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Influência do ângulo de impressão nas propriedades mecânicas de diferentes resinas 3D utilizadas para base de próteses totais

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Dissertação apresentada ao Programa de Pós-Graduação em Ciências Aplicadas à Saúde, da Universidade Federal de Juiz de Fora, Campus Governador Valadares, como requisito parcial à obtenção do título de Mestre em Ciências Aplicadas à Saúde, área de concentração Biociências.

Orientador: Prof. Dr. Cleidiel Aparecido Araújo Lemos

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RESUMO

O edentulismo segue sendo uma questão de saúde pública, apesar da redução na prevalência de indivíduos totalmente edêntulos. As próteses totais convencionais de PMMA enfrentam limitações, e a impressão 3D oferece vantagens como economia de material e design flexível. No entanto, pouco se sabe sobre como o ângulo de impressão influencia as propriedades mecânicas das resinas utilizadas para bases de dentadura. Este estudo tem como objetivo analisar se a variação no ângulo de impressão influencia as propriedades mecânicas das resinas impressas.Foram impressas 240 amostras retangulares (64 × 10 × 3,3 ± 0,03 mm) e foram divididas em 4 grupos de resinas referente a cada marca (CD, SP, PZB, PXBB) e subdivididas em 12 grupos (n=20) de acordo com o ângulo de impressão (0º, 45º e 90º). Em cada subgrupo, 10 amostras foram submetidas a termociclagem durante 10.000 ciclos. Testes mecânicos foram realizados, envolvendo resistência à flexão com carga 100 kg/F numa velocidade de 5 mm/min até a fratura e microdureza com três indentações Knoop (HK) com carga de 25g com um tempo de permanência de 10s. A análise de variância (ANOVA) revelou que a resistência à flexão das resinas impressas em 3D é influenciada pela marca da resina, ângulo de impressão e envelhecimento térmico, com a resina PZB apresentando os melhores resultados. A termociclagem afetou significativamente a resistência à flexão e aumentou a microdureza de todas as resinas, exceto para a PXB. Além disso, a orientação de impressão teve pouco impacto, sendo relevante apenas para a resina CD a 0º, que mostrou maior resistência à flexão. O estudo concluiu que a escolha do material e as condições de impressão devem ser cuidadosas para otimizar o desempenho das próteses, sugerindo a necessidade de mais pesquisas sobre a impressão 3D na odontologia.

Palavras-chave: Resina impressa, ângulo de impressão, resistência a flexão, microdureza, envelhecimento

ABSTRACT

3D printing has become a prominent method for manufacturing denture bases due to its advantages; however, improving the mechanical properties of these materials remains challenging. This study evaluated the flexural strength and microhardness of four 3D-printed denture base resins (Cosmos Denture [CD], Smart Print Biodenture [SP], PriZma 3D Bio Denture [PZB], and Printax BB Base [PXBB]) under different printing angles (0º, 45º, and 90º) and aging conditions. A total of 240 rectangular samples were printed using a digital light processing printer, polished, and divided into experimental groups. Half of the samples underwent thermal aging (10,000 thermocycles). Flexural strength and microhardness were then tested, and statistical analyses were conducted (three-way ANOVA, $P<0.05$). The results revealed significant differences in flexural strength among resins, with PZB showing the highest values, followed by SP, CD, and PXBB ($P<0.001$). Printing orientation had no significant effect on most resins ($P>0.05$), except for CD, which displayed higher flexural strength at 0º compared to 45º and 90º ($P<0.001$). Aging reduced flexural strength in PZB and SP resins ($P<0.001$), but PZB still maintained the highest values. Microhardness results showed no significant influence of printing orientation ($P=0.865$). Resin type and thermocycling significantly affected microhardness ($P<0.001$), with PZB and PXBB demonstrating the highest values. Aging increased microhardness in all resins except PXBB, which showed no change ($P=0.765$). This study concluded that the mechanical properties of 3D-printed denture base resins are influenced by resin brand and aging conditions, with unique behaviors observed for flexural strength and microhardness. Printing orientation generally had no effect, except in one resin. Thermocycling decreased flexural strength in some resins while enhancing microhardness in most. These findings emphasize the importance of considering material-specific properties and aging effects in 3D-printed denture bases.

Keywords: Printing angle, hardness, build angle, 3D printing, thermocycling

LISTA DE SIGLAS

PMMA	Polimetilmetacrilato
CD	Cosmos Denture – Yller ®
SP	3D Smart Print Biodenture – Smart Dental ®
PZBD	PriZma 3D Bio Denture – Makertech ®
PXB	Printaxx BB Base – Odontomega ®

SUMÁRIO

1 INTRODUÇÃO

O edentulismo, caracterizado pela ausência total ou parcial de dentes, é amplamente considerado um sério problema de saúde pública que tem perdurado nas últimas décadas (LI, X. *et al.*,2022. FELTON, D. A. 2016). Apesar das evidências de uma redução no número de indivíduos afetados por essa condição na atual geração, um fenômeno notável é o aumento absoluto de pacientes edêntulos, especialmente em função do crescente envelhecimento populacional e da expansão da expectativa de vida (GARG, P*. et al.*,2022, POLZER, I. *et al.*2010, WU, J. *et al.,* 2012). Nesse contexto, a prótese total convencional continua a ser uma alternativa de tratamento frequentemente indicada e considerada eficaz para pacientes totalmente edêntulos (MURRAY, M. D, *et al.*,1993).

Entre os materiais utilizados na confecção de próteses totais, o polimetilmetacrilato (PMMA) é o mais amplamente empregado (MUBARAKI, M. Q. *et al.*,2022). Este material é amplamente valorizado por suas qualidades, como facilidade de processamento e reparo, além de ser biocompatível e apresentar uma estética aceitável para os pacientes (LI, X. *et al.*,2022, ANADIOTI, E. *et al.*,2020). No entanto, o PMMA possui várias limitações, incluindo alta taxa de contração durante a polimerização, susceptibilidade à proliferação microbiana, potencial para reações alérgicas devido ao monômero, ausência de radiopacidade, deterioração das propriedades mecânicas com o tempo e resistência reduzida ao desgaste, especialmente quando exposto à saliva humana (LI, X. *et al.*,2022, GAUTAM, R. *et al.* 2012, AKIN, H. *et al.*, 2015)

O advento da tecnologia digital na odontologia trouxe consigo avanços significativos na prática clínica, promovendo maior eficiência para o Cirurgião Dentista (CD) e aprimorando o conforto dos pacientes. Especificamente no campo das próteses totais, destacam-se dois métodos computacionais de fabricação para as bases dentárias: o método subtrativo, baseado em fresagem, e o método aditivo, que envolve a impressão 3D. O primeiro, consolidado desde a década de 2010, já apresenta estudos clínicos comparativos que indicam que as próteses fresadas podem oferecer resultados similares (KATTADIYIL, M. T. *et al*.,2015) ou até superiores às próteses convencionais (AL-DULAIJAN, Y. A. *et al*., 2022).

Em paralelo, a impressão 3D, que tem ganhado crescente popularidade nos últimos anos, tem sido associada a diversas vantagens. Entre elas, destacam-se a economia de material, a ausência de desgaste das brocas de fresagem, a capacidade de criar próteses com detalhes finos e a possibilidade de um design praticamente ilimitado (AL-QARNI, F. D. *et al*.,2022, BILGIN, M. S. *et al*.,2016). Adicionalmente, o uso da impressão 3D tem permitido uma redução no tempo clínico e na fabricação, um controle de qualidade superior, além de melhor resistência e ajuste das restaurações (AL-QARNI, F. D. *et al*., 2022, GOODACRE, B. J. *et al*., 2022). Outro ponto positivo é a capacidade de imprimir várias dentaduras simultaneamente, otimizando os recursos e o tempo (GOODACRE, B. J. *et al*., 2022).

Diante desse cenário de inovação tecnológica, uma recente revisão narrativa realizada por Goodacre e Goodacre ressaltou a importância de novos estudos sobre a impressão 3D na confecção de próteses, uma vez que ainda existem inúmeras questões não resolvidas sobre essa tecnologia. Durante o processo de impressão 3D, há uma série de variáveis que precisam ser rigorosamente controladas, como a espessura da camada impressa, a profundidade de polimerização, a quantidade de encolhimento e o ângulo da fonte de luz, os quais têm impacto direto nas propriedades mecânicas e físicas dos materiais. Diversas revisões de literatura também destacaram a necessidade de se avaliar com mais profundidade como os parâmetros de ângulo de impressão influenciam as características mecânicas das resinas utilizadas na impressão 3D de bases de dentadura (AL-QARNI, F. D. *et al*; 2022, VILELA TEIXEIRA, A. B. *et al*.,2023).

Uma revisão de escopo realizado por Teixeira e colaboradores concluiu que a influência do ângulo de impressão sobre as propriedades mecânicas das resinas deve ser mais bem investigada, dada a grande variedade de materiais disponíveis para impressão 3D e as variações significativas em suas propriedades. A compreensão de como esses fatores se inter-relacionam poderá ser determinante para a otimização das características mecânicas dessas resinas (GOODACRE, B. J. *et al*., 2022, PRPIC, V. *et al*.,2020)

Embora as propriedades mecânicas de materiais acrílicos, como o PMMA, tenham sido amplamente investigadas na literatura (MURRAY, M. D. *et al*.,1993, BENTO, V. A. A. *et al*., 2024, SHIM, J. S. *et al*., 2020), há uma lacuna significativa no conhecimento sobre as características mecânicas das bases de dentadura produzidas com resinas impressas em 3D, especialmente no que tange aos diferentes ângulos de impressão utilizados no processo de fabricação.

O objetivo deste estudo é avaliar a microdureza e resistência à flexão de quatro diferentes marcas de resinas 3D nacionais para impressão, em relação ao ângulo de impressão (0º, 45º e 90º) e ao envelhecimento térmico. A hipótese nula, que será testada neste trabalho, é a de que não há diferenças significativas entre as marcas de resinas impressas em 3D em relação às características mecânicas avaliadas, quando orientadas em diferentes ângulos de impressão.

2 ARTIGO CIENTÍFICO

Artigo Científico enviado para publicação no periódico Dental Materials CAPES A1. A estruturação do artigo baseou-se nas instruções aos autores preconizados pelo periódico (ANEXO A).

Influence of Printing Orientation on the Mechanical Properties of Different 3D-Printed Resins Used for Denture Bases Under Aging Conditions

ABSTRACT

3D printing has become a prominent method for manufacturing denture bases due to its advantages; however, improving the mechanical properties of these materials remains challenging. This study evaluated the flexural strength and microhardness of four 3D-printed denture base resins (Cosmos Denture [CD], Smart Print Biodenture [SP], PriZma 3D Bio Denture [PZB], and Printax BB Base [PXBB]) under different printing angles (0º, 45º, and 90º) and aging conditions. A total of 240 rectangular samples were printed using a digital light processing printer, polished, and divided into experimental groups. Half of the samples underwent thermal aging (10,000 thermocycles). Flexural strength and microhardness were then tested, and statistical analyses were conducted (three-way ANOVA, $P<0.05$). The results revealed significant differences in flexural strength among resins, with PZB showing the highest values, followed by SP, CD, and PXBB ($P<0.001$). Printing orientation had no significant effect on most resins ($P>0.05$), except for CD, which displayed higher flexural strength at 0º compared to 45º and 90º ($P<0.001$). Aging reduced flexural strength in PZB and SP resins ($P<0.001$), but PZB still maintained the highest values. Microhardness results showed no significant influence of printing orientation ($P=0.865$). Resin type and thermocycling significantly affected microhardness ($P<0.001$), with PZB and PXBB demonstrating the highest values. Aging increased

microhardness in all resins except PXBB, which showed no change (P=0.765). This study concluded that the mechanical properties of 3D-printed denture base resins are influenced by resin brand and aging conditions, with unique behaviors observed for flexural strength and microhardness. Printing orientation generally had no effect, except in one resin. Thermocycling decreased flexural strength in some resins while enhancing microhardness in most. These findings emphasize the importance of considering material-specific properties and aging effects in 3D-printed denture bases.
Keywords: Printing angle, hardness, build angle, 3D printing, thermocycling

1. INTRODUCTION

Edentulism has remained a significant public health concern over the last decades, although its prevalence has declined in recent generations due to improved access to preventive oral care and dental treatment [1,2]. Despite this decline, it is currently estimated that approximately 35.2 million individuals in the world experience edentulism [1]. This condition is linked to a higher risk of comorbidities, including malnutrition, obesity, cardiovascular and pulmonary diseases, and even mortality [2]. Consequently, rehabilitating edentulous patients, whether with or without implants, is essential for maintaining their quality of life. This rehabilitation enhances functionality and esthetics while playing a critical role in preserving psychosocial and cognitive health [3].

While dental implants are increasingly regarded as one of the most effective rehabilitation options, conventional complete dentures remain a widely used and favorable treatment choice for completely edentulous patients [2, 4, 5]. Polymethylmethacrylate (PMMA) continues to be the most commonly used material for fabricating complete dentures [6], owing to its biocompatibility, aesthetic appeal, and ease of processing [7]. However, PMMA also has notable limitations, including high polymerization shrinkage, low wear resistance, and a propensity for microbial proliferation [8-10].

Digital technology has transformed dentistry, especially in the production of complete dentures, by utilizing computer-aided manufacturing techniques such as milling and 3D printing. Among these, 3D printing has gained prominence due to its material efficiency, flexible design, superior quality control, enhanced accuracy, and mainly reduced clinical and manufacturing time [11-14]. A recent review highlights the growing role of 3D-printed treatments in the future of complete denture fabrication while emphasizing the need for further research into the potential of 3D-printed dentures [15]. However, despite its promising applications, 3D printing presents disadvantages, including lower flexural strength [15] and higher susceptibility to fractures [16]. Thus, evaluating different parameters that may improve the mechanical properties of 3D-printed resins is of critical importance.

Several aspects of 3D-printed resins remain underexplored, particularly regarding printing parameters such as printing angles. A recent scoping review suggests that printing orientation may significantly impact the physicomechanical properties of 3D printed resins. However, the authors pointed out that few studies have specifically examined these properties in 3D-printed denture bases, emphasizing the need for further research to better understand the relationship between printing orientation and the mechanical properties of denture bases [17].

Therefore, this study aims to assess the variations in microhardness and flexural strength of different 3D printing resins based on varying printing angles (0º, 45º, and 90º). The null hypothesis is that there are no significant differences in the mechanical properties of the 3D printed resins concerning the different printing angles.

2. METHODOLOGY

2.1 EXPERIMENTAL DESIGN

Four 3D printed resins used for the fabrication of complete denture bases were selected for this study: Cosmos Denture - Yller (Pelotas/RS, Brazil), Smart Print Biodenture – Smart Dent (São Carlos, SP, Brazil), PriZma 3D Bio Denture – Makertech (Tatuí, SP, Brazil), and Printax BB Base – Odontomega (Ribeirão Preto, SP, Brazil). A total of 240 rectangular samples (64 × 10 × 3.3 ± 0.03 mm) were printed according to the ISO 20795-1:2013 International Standard and measured using a digital caliper [18, 19] These samples were divided into four main resin groups and further subdivided into three subgroups based on printing angles (0º, 45º, and 90º), resulting in n = 20 for each subgroup, as illustrated in Table 1.

2.2 SAMPLE ACQUISITION

The samples were fabricated using the 3D printing method, initially designed in CAD software (Exocad; Exocad GmbH) according to the dimensions previously reported. The CAD standard tessellation language files were sent to the printer's CAM software. A stereolithographic printer utilizing digital light processing technology. (MoonRay Model S; VertySystem) was used to obtain the 3D printed samples with orientations of 0º, 45º, and 90º for each of the resins used in the study. The rectangular samples were printed according to the printing angle parameter, based on the prior work of Shim and colleagues [20]. The resin curing was carried out according to the manufacturer's recommendations. After sample fabrication, they underwent a standardized metallographic finishing and polishing process using an automatic polishing machine (Aropol E; Arotec) with silicon carbide abrasive papers (#240, #400, #600, and #1200) under constant water irrigation at 300 rpm for 20

seconds on each face. Subsequently,polishing was performed with felt discs and 1 μm alumina suspension. After finalizing the samples, they were immersed in an ultrasonic bath for 5 minutes to remove any possible debris. Following processing, each sample was stored in distilled water.

2.3 THERMOCYCLING

After the finishing and polishing stage, the aging process was performed on 10 samples from each group using a thermocycler (OMC 250 TS, Odeme). The samples were subjected to water baths maintained at 5±1°C and 55±1°C for 30 seconds per cycle, completing 10,000 cycles in total, following the guidelines of ISO 11405. This procedure simulates approximately two years of intraoral use [21].

2.4 MICROHARDNESS

Microhardness measurements were conducted using a microhardness tester (HMV II; Shimadzu Corporation, Kyoto, Japan) equipped with a Knoop indenter (HK), applying a 25g load with a dwell time of 10 seconds [22]. Three indentations were performed on each specimen, maintaining a minimum distance of 100 μm between them, and the average HK value was calculated.

2.5 FLEXURAL STRENGTH

Flexural strength was tested through a three-point bending test on a universal testing machine (EMIC, São José dos Pinhais, SP, Brazil), following the guidelines of ISO 20795-1:2013 for denture base polymers. The samples were positioned on circular support beams with a span of approximately 50 mm. A load cell of 100 kg/F was used to apply a constant load at the center of the sample at a crosshead speed of 5 mm/min until fracture. The point of fracture was defined as the moment when the applied load dropped to zero. Data were recorded using software (Tesc; Intermetric Ltd). The flexural strength was then calculated using the following equation: Flexural Strength (MPa) = $3Fl / 2bh^2$. In this equation, F is the maximum load, l is the distance between the supports, b is the width, and h is the height [19].

2.6 STATISTICAL ANALYSIS

The Shapiro-Wilk test confirmed a normal distribution for microhardness and flexural strength. A three-way analysis of variance (ANOVA) followed by Tukey post-hoc tests was conducted to assess the interaction effects of 3D-printed resins, printing angle, and aging on microhardness and flexural strength. Statistical analysis was performed using JAMOVI Version 2.3.28 (https://www.jamovi.org), with all tests conducted at a significance level of $P < 0.05$.

3. RESULTS

The results of the analysis of variance (ANOVA) for flexural strength indicated a significant difference in terms of 3D printed resin, printing orientation, and aging ($P<0.001$). The interactions between 3D printed resin x printing angle ($P<0.001$) and 3D printed resin x aging ($P<0.001$) were also statistically significant, indicating that the performance of the resins depends on printing conditions and thermal aging. However, the interactions between printing angle x thermocycling ($P<0.887$) and 3D printed resin x printing angle x aging ($P<0.144$) were not statistically significant, suggesting that these combinations of factors did not significantly impact the flexural strength values (Table 2).

In post hoc analysis of the different 3D printed resins, the highest flexural strength values were observed for the PZB resin, followed by the SP, CD, and PXBB resins, respectively (P<0.001) (Figure 1). Difference in the printing angle was observed between 0º and 45º (P=0.040) and 90º (P<0.001), but no difference was observed for printing angle at 45º and 90º (P=0.255). The thermocycling affected the flexural strength values (P<0.001).

Regarding the interaction between 3D printed resin and printing angle, it was observed that, for most resins, there was no significant effect on flexural strength (P>0.05). However, the 3D printed resin in the CD group showed significant higher flexural strength made at 0º compared to 45º and 90º (P<0.001), regardless of aging. The analysis of the impact of thermal aging revealed a significant reduction in flexural strength for the SP and PZBD 3D printed resins, regardless of printing orientation (P<0.001). In contrast, thermocycling did not significantly affect the CD and PXB 3D printed resins, indicating greater stability of these resins against aging (P>0.05)

When specifically evaluating the interactions between 3D printed resins in relation to printing angle, it was observed that for the CD resin, prints made at 0° exhibited flexural strength similar to that of the SP resin before aging (P=0.997), as well as to the SP (P=0.859) and PZB (P=0.393) 3D printed resins after aging. For prints at 45°, the PZB resin remained superior to the others, while a similarity was observed between the CD and PXB resins before (P=0.062) and after aging (P=0.426). In the samples printed at 90°, before aging, a similarity was observed between the PZB and SP resins (P=0.314), and between the CD and PXBB resins (P=0.843). After aging, the PZB resin exhibited the highest flexural strength values compared to the others (P<0.001) (Figure 2).

In the microhardness analysis, the results showed that the resin type (p<0.001) and thermocycling (p<0.001) significantly influenced the microhardness values, while printing angle had no significant effect in this outcome (P=0.865) (Table 3). Before aging, the PZB and PXBB resins exhibited the highest microhardness values, significantly superior to the CD and SP resins, which showed the lowest value without difference between them (P=0.999). After aging, the CD and SP resins maintained the lowest microhardness values without difference (P=0.888), while the PZB and PXBB resins continued to exhibit the highest values, with difference significant favorable for PXBB (P<0.001). Thermocycling increased the microhardness values for all resins (P<0.01), except for PXB, which maintained similar results before and after aging (P=0.765) (Figure 3).

4. DISCUSSION

The results of this study highlight that the 3D printed resin, printing angle, and aging play significant roles in the mechanical properties of 3D printed materials for complete denture bases, rejecting the hypothesis tested. These findings are important for material selection and printing conditions for clinical applications, considering the balance between flexural strength and microhardness, as well as the stability of mechanical properties during the longevity of complete dentures.

The PZB resin demonstrated the best performance in terms of flexural strength, corroborating with previous studies that reported high flexural strength of the PZB resin similar to other techniques, as conventional press and mold denture base [23] or other 3D printed resins [24]. This superior performance can be attributed to its chemical composition and its behavior in response to aging, contributing to greater durability and stability of its mechanical properties [23]. However, in our study the PZB resin demonstrated a significant reduction in the flexural strength after aging. This was also observed in previous study that observed a significant reduction in flexural strength of PZB after aging [24].

Denture bases must exhibit high flexural strength to withstand various stresses, as they are subjected to different types of forces during cleaning, insertion, removal, and the masticatory process. The ISO requirements for flexural strength recommend a minimum of 65 MPa to ensure the functionality and durability of denture bases [18, 25-27]. In this study, among the tested variables, the 3D printed resins still met the ISO requirements for flexural strength, except the PXBB resins that demonstrated values below this threshold, independently of printing orientation. The same findings were also reported in a previous study [24], and this influence may be attributed to differences in the internal structures of 3D-printed resin.

Printing orientation is an important factor in achieving optimal outcomes in 3D printed resins, as it determines the alignment of the denture base relative to the horizontal plane. This orientation directly influences the number of layers, and the time required to complete the printing process [28, 29]. Despite this, no influence of printing orientation was observed for most of 3D printed resins evaluated in terms of flexural strength. This result is supported by previous studies that concluded printing orientation does not influence the flexural strength of 3D-printed resins [28, 30].

However, the CD group showed a significant difference between 0º than those 45º and 90º. This is an interesting finding that may reflect the minimal variation in the mechanical properties of these materials at different printing angles. This can be attributed to the fact that prints parallel to the horizontal plane, with layer construction perpendicular to the direction of applied forces, tend to provide greater resistance [20, 28, 31, 32]. These findings indicate that printing orientation can influence the flexural strength of the material, although this effect appears to be specifically linkedto the type of resin used because depends on material composition and printing conditions [32]. Therefore, generalizing standards and recommendations for printing orientations across different types of resin may not be entirely appropriate. Instead, the optimal performance of each resin should be evaluated considering its unique characteristics and properties.

The flexural strength of the 3D printed resins was significantly influenced by the interaction between resin type and thermocycling, confirming that artificial thermal aging has a relevant impact on flexural strength of the resins [33], suggesting that these materials may be more susceptible to thermal wear [34]. However, in the factor's interactions the reduction of flexural strength was observed only for the SP and PZB resins, while CD and PXBB resins did not show influence of thermal aging. The same results are observed in previous study that identified absence of difference for PXBB after aging [24].

A hardness analysis is crucial as it assesses the material resistance on to plastic deformation caused by mechanical action. Denture bases with low surface hardness are more susceptible to damage during cleaning processes, which can ultimately shorten the functional lifespan of the dentures [26]. Regarding the Knoop microhardness, a significant interaction was observed only for 3D printed resins and aging, without influence in printing orientation. This can be explained by the fact that the literature indicates microhardness values are typically unaffected by the printing angle, as this property is more strongly influenced by the filler content of the resins [12, 28].

This possibly justifies the differences observed in the PXB resins, since this 3D printed resin exhibited the highest microhardness values, in contrast to its flexural strength, which showed the lowest values. According to the manufacturer, the chemical composition of PXB includes aromatic methacrylic oligomer (<80%), aliphatic methacrylic oligomer (<30%), and phosphine oxide (<5%). The aromatic methacrylic oligomer is responsible for increasing rigidity of material. Thermocycling can cause a slight contraction or expansion of the material. This occurs because thermoplastic materials may experience micro-expansions or contractions when alternating between high and low temperatures. As the PXB resin contains a significant amount of this compound, it could explain the increase in microhardness. Therefore, the greater hardness of the material, the lower its capacity for deformation, which could consequently result in reduced flexural strength values.

Another important finding in the microhardness analysis is that, with the exception of PXBB resin, all other 3D-printed resins demonstrated a significant increase in microhardness after thermocycling. This phenomenon can be attributed to the artificial thermal aging process, during which the resins absorb water as they are subjected to temperature variations. This process may promote the release of residual monomers, leading to further polymerization of the resin and ultimately resulting in an increase in microhardness values after thermocycling [24].

This study has inherent limitations that should be acknowledged. It was restricted to evaluating only flexural strength and microhardness, and further studies exploring other factors such as color stability, roughness, wettability, sorption, solubility, and biocompatibility are recommended to assess the influence of 3D printed resins comprehensively. Additionally, the effects of varying pos-curing polymerization times, cycles, and layer deposition were not examined and should be investigated in future research. Another limitation is that the chemical compositions of the 3D printed resins was not disclosed by all manufacturers. Furthermore, all analysis was conducted under controlled laboratory conditions, which may not fully replicate oralconditions. Therefore, in addition to laboratories, well-designed clinical studies are essential to further evaluate these characteristics.

5. CONCLUSION

Based on the findings of this in vitro study the conclusions can be drawn:

- Different brands of 3D-printed resins exhibit distinct behaviors regarding their flexural strength and microhardness properties
- Printing orientation showed no significant effect on the mechanical properties of the resins. However, depending of 3D printed resin the printing orientation could improve the flexural strength.
- Thermocycling led to a reduction in flexural strength for certain resins, while simultaneously contributing to an increase in microhardness.

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TABLES

Table 1. Experimental design of the groups evaluated.

Groups	Commercial Name – Manufacturer	Composition	Printed Angle	Number of specimens*
CD	Cosmos Denture – Yller	Oligomers, monomers, photoinitiators, stabilizer and pigment	0º	20
			45º	20
			90º	20
SP	3D Smart Print Biodenture – Smart Dental	Oligomers, monomers, photoinitiators, stabilizer and pigment	0º	20
			45º	20
			90º	20
PZB	PriZma 3D Bio Denture – Marketech	Proprietary acrylate and triacrylated monomers (>10%),amorphous silica (≤5%), fillers—proprietary (<10%),proprietary meta-acrylated oligomers (<70%), diphenyl(2,4,6-trimethylbenzoyl)- phosphine oxide (<5%)	0º	20
			45º	20
			90º	20
PXBB	PrintaX BB Base – PrintaX	Aromatic methacrylic oligomer (<80%), aliphatic methacrylicoligomer (<30%), phosphine oxide (<5%)	0º	20
			45º	20
			90º	20

* 10 specimens for analysis before and after thermal aging

Table 2. Three-way ANOVA analyzing flexural strength between 3D printed resins, printing orientation and aging.

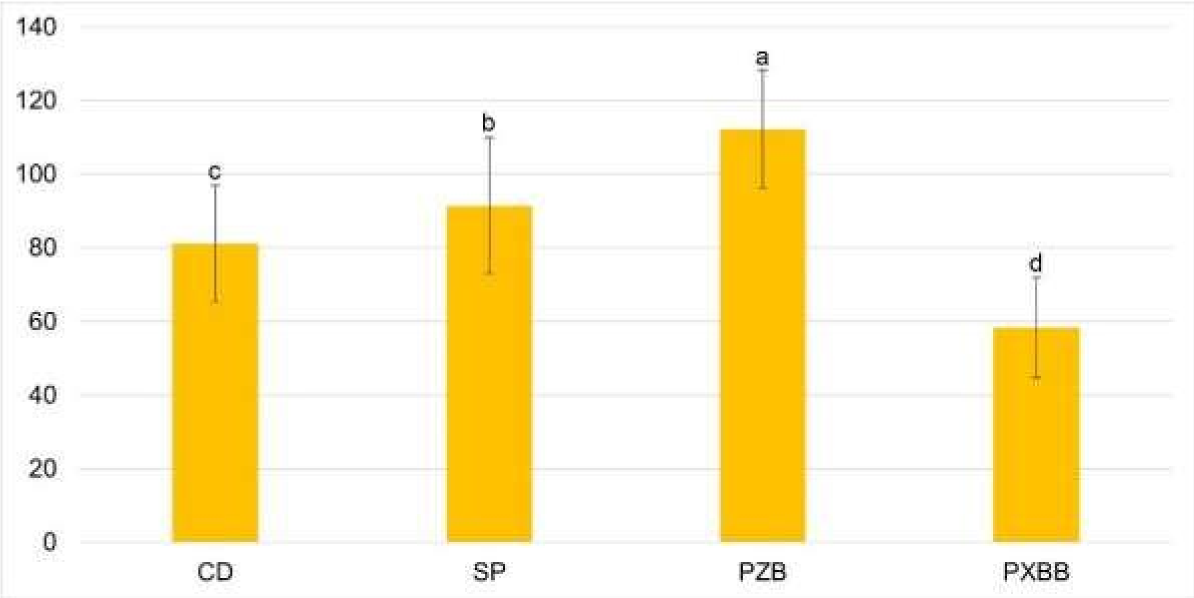
	Sum of Squares	Degree of freedom	Mean Square	F	P
3D PRINTED RESIN	90691.9	3	30230.6	333.944	< .001
PRINTING ORIENTATION	1483.4	2	741.7	8.193	< .001
AGING	26160.5	1	26160.5	288.983	< .001
3D PRINTED RESIN ✻ PRINTING ORIENTATION	5775.7	6	962.6	10.634	< .001
3D PRINTED RESIN ✻ AGING	6603.3	3	2201.1	24.315	< .001
PRINTING ORIENTATION ✻ AGING	21.7	2	10.8	0.120	0.887
3D PRINTED RESIN ✻ PRINTING ORIENTATION ✻ AGING	876.8	6	146.1	1.614	0.144
Resíduos	19372.6	214	90.5		

Table 3. Three-way ANOVA analyzing microhardness between 3D printed resins, printing orientation and aging.

	Sum of Squares	**Degree of freedom**	**Mean Square**	**F**	**P**
3D PRINTED RESIN	597.133	3	199.044	75.605	< .001
PRINTING ORIENTATION	0.767	2	0.384	0.146	0.865
AGING	72.380	1	72.380	27.493	< .001
3D PRINTED RESIN ✻ PRINTING ORIENTATION	22.298	6	3.716	1.412	0.211
3D PRINTED RESIN ✻ AGING	63.209	3	21.070	8.003	< .001
PRINTING ORIENTATION ✻ AGING	5.055	2	2.527	0.960	0.385
3D PRINTED RESIN ✻ PRINTING ORIENTATION ✻ AGING	27.153	6	4.525	1.719	0.118
Resíduos	568.662	216	2.633		

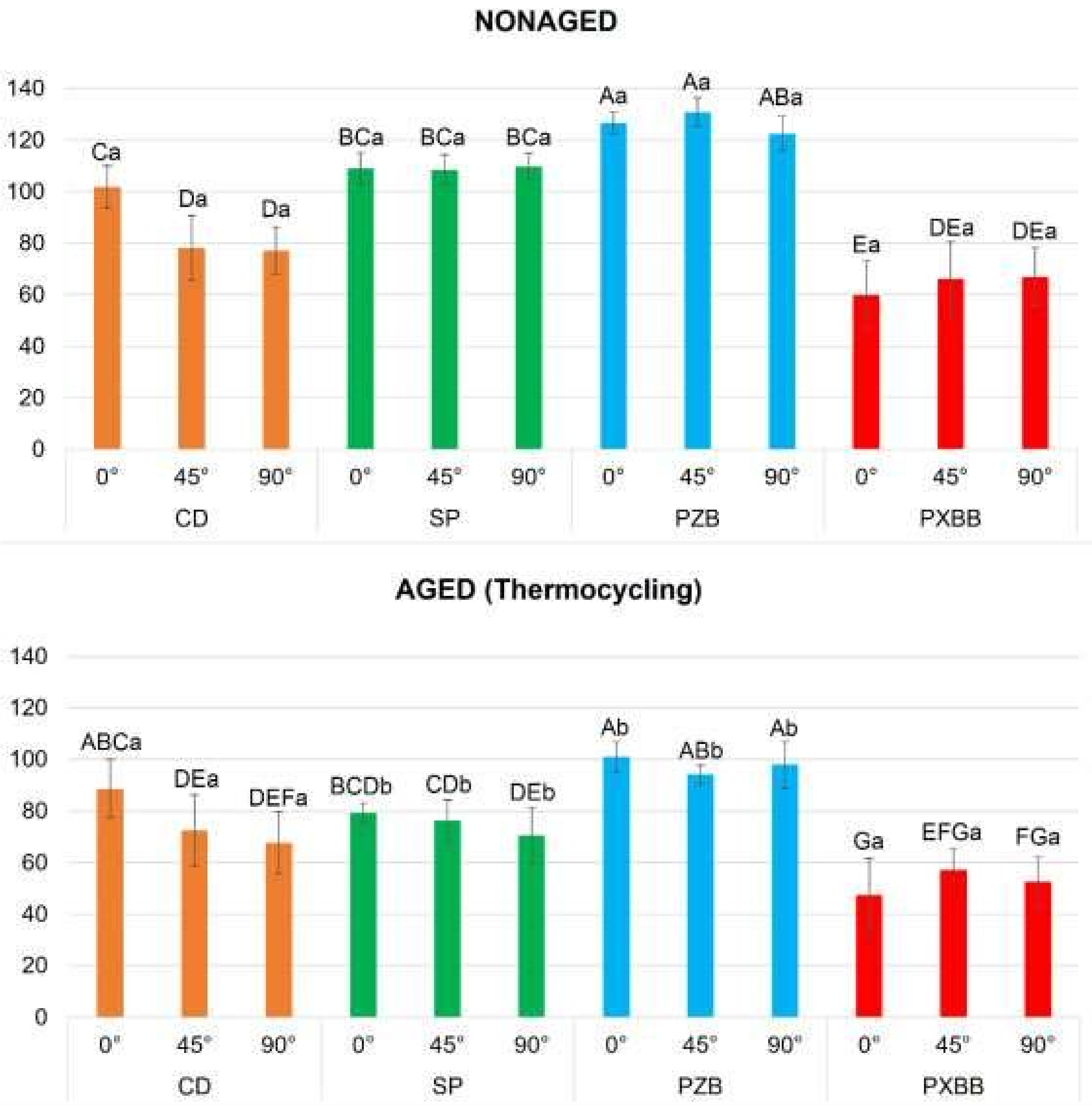
FIGURES

Figure 1. Flexural strength of different 3D printed resins.



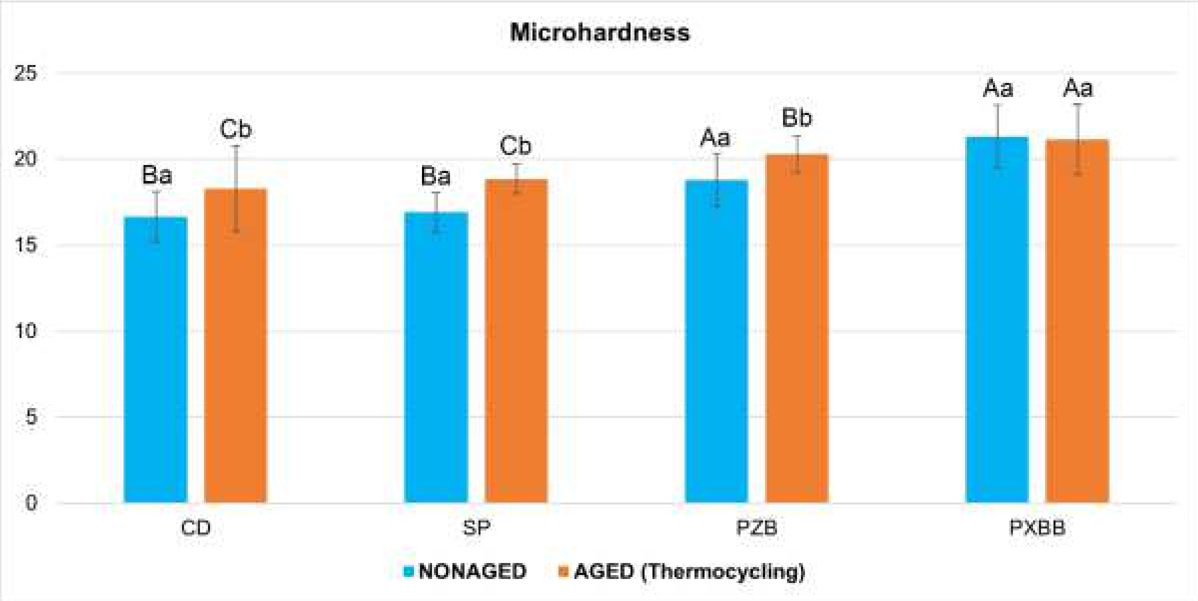
Different lowercase letters indicated significant differences between evaluated 3D printed resins.

Figure 2. Flexural strength of different 3D printed resins in terms of printing orientation for nonaged and aged group.



Different uppercase letters indicated significant differences between 3D printed resins and printing orientation. Different lowercase letters indicated differences between 3D resins and aging.

Figure 3. Microhardness of different 3D printed resins in terms of nonaged and aged group.



Different uppercase letters indicated significant differences between 3D printed resins. Different lowercase letters indicated differences between aging.

3 CONCLUSÃO

Com base nos resultados deste estudo in vitro, pode-se concluir que diferentes marcas de resinas apresentam, comportamentos distintos em relação às propriedades mecânicas avaliadas (microdureza e resistência à flexão). Embora a orientação de impressão não tenha mostrado efeito significativo nas propriedades das resinas, ela pode melhorar a resistência à flexão dependendo da resina utilizada. Por fim, a termociclagem resultou em uma redução na resistência à flexão de algumas resinas, ao mesmo tempo em que contribuiu para o aumento da microdureza.

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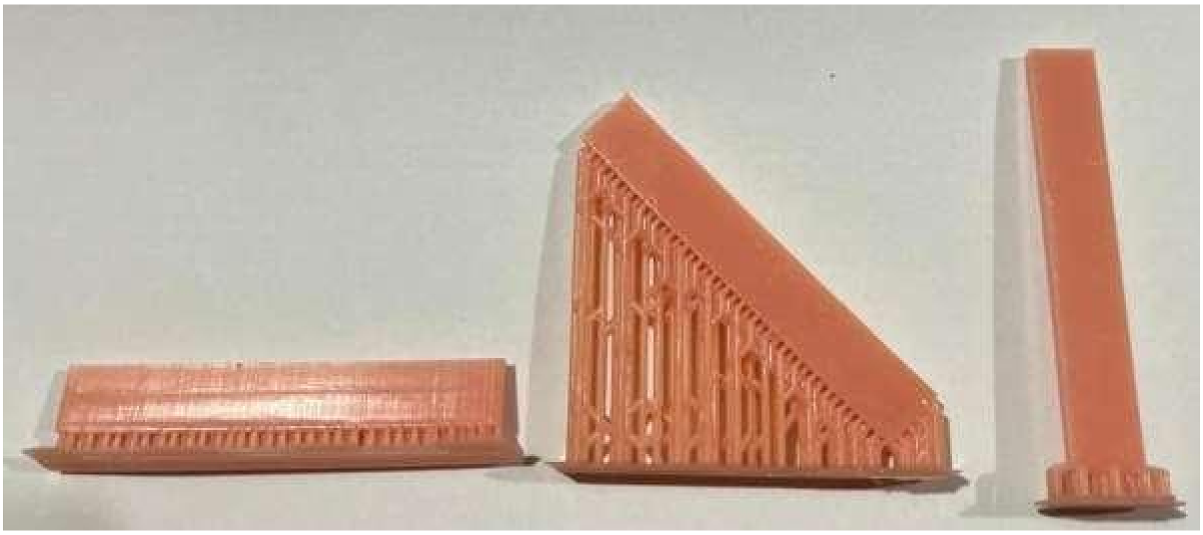
ANEXO A

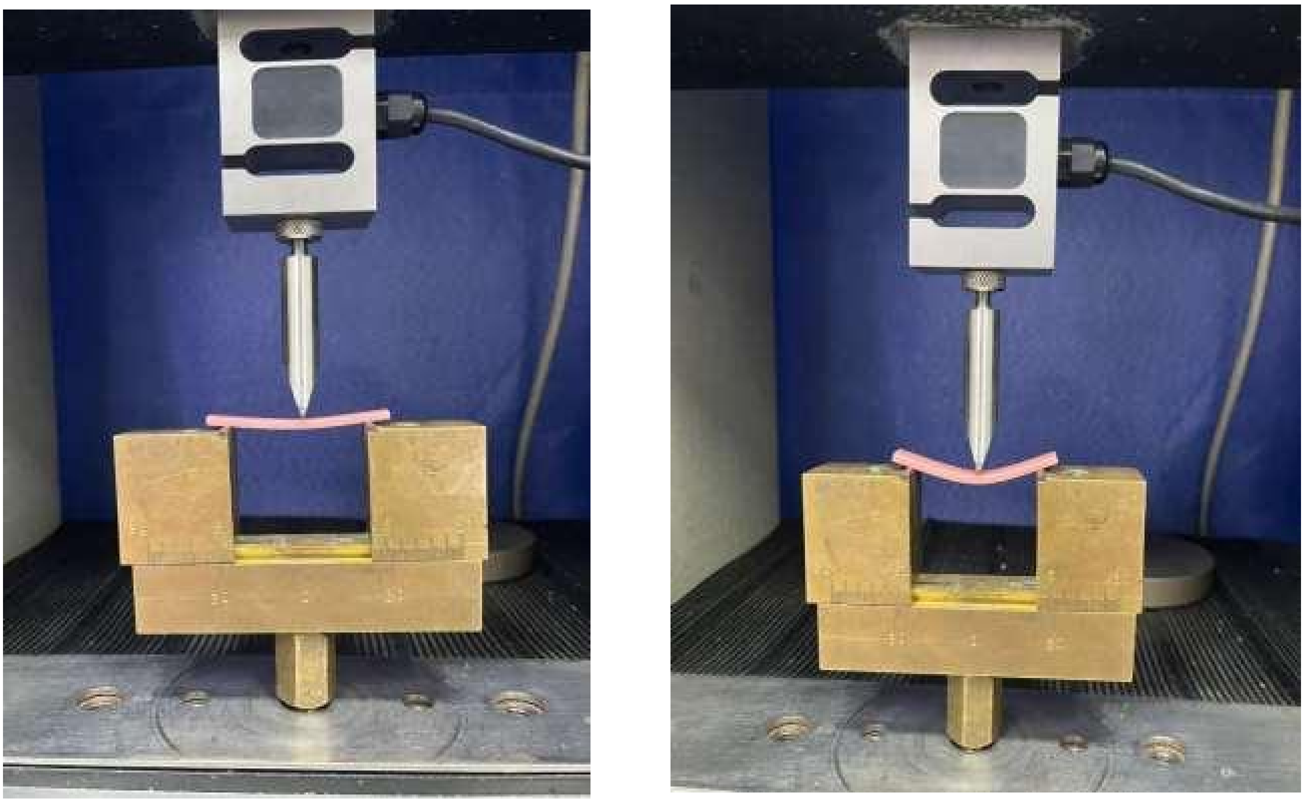
Instruções para submissão no periódico “Dental Materials”, disponível em:

https://www.sciencedirect.com/journal/dental-materials/publish/guide-for-authors

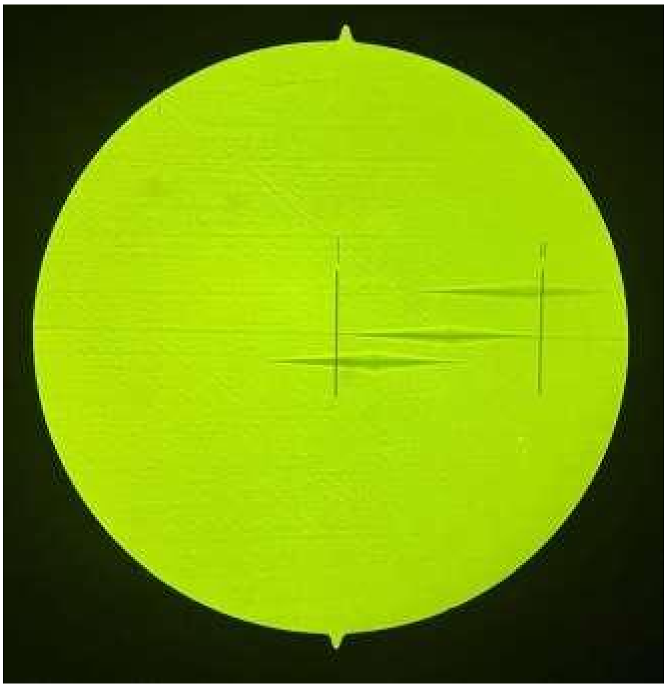
ANEXO B



Amostras impressas sem acabamento/polimento em 0°, 45° e 90°, respectivamente.



Teste de flexão de três pontos em EMIC.



Mensuração de indentações em teste de microdureza.