D=05), were fabricated for conducting tests on mean surface roughness (Ra), Vickers hardness, and three-point flexural strength. Subsequently, the specimens were evaluated after fracture. Surface characterization was also performed with significant specimens per experimental group (N=1) using a stereomicroscope, scanning electron microscope, and profilometer. **Result:** Data on surface roughness, hardness, and mechanical resistance were subjected to one-way ANOVA ($p < 0.05$), followed by Tukey's test when a statistically significant difference was identified. Findings from surface analysis and fractography were presented qualitatively. The R3D group exhibited a surface with successive layers distinct from other resins. There was no statistical difference between groups for surface roughness (p=0.220). However, statistical differences were identified among experimental groups for hardness and mechanical resistance (p=0.000). Notably, the R3D group showed higher mean hardness (19.50 VD) and lower mean mechanical resistance (54.08 MPa). Specimens from the R3D group showed two or more fragments after fracture, whereas other groups exhibited only two fragments. Similarity was observed regarding surface roughness between conventional acrylic resins and 3D printed resin. **Conclusion:** The 3D printed resin demonstrated both superior and inferior performance compared to conventional acrylic resins in terms of hardness and mechanical strength.

Descriptors: Dental prosthesis; 3D printing; polymers; flexural strength.

INTRODUCTION

During prosthetic restorative treatment, dentists use crowns or provisional prostheses to protect dental preparations and periodontal tissue against any aggression that may have negative effects on patient health during the waiting period for the definitive or final prosthesis. Depending on the functional and aesthetic outcome of these restorations, some of them can be used for long periods, such as in prosthetic rehabilitation with implants[1].

Currently, different manufacturing methods can be adopted for obtaining these prostheses, including conventional and digital methods. Resins manufactured by the conventional method offer good cost-effectiveness and ease of fabrication; however, they fall short in terms of physical and mechanical properties. On the other hand, resins manufactured by the digital method have shown high quality, precision, and reduced errors during fabrication. Computer-Aided Design-Computer-Aided Manufacturing (CAD/CAM) technology is gaining ground in the provisional fabrication field. Thus, different methods can be employed, such as CAD-CAM milling and 3D printing[2].

CAD-CAM milled resin has demonstrated greater strength and durability compared to acrylic resin, but it has the disadvantage of high cost. Meanwhile, the 3D printing method requires lower costs than milling, has less material waste, and shorter fabrication time[2]. It is noteworthy that 3D printing resins have emerged as an alternative for long-term use in fixed prosthetic crowns due to favorable mechanical properties compared to milled and conventional acrylic resins. Conversely, Polymethylmethacrylate (PMMA) acrylic resin, the most common material used for everyday clinical use in patients for provisional restorations, presents disadvantages such as the need for readjustment and mechanical failure[2].

Several studies in the field have demonstrated the physical and mechanical properties of 3D printed resins compared to other materials with similar restorative indications[2-5]. However, research shows conflicting results regarding flexural strength and surface roughness in the comparison between 3D printed resins and other provisional materials such as milled resins and acrylic resins[3,5-7]. In other words, the literature indicates that the application of 3D printed resin for crowns or provisional prostheses is still inconclusive, and new in vitro studies should aim to develop research protocols to eliminate biases[3]. Because the mechanical behavior of provisional prosthetic materials can guide dentists in choosing the best material for the clinical case, considering masticatory forces, biting force, chewing pattern, jaw muscle activity, parafunctions, diet, length of edentulous spaces, and the type of prosthetic restoration[5].

Based on the foregoing, there is a need for further research to clarify to the dental community about the properties of 3D printed resins compared to other material options for fabricating provisional crowns. Therefore, the aim of this study is to compare conventional acrylic resin and 3D printed resin for the fabrication of provisional prostheses through an in vitro study on surface roughness, hardness, and mechanical resistance. The hypotheses to be tested are: Null Hypothesis (H0) - there will be no statistically significant difference in the type of resin for provisional prosthesis regarding the tested analyses; Alternative Hypothesis (H1) - there will be a statistically significant difference in the type of resin for provisional prosthesis regarding the tested analyses.

METHODOLOGY

The present study was an in vitro experiment on polymeric materials, conducted in the INTM laboratory at the Federal University of Pernambuco, comparing conventional acrylic resins and 3D printed resin in terms of surface roughness, hardness and mechanical resistance.

Fabrication of Specimens

Specimens were fabricated using self-polymerizing and heat-polymerizing acrylic resin (VIPI Dental Products, Pirassununga, São Paulo, Brazil), and 3D printed resin (Prizma 3D Bio Prov Resin, Makertech Labs, São Paulo, São Paulo, Brazil). Conventional resin bars were fabricated using silicone matrices through addition reaction (3M ESPE, Bayern, Germany), with dimensions of 25 x 12 x 2 mm, according to ISO 4049 standard. Wax patterns were made to facilitate the acrylicization of the specimens, following the manufacturer's recommendations for heat-polymerizing resin. For the self-polymerizing resin, the Brush Technique was adopted, using two dappen dishes, one containing the powder and the other containing the liquid. The end of the brush was moistened with liquid and brought into contact with the powder, incorporating powder particles into the moistened brush to form a resin sphere that was then transferred into the matrix until completely filled.

Processing of specimens in 3D printed resin followed the manufacturer's guidelines (Prizma 3D Bio Prov, Marketech Lab, Tatuí, São Paulo, Brazil) and the 3D printer (Anycubic Photon S Talmax Dental Prosthesis 3D Printer, Curitiba, Paraná, Brazil) using the Digital Light Processing (DLP) printing method. Thus, the specimens were designed in 3D Exocad software, and the images were exported in Standard Tessellation Language (STL) format. Printing took approximately 20 minutes with specimens positioned horizontally, forming a 0° angle with the build platform, and the layer thickness was set at 50μm[2,8]. After processing, the specimens were cleaned in isopropyl alcohol for 10 minutes via ultrasonic bath, followed by post-curing in a UV chamber for 10 minutes, according to the manufacturer's recommendations.

After completing the polymerization process, excess material on the sides was removed using cross-cut burs (American Burrs), mandrel (Microdont), and water sandpaper (#600) for conventional resins, in addition to calipers (VRC, Guarulhos, São Paulo) to verify dimensions[4]. Finally, the fabricated specimens were stored in distilled water in an oven (FANEM, Orion Culture Oven 502) at a temperature of 37°C, and after 24 hours, testing analyses were initiated.

Experimental Groups and Sample Size

Three experimental groups (N=5) were formed: RAA - Self-Polymerizing Acrylic Resin; RAT - Heat-Polymerizing Acrylic Resin; and R3D - 3D Printed Resin for the study analyses. The sample size was calculated (using Minitab version 16.1 for Windows, Pennsylvania, USA) based on the standard deviation of similar research studies: for mechanical resistance with a standard deviation of 9.13 by Alshamrani et al.[8]; and for surface roughness with a standard deviation of 0.07 by Myagmar et al.[4]. Thus, N=5 achieves a sample power of 80.0% for maximums regarding surface roughness and mechanical resistance analyses.

Surface Analysis

The surface of all specimens was analyzed for morphology using a stereomicroscope to identify defects, pores, and surface behavior of the materials under study. A significant sample from each experimental group (N=1) was evaluated using Scanning Electron Microscopy (SEM) (HITACHI, Model TM300).

Surface Roughness

Specimens were evaluated for average surface roughness (Ra - µm) using a Taylor Hobson contact profilometer, connected to a computerized unit with the Tayle Profile Gold software. Three roughness values were obtained for each specimen, with readings performed parallel to each other and horizontally. Finally, the average Ra values were calculated, representing the mean roughness value of the specimen[6]. To present the surface profile of the materials under study, a significant specimen from each experimental group underwent analysis using a Talysurf CCI MP-Lite digital optical profilometer (Taylor Hobson, United Kingdom). This microscope is connected to a computerized unit containing TalyMaps Lite software, both from Digital Surf (Besançon, France).

Hardness

One specimen from each experimental group underwent 5 measurements on a Vickers microhardness tester (Micromet 5101, Buehler), under a load of 500 g and a dwell time of 20s[6,9]. Five indents were made in each specimen near the center, at least 0.5 mm apart from each other. The major Vickers indentation diameters (d1 and d2) were measured with an optical microscope, and hardness was calculated using Formula 1:

$$\text{Hardness} = 1850 \times \text{Load} / (d1 \times d2) \qquad (1)$$

Mechanical Resistance

The three-point flexural strength test was conducted using an EMIC DL-1000 universal testing machine (EMIC DL 1000, São José dos Pinhais, Brazil). Specimens were fixed between two supports at a span length of 20 mm and subjected to tension until fracture[8]. The machine was programmed with a 100 Kgf load cell at a constant speed of 5 mm/min. Flexural strength values were obtained in megapascals (MPa) using Formula 2 (ISO 4049), where γ is the flexural strength, F is the load at the fracture point, D is the span length, L is the width of the sample, and H is the thickness of the sample (Formula 2).

$$\gamma = 3FD / 2LH^2 \qquad (2)$$

Fractography

Fractured specimens were analyzed using a stereomicroscope (Discovery V20, Carl Zeiss, Germany) to determine fracture characteristics.

Results Analysis

The results were tabulated and analyzed using Minitab (version 16.1 for Windows, Pennsylvania, USA), with a significance level of 5%. Data on surface roughness, hardness, and mechanical resistance were subjected to one-way ANOVA ($p < 0.05$), followed by Tukey's test when a statistically significant difference was identified. Findings from surface analysis and fractography were presented qualitatively. The Kolmogorov-Smirnov test showed a p-value greater than 1% for the data.

RESULT

Regarding the surface characterization of the tested materials (Figure 1 and Figure 2), the RAA group showed a surface predominantly with pores and defects compared to the RAT group, which presented a lower frequency of these surface findings. Meanwhile, the R3D group showed a surface with successive layers distinct from the other resins under study, although with the presence of some surface defects. The same surface condition was confirmed by SEM images of the experimental groups, with pores also identified on the surface of the 3D printed resin. In terms of Ra findings, although the R3D group showed the lowest mean surface roughness, there was no statistical difference between groups (Table 1).

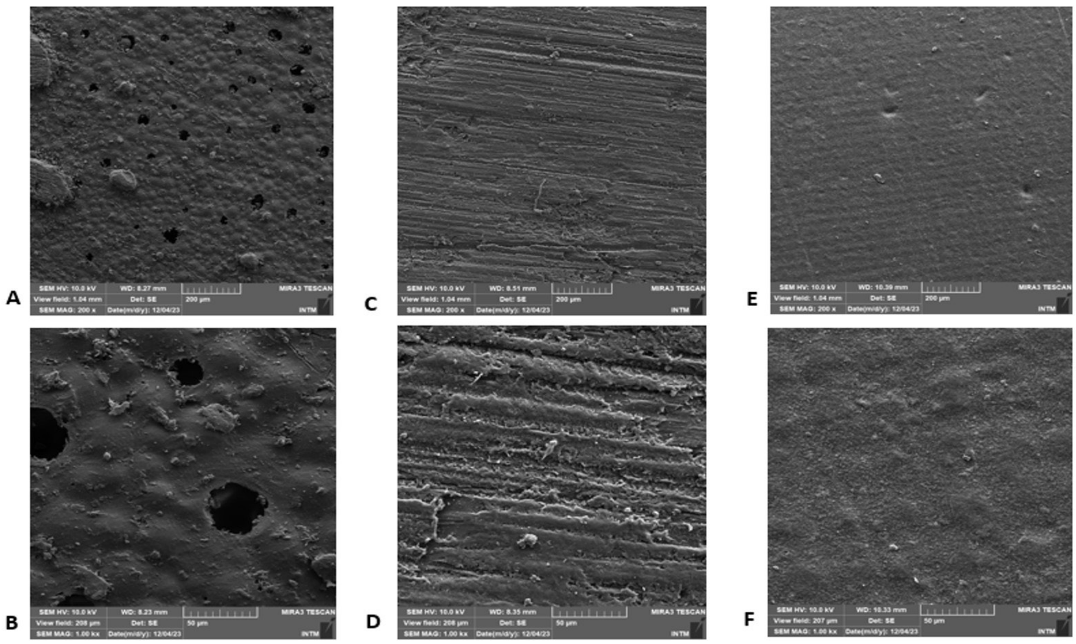

Figure 1. Surface Images of Experimental Groups in SEM, A and B RAA group, magnifications of 200x and 1,000x; C and D RAT group, magnifications of 200x and 1,000x; E and F R3D group, magnifications of 200x and 1,000x. Source: Own work.

Through profilometry analysis, the 3D surface of the materials in question was observed to be compatible with the findings of the other surface analyses. Regarding hardness, a statistical difference was identified between experimental groups, with the R3D group showing the highest mean hardness. The difference between groups for hardness analysis is depicted in Table 2.

Table 1. Surface roughness data (Ra - μm)

Experimental Group	Mean	Standard Deviation	Maximum	Minimum	P-value
RAA	1,0402	0,2095	1,1786	0,6743	
RAT	1,1209	0,1468	1,2933	0,9593	0,220
R3D	0,707	0,594	1,746	0,307	

Source: Own work.

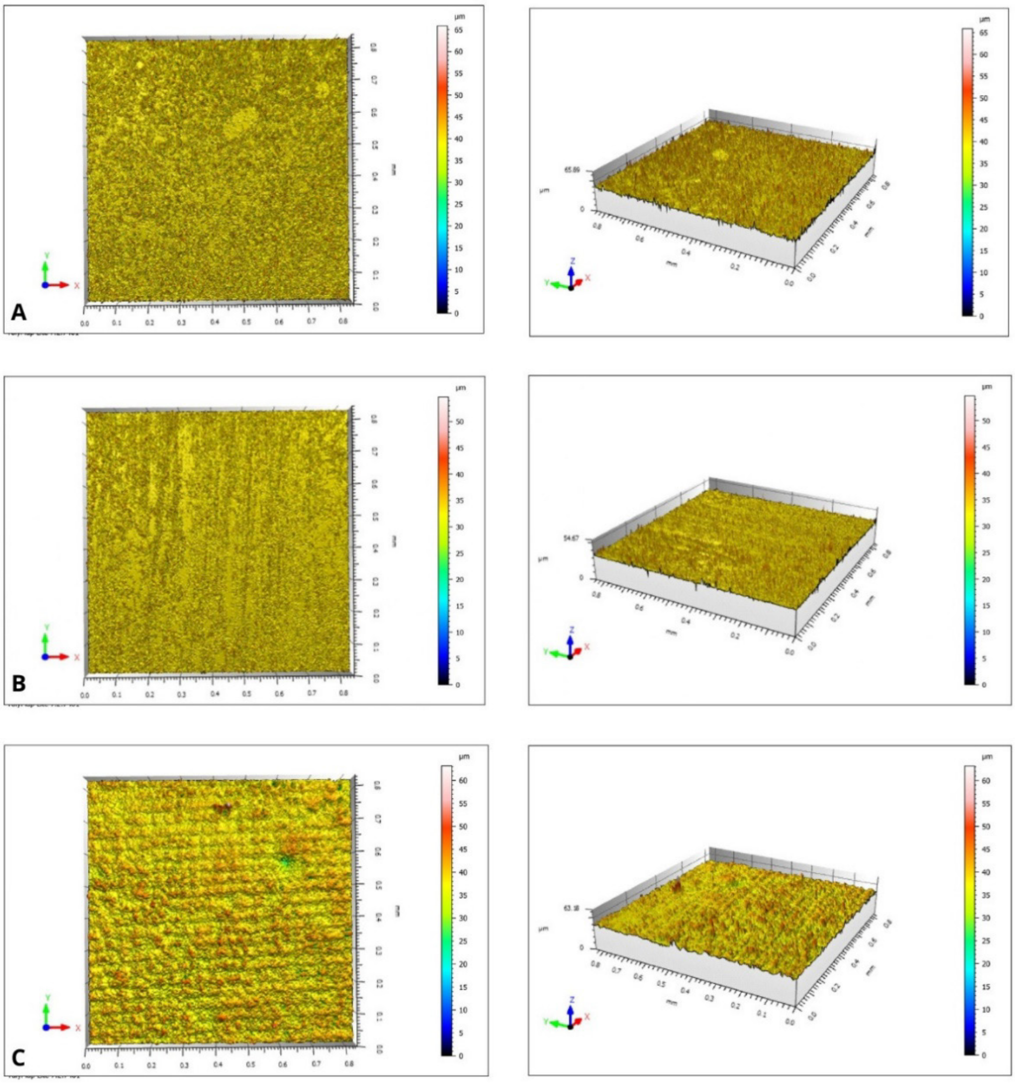

Figure 2. A - Profilometry Analysis, magnification of 20X, RAA Group. B - Profilometry Analysis, magnification of 20X, RAT Group. C - Profilometry Analysis, magnification of 20X, Grupo R3D. Source: Own work.

Table 2. Vickers Hardness Data

Experimental Group	Mean	Standard Deviation	Maximum	Minimum	Difference between Groups*	P-value
RAA	13,960	0,321	14,300	13,500	A	
RAT	18,200	0,339	18,600	17,700	B	0,000
R3D	19,520	0,867	20,400	18,400	C	

*Different letters indicate a difference between groups. Source: Own work.

Lastly, a statistical difference between groups was observed in terms of mechanical resistance, with the R3D group showing lower resistance compared to conventional resins. Table 3 demonstrates the difference between groups, and Figure 3 shows the fractographic analysis, with specimens from the RAA and RAT groups exhibiting only two fragments, while specimens from the R3D group exhibited three or more fragments. This 3D printed resin group showed two or more fragments after fracture. Figure 4 presents the presence of a rough surface and internal defects in the fractographic analysis of specimens from the R3D group.

Table 3. Mechanical Resistance Data (MPa)

Experimental Group	Mean	Standard Deviation	Maximum	Minimum	Difference between Groups*	P-value
RAA	213,9	33,2	271,203	187,794	A	
RAT	181,9	32,2	232,797	170,79	A	0,000
R3D	54,08	8,43	67,962	45,432	B	

*Different letters indicate a difference between groups. Source: Own work.

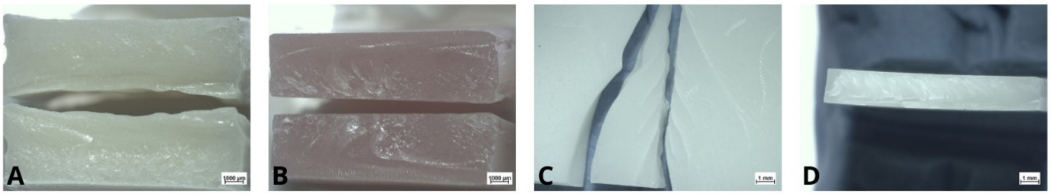

Figure 3. Fractured specimens from the experimental groups magnification 6.5X; A- RAA; B- RAT; C and D - R3D. Source: Own work.

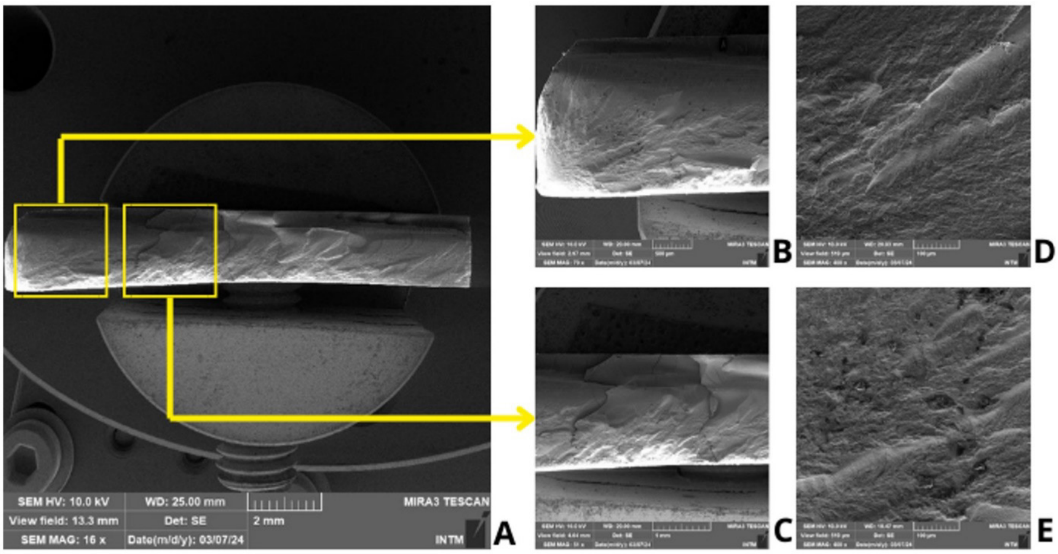

Figure 4. A- Fractured specimen from the R3D group magnification 16X; B- Cracks inside the specimen magnification 51X; C- Fracture end area magnification 70X; D- Internal roughness from crack area of the specimen magnification 400X; E- Defects inside the specimen from the specimen end area magnification 400X. Source: Own work.

DISCUSSION

Based on the findings of this research, the alternative hypothesis (H1) will be partially accepted, due to the analysis of surface roughness not showing a statistically significant difference, while the other tests did demonstrate this difference.

In this study, the surface of the 3D printed resin showed fewer surface alterations than the acrylic resins, corroborating similar research by Alageel et al.[1] and Myagmar et al.[4] This finding supports clinical use, as a smoother surface facilitates more effective hygiene of the provisional prosthesis[1]. However, regarding surface roughness, no statistical difference was observed between the experimental groups, although the 3D printed resin obtained the lowest average Ra value. A study comparing different resins for temporaries observed that 3D printed resin and milled resin had lower volume loss and lower surface roughness than conventional resin after prolonged masticatory simulation tests[4]. For Simoneti et al.[6], the surface roughness of SLS 3D printed resin had the highest Ra value, while bis-acrylic resin and SLA printed resin had lower values than the former and conventional resin, with this result being statistically significant. In Al-Qahtani et al.[7] research, 3D printed resin had higher Ra values than CAD-CAM milled resin and conventional resin, representing a statistically significant difference. However, in a study with 3D printed resin for denture bases, no statistical difference was found in surface roughness compared to heat-polymerized resin, and factors like print orientation and post-curing time did not affect Ra values[10].

Jain et al.[3] in reviewing the literature on the properties of 3D printed resin, found contrasting results when comparing surface roughness of 3D printed materials and other provisional materials. Different printing methods used in studies may explain the heterogeneous Ra findings. The Digital Light Processing (DLP) method used in this research produces objects by constructing successive layers of polymerized liquid resin through light, making it suitable for dental purposes due to its speed and ability to produce delicate cuts like dental anatomy. However, SEM images showed crowns with a rough surface due to numerous transitions between print layers. Similar images were observed in SEM and through optical profilometry in this research, suggesting that the limitation of the DLP method might be the reason for the lack of statistical difference between groups in this study and should be investigated further regarding biofilm formation.

Regarding hardness, the 3D printed resin obtained a higher average value compared to the other acrylic resins, with this result being statistically significant. This finding corroborates with the studies of Alageel et al.[1] and Al-Qahtani et al.[7], but contrasts with the data of Ellakany et al.[2] and Simoneti et al.[6] 3D resins have superior physical and mechanical properties to conventional resins, even after accelerated aging tests[1]. The highest and lowest mean microhardness values were observed in 3D printed resin and acrylic resin, respectively, with this difference being statistically significant, and CAD-CAM milled resins showed intermediate values[7]. Milled resins had better microhardness results than the others tested, even superior to 3D resins, followed by conventional resins[2]. SLA printed resin had hardness equivalent to bis-acrylic resin but inferior to acrylic resin in Simoneti et al.'s study[6].

The high hardness values may be due to the way the sample was printed in horizontal layers and the printing method, resulting in a smoother surface and fewer observed internal defects during fractographic analysis, favoring test execution. However, studies showing different results can be explained by the use of different printing methods, such as Stereolithography (SLA) and Selective Laser Sintering (SLS)[2,6], resin chemical composition, and post-curing[8,10]. These are factors that interfere with the mechanical properties[11].

For mechanical resistance, the performance of 3D printed resins was inferior to the tested acrylic resins, with a different fracture pattern observed, contrary to some literature findings[1,3,5,7,8]. Concerning mechanical properties, reviewed studies showed better results for 3D printed resins regarding fracture resistance, flexural strength, maximum stress, modulus of elasticity, and wear resistance compared to conventional and milled provisional materials[3]. Pantea et al.[5], when comparing the mechanical behavior of 3D resins and conventional resins, indicated the superiority of 3D printed resins in compression and flexural tests. However, when fracture resistance was tested, both resins showed a fragile surface with low plastic deformation capability. In Alshamrani et al.[8]'s study, variations in resin thickness and polymerization degree impacted the mechanical properties of 3D printed resin, and groups of resins not subjected to water storage showed higher flexural strength. According to Alageel et al.[1], 3D printed resins exhibit high quality and error reduction, even after accelerated aging tests. In AL-Qahtani et al.[7]'s study, 3D printed resin had mechanical results similar to milled resin and superior to acrylic resin. However, in Simoneti et al.[6]'s study, only a group of 3D printed resin made by SLS printing method showed superior mechanical performance to other resins. On the other hand, a 3D printed resin manufactured by Stereolithography, similar to DLP, showed lower flexural strength than acrylic resin and bis-acrylic resin, thus corroborating the findings of this research.

The reason for the reduction in mechanical resistance of 3D resin is the printing method[6,11]. The formation of the object in the DLP method is limited by the printer's chipset resolution, resulting in rougher layers. Thus, in specific areas where the bond between layers is weak or rougher, fracture can occur more quickly, generating several fragments. The greater number of fragments observed in this material is a factor to be clinically evaluated, as it may not provide safety for the patient and may cause injury[11]. Additionally, mechanical testing, aging, specimen type, and resin chemical composition[6,11] can alter the mechanical performance of a material under study.

Do 3D printed resins have applications for daily clinical practice? This study showed satisfactory results regarding surface, surface roughness, and hardness; however, mechanical performance was inferior to conventional resins. Moreover, this research is an in vitro study, limiting the extrapolation of data to daily clinical practice. Further research is needed to assess the effects of accelerated aging on the mechanical and physical properties of 3D printed resins compared to resins manufactured by other methods[1]. Some studies suggest that 3D printed resins may be better for long-term clinical use and exhibit adequate results for clinical use in patients[2].

The limitation of this research is the number of specimens per experimental group, although statistically significant according to the sample size calculation, the absence of data from the tests after aging, and the comparison with other resins indicated for temporary crowns. Therefore, further studies should be proposed to understand the long-term mechanical performance of 3D printed resins and the behavior of this resin under microbiological conditions to expand the use of the researched material in daily clinical practice.

CONCLUSION

Through the findings of this research and the resins tested for the manufacture of temporary prostheses, similarity was identified regarding surface roughness between conventional acrylic resins and 3D printed resin. Regarding hardness and mechanical resistance, however, 3D printed resin showed superior and inferior performance, respectively, compared to conventional acrylic resins.

AUTHORS' CONTRIBUTIONS

Heloisa Émilly da Silva Santos: Investigation, Visualization, Writing –original draft, Writing –review & editing. Milena Danubia Lima Nscimento: Formal Analysis, Writing – original draft, Writing – review & editing. Klennye Lorranny de Sousa Penafort: Investigation, Writing – original draft, Writing – review & editing. Antonio José Tôrres Neto: Formal Analysis, Writing – review & editing. Larissa Araújo Lopes Barreto: Writing – original draft, Writing – review & editing. Manassés Tercio Vieira Grangeiro: Writing – original draft, Writing – review & editing. Rebeca Tibau Aguiar Dias: Writing – original draft, Writing – review & editing. Viviane Maria Gonçalves de Figueiredo: Conceptualization, Supervision, Writing – original draft, Writing – review & editing.

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CONFLICTS OF INTERESTS

There is no conflict of interest among the authors of this research.

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