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PROPRIEDADES MECÂNICAS DE RESTAURAÇÕES OBTIDAS
POR IMPRESSORA 3D

Mechanical properties of restorations obtained by 3D-printer

Tese apresentada à Faculdade de Odontologia da universidade Federal de Uberlândia como requisito parcial para obtenção do Título de Doutor em Odontologia na Área de concentração Clínica Odontológica Integrada.

Uberlândia, fevereiro de 2023

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EPÍGRAFE

“Happiness can be found in the darkest of times, if one only remembers to turn on the light.”

Albus Dumbledore

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RESUMO

No contexto da prática clínica moderna, a utilização do fluxo digital para a obtenção de restaurações odontológicas tem se destacado, oferecendo benefícios como rapidez, precisão, redução de custos e maior conforto para os pacientes. O avanço das tecnologias de impressão permitiu a aplicação de resinas em processos de reabilitação, buscando aprimorar a resistência e prolongar a vida útil das restaurações através da incorporação de micropartículas de cerâmica e óxido de zircônia. A presente tese abordou três objetivos específicos nesse campo. O primeiro objetivo consistiu na avaliação das propriedades físicas e mecânicas de quatro resinas impressas em duas espessuras de camada. Isso envolveu a análise do grau de conversão por meio de espectroscopia Raman, a rugosidade superficial através de microscopia confocal e microscopia eletrônica de varredura, a resistência flexural por meio de ensaios de três pontos e o módulo de elasticidade utilizando uma máquina de ensaios universais, além da dureza Vickers por meio de microdurômetro. O segundo objetivo concentrou-se na análise da composição, macro e microestrutura das quatro resinas, utilizando técnicas como espectroscopia Raman para obtenção de espectros, Espectroscopia de raios-X com dispersão de energia (EDS) para composição, e Microscopia Eletrônica de Varredura e microscópio confocal para a avaliação da macro e microestrutura. O terceiro objetivo envolveu a avaliação da sobrevivência de coroas unitárias implantossuportadas, por meio de um estudo de coorte prospectivo com 33 pacientes e 76 coroas instaladas. Os dados foram devidamente analisados, considerando um nível de significância de 0,05. Os resultados indicaram que as resinas utilizadas e as diferentes espessuras de camada exerceram influência direta na maioria dos testes realizados. Maiores valores de resistência flexural foram observados, enquanto menores valores de rugosidade superficial foram encontrados em espécimes impressos com menor espessura de camada. A composição e estrutura das micropartículas mostraram-se como fatores influentes nas propriedades mecânicas das resinas. Embora a taxa de sobrevivência das coroas tenha sido relativamente baixa nos períodos analisados, a técnica demonstrou ser promissora para a confecção de provisórios imediatos.

PALAVRAS-CHAVE: Impressão Tridimensional; Testes Mecânicos; Estudos de Coortes.

ABSTRACT

In the context of modern clinical practice, the use of digital workflows for obtaining dental restorations has gained prominence, offering benefits such as speed, precision, cost reduction, and increased patient comfort. Advances in printing technologies have enabled the application of resins in rehabilitation processes, aiming to enhance resistance and extend the lifespan of restorations through the incorporation of ceramic microparticles and zirconia oxide. This thesis addressed three specific objectives in this field. The first objective involved evaluating the physical and mechanical properties of four printed resins at two different layer thicknesses. This included the analysis of conversion degree through Raman spectroscopy, surface roughness through confocal microscopy and scanning electron microscopy, flexural strength through three-point testing, and modulus of elasticity using a universal testing machine, as well as Vickers hardness through a microdurometer. The second objective focused on analyzing the composition, macro, and microstructure of the four resins, employing techniques such as Raman spectroscopy for spectrum acquisition, Energy Dispersive X-ray Spectroscopy (EDS) for composition, and Scanning Electron Microscopy and confocal microscopy for macro and microstructure evaluation. The third objective involved assessing the survival of implant-supported single crowns through a prospective cohort study with 33 patients and 76 installed crowns. The data were properly analyzed, considering a significance level of 0.05. The results indicated that the resins used and different layer thicknesses directly influenced most of the conducted tests. Higher values of flexural strength were observed, while lower values of surface roughness were found in specimens printed with a smaller layer thickness. The composition and structure of microparticles proved to be influential factors in the mechanical properties of the resins. Although the survival rate of crowns was relatively low in the analyzed periods, the technique showed promise for the fabrication of immediate provisional restorations.

KEYWORDS: 3D Printing; Mechanical Tests; Cohort Studies.

1. INTRODUÇÃO COM REFERENCIAL TEÓRICO

A fabricação aditiva, ou impressão 3D, tem se destacado como uma tecnologia de vanguarda em diversas áreas, incluindo a odontologia. A aplicação da impressão 3D na odontologia abrange uma ampla gama de aplicações, desde a fabricação de restaurações temporárias até a produção de guias cirúrgicos precisos para implantes dentários. No entanto, a otimização dos materiais e processos é essencial para garantir a eficácia e confiabilidade dessas aplicações. Neste contexto, este estudo visa explorar o estado atual da impressão 3D na odontologia, com foco especial em próteses e restaurações dentárias.

A qualidade e o desempenho de restaurações odontológicas são de suma importância para a saúde bucal e a satisfação do paciente. Portanto, é crucial avaliar a viabilidade de materiais produzidos por impressão 3D para uso em restaurações temporárias e definitivas. Autores (ALHARBI; WISMEIJER; OSMAN, 2017) fornecem uma visão crítica sobre as técnicas de fabricação aditiva em próteses dentárias, destacando a necessidade de aprimoramentos contínuos para atender aos requisitos clínicos.

A escolha dos materiais é um aspecto fundamental na impressão 3D para odontologia. Materiais poliméricos têm sido amplamente utilizados na fabricação de restaurações temporárias. Autores (REVILLA-LEÓN *et al.*, 2019) conduziram uma revisão abrangente sobre a composição química, propriedades mecânicas e fluxo de trabalho de materiais poliméricos usados em restaurações dentárias temporárias produzidas por impressão 3D. Esta revisão destaca a importância de equilibrar propriedades mecânicas e biocompatibilidade na seleção de materiais.

As inovações tecnológicas também têm contribuído para a expansão da impressão 3D na odontologia. Autores (WHITLEY *et al.*, 2017) relatam a fabricação de guias cirúrgicos para implantes dentários no consultório odontológico, utilizando impressão estereolitográfica de mesa e software de planejamento de tratamento. Esse avanço demonstra a capacidade de personalização e produção de dispositivos de alta precisão na prática clínica. A aplicação de impressão 3D em odontologia abrange uma variedade de áreas, desde a fabricação de restaurações dentárias até a produção de modelos dentários precisos. Autores (KESSLER; HICKEL; REYMUS, 2020) oferecem uma visão abrangente do estado atual da impressão 3D na odontologia, abordando aspectos técnicos e clínicos. Eles destacam a crescente importância dessa tecnologia na criação de restaurações de alta qualidade.

A busca por materiais avançados na impressão 3D odontológica é evidente. Como demonstrado, os autores (SCOTTI *et al.*, 2020) exploraram as propriedades físicas e de superfície de uma resina composta impressa em 3D, destacando seu potencial em fluxos de trabalho digitais. Uma pesquisa (DAHER *et al.*, 2022) avaliou a eficiência de restaurações de resina composta impressas em 3D em comparação com materiais subtrativos, levando em consideração o comportamento à fadiga, custo e tempo de produção.

A precisão e a qualidade da impressão 3D são áreas de constante pesquisa e aprimoramento. Autores (PEREIRA *et al.*, 2022) investigaram se impressoras 3D de baixo custo produzem modelos dentários adequados. Pesquisas (IGAI *et al.*, 2021; NULTY, 2022) comparam a precisão de impressoras 3D usadas na odontologia, ressaltando a importância de avaliar a qualidade de impressão de modelos.

A incorporação de nanopartículas em materiais de impressão 3D tem sido uma estratégia para melhorar as propriedades mecânicas e biológicas. Autores (AATI *et al.*, 2021) desenvolveram uma resina reforçada com nanopartículas de ZrO₂ para restaurações dentárias provisórias de longa duração, considerando tanto propriedades mecânicas quanto biológicas. A biocompatibilidade e eficiência antimicrobiana de materiais de impressão 3D também são fatores críticos. Um estudo (AATI; SHRESTHA; FAWZY, 2022) avaliou a citotoxicidade e eficiência antimicrobiana de resinas impressas em 3D reforçadas com ZrO₂. Essas considerações são cruciais para a segurança do paciente e a qualidade das restaurações.

Além disso, os processos de impressão 3D desempenham um papel fundamental na qualidade das restaurações. Andjela *et al.*, (2022) revisaram os processos de fotopolimerização por vat 3D-printing para aplicações dentárias, ressaltando a influência da orientação de construção e cura nos resultados dimensionais e propriedades mecânicas das peças. A seleção e otimização de materiais e processos de impressão 3D desempenham um papel crítico na produção de restaurações dentárias de alta qualidade. Outros autores (GRZEBIELUCH; MIKULEWICZ; KACZMAREK, 2021) compararam propriedades mecânicas de materiais de impressão 3D para restaurações dentárias com materiais convencionais, destacando considerações importantes na seleção de materiais. Tahayeri *et al.*, (2018) investigaram materiais para coroas e pontes temporárias impressas em 3D em comparação com materiais convencionalmente curados, enfatizando a necessidade de avaliar as propriedades mecânicas e de longo prazo.

A estabilidade de cor e a resistência à mancha também são considerações cruciais para restaurações dentárias. Kim *et al.*, (2020) exploraram os efeitos do tempo de pós-cura nas propriedades mecânicas e de cor de materiais impressos em 3D para coroas e pontes. Lee *et al.*, (2022) avaliaram a influência da espessura da camada de impressão e da orientação de impressão na estabilidade de cor e susceptibilidade a manchas em materiais de resina impressos em 3D.

A orientação de impressão desempenha um papel crucial na precisão e qualidade de peças impressas em 3D. Outros autores (SHIM *et al.*, 2020) investigaram a precisão de impressão, propriedades mecânicas, características de superfície e aderência microbiana de resinas impressas em 3D com diferentes orientações de impressão. Além disso, a otimização de parâmetros de impressão é essencial para obter resultados de alta qualidade. Em outro estudo (ARNOLD *et al.*, 2019) foi explorado a qualidade de superfície de modelos dentários impressos em 3D em relação a vários parâmetros de impressão. Alshamrani *et al.*, (2022) examinaram o efeito da espessura da camada de impressão e das condições pós-impressão na resistência à flexão e dureza de uma resina impressa em 3D. A precisão de ajuste é fundamental para o sucesso das restaurações dentárias. Ale de outro estudo (PARK *et al.*, 2019) que investigou os efeitos dos parâmetros de impressão no ajuste de próteses impressas em 3D em implantes dentários. A precisão de modelos dentários impressos em 3D em relação a influência dos diferentes tempos de armazenamento leva a crer que pode ser extrapolado para outros materiais também (SABBAH; ROMANOS; DELGADO-RUIZ, 2021). A qualidade de superfície e as propriedades mecânicas de peças impressas em 3D são influenciadas por diversos fatores, incluindo a orientação de construção e a cura. Outros autores (UNKOVSKIY *et al.*, 2018) examinaram como a orientação de construção, a posição e a cura influenciam a precisão dimensional e as propriedades de flexão de peças impressas por estereolitografia.

A avaliação da resistência e propriedades mecânicas de materiais é essencial para garantir sua adequação clínica (ALTARAZI *et al.*, 2022). A resistência à flexão e dureza de uma resina impressa em 3D em relação à espessura da camada de impressão e às condições pós-impressão têm correlação, além de que os parâmetros de impressão afetam o ajuste de próteses impressas em 3D em implantes dentários (PARK *et al.*, 2019).

A investigação de materiais de impressão 3D para próteses dentárias é fundamental para aprimorar a qualidade e o desempenho das restaurações. Além disso, é essencial entender como fatores como orientação de construção, parâmetros

de impressão e pós-impressão afetam as propriedades dos materiais e das peças impressas. Portanto, este estudo tem como objetivo investigar e avaliar essas considerações críticas, levando em consideração a evolução contínua da tecnologia de impressão 3D na odontologia.

Em resumo, este estudo visa contribuir para o avanço do conhecimento sobre a impressão 3D na odontologia, abordando aspectos relacionados a materiais, processos de impressão, qualidade de impressão e propriedades das restaurações. A pesquisa se baseará em uma revisão abrangente da literatura e na realização de experimentos práticos para avaliar o desempenho de materiais e peças impressas em 3D em cenários clínicos relevantes.

Esta introdução explora a pesquisa relacionada à impressão 3D na odontologia, destacando a importância da seleção de materiais, processos de impressão e parâmetros na qualidade e desempenho das restaurações. O resumo dos estudos citados oferece uma visão ampla das considerações críticas nesse campo de pesquisa.

2. JUSTIFICATIVAS

- As impressoras 3D vêm sendo amplamente utilizadas devido sua comodidade e capacidades em reproduzir as características dos dentes naturais.
- A qualidade das restaurações obtidas por esse sistema está relacionada com a acurácia na impressão e propriedades biomecânicas dos materiais de impressão, que ainda é pouco discutida na literatura.
- A qualidade de precisão influencia diretamente na adaptação marginal, proximal e oclusal.
- Pouco ainda se sabe sobre as coroas impressas em resina definitiva e seu desempenho clínico.
- O correto funcionamento dos materiais pode mudar os paradigmas da odontologia atual e promover tratamentos mais rápidos e com baixo custo.

3. OBJETIVOS

- 3.1. **Capítulo 1** – Avaliar propriedades físicas e mecânicas de 4 resinas impressas em duas espessuras de camada.
- 3.2. **Capítulo 2** – Avaliar propriedades químicas e estruturais das 4 resinas utilizadas no Cap 1.
- 3.3. **Capítulo 3** – Avaliar a sobrevivência de coroas sobre implante unitárias obtidas por meio de fluxo digital

4. Capítulos

4.1. Capítulo 1 –

CAPÍTULO 1

Borella PS, Alvares LAS, Ribeiro MTH, Moura GF, Soares CJ, Zancopé K, Mendonça G, Rodrigues FP, das Neves FD. Physical and mechanical properties of four 3D-printed resins at two different thick layers: An in vitro comparative study. Dent Mater. 2023 Aug;39(8):686. doi: 10.1016/j.dental.2023.06.002. Epub 2023 Jun 23. PMID: 37357046.

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Physical and mechanical properties of four 3D-printed resins at two different thick layers: An in vitro comparative study

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ABSTRACT

Objectives: This in vitro comparative study aimed to evaluate the physical and mechanical properties of four 3D-printed resins with two different thickness layers.

Methods: Four printed resins (VarseoSmile Crown Plus, VSC; NexDent C&B MFH, MFH; Nanolab 3D,>NNL; and Resilab 3D Temp, RSL) were printed with 50 µm and 100 µm layer thickness, resulting in 80 bars measuring 25 × 2 × 2 mm. The specimens underwent a Raman spectroscopy for degree of conversion, confocal laser scanning microscopy for surface roughness (Sa), three-point bending test for flexural strength and elastic modulus, and a Vickers hardness test (VHN). Data was tested for normality using the Shapiro-Wilk, two-way ANOVA, and Tukey test (α = 0.05) for statistical analysis.

Results: The layer thickness affected all performed tests, but the elastic modulus (p < 0.001). Specimens with 100 µm showed, in general, worse results outcomes than those with 50 µm (p < 0.001). However, within the limitations of this comparative in vitro study, it could be concluded that the tested resins and layer thicknesses directly influenced physical and mechanical properties.

Significance: The physical and mechanical properties of three-dimensional printed restorations can be affected by the layer thickness, which can interfere with the choice of the 3D printing resin for a desired clinical outcome.



Physical and mechanical properties of four 3D-printed resins at two different thick layers: An in vitro comparative study

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ABSTRACT

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1. Introduction

Three-dimensional (3D) printing has been widely used in several areas, including Dentistry. Due to the development of biocompatible materials, 3D printers enable the fabrication of temporary dental restorations, surgical guides, interocclusal appliances, and orthodontic aligners [1–3]. Additive manufacturing (AM) is the most recent form of prototyping Computer Aided Designed (CAD) files in Dentistry [4]. A Standard Tessellation Language (.STL) file is generated, and the voxels are light-cured in 3D printing resin by ultraviolet light. This alternative represents a cost reduction since one liter of resin can print up to 300

single crowns [5], while subtractive manufacturing tends to waste material [6]. There is a substantial availability of 3D-Printers and resins in the market. Some of those printers are affordable printers, and they are frequently open-source systems, letting change the impression parameters such as layer thickness and exposure time to adapt to the variety of resin [7,8]. AM is more accurate than subtractive manufacturing for certain objects when overlapping data from disto-occlusal inlays obtained by 3D printing and milled zirconia/wax blocks [9]. Despite this, most CAD/CAM systems in dentistry still involve subtractive processes, in which the restoration is digitally designed and fabricated using a computerized milling unit.

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Table 1
Materials used in this study and their printing parameters.

Commercial name and Abbreviation	Composition and Shade	Exposure layer time (s) for 50 μ m and 100 μ m, respectively	Batch N°
VarseoSmile Crown Plus (VSC)	4'-isopropylidiphenol, ethoxylated and 2-methylprop-2-enoic acid. Silarised dental glass, methyl benzoyl formate, diphenyl (2,4,6-trimethyl benzoyl) phosphine oxide, 30–50 wt%—inorganic fillers (particle size 0.7 μ m). Shade A1 dentin	2 and 2.5	600181
NexDent C&B MFH (MFH)	Methacrylic oligomers, methacrylate monomers, inorganic urethane methacrylate oligomers, acrylate monomers, filler, phosphine oxides, pigment, methacrylate monomer, phosphine oxide. Shade N1	1.7 and 2.5	wx044N01
Nanolab 3D (NNL)	Nanohybrid resin (1419, 210102). Shade A1	1.8 and 2.2	2101012
Resilab 3D Temp (RSL)	Unavailable, Shade A1	2 and 2.5	1572

Resin composites for 3D printing are acrylic-based photopolymers [10]. The addition of ceramic particles and nanoparticles originated a new class of materials, the nanohybrid resin composites for 3D printing, which allow the manufacture of permanent dental restorations [11,12]. The biomechanical properties of resin composites for 3D printing that have been on the market for temporary dental restorations are considered adequate for dental applications [13,14]. These resins are filler-free and comparable to self-curing acrylic resin/bis-acryl resin [15]. Adding inorganic fillers can modify the material's purpose as it increases both flexural strength and elastic modulus, as well as the hardness of printed resins [16], avoiding the overload of remaining dental structures [14].

Aligned with the personalized printing resins and times, most manufacturers recommend a specific printed layer thickness. For resin composites, most manufacturers suggest a layer thickness of 50 μ m to reduce the staircase effect and surface roughness [17,18]. However, increasing the layer thickness to 100 μ m can reduce the printing time reduces by approximately 40 % [19]. Nevertheless, altering these parameters may impact the physical and mechanical properties of the printed materials [20–22].

Little has yet been discussed about the influence of layer thickness alteration on the nanohybrid resin compounds for 3D printing and its impact on the biomechanical properties of these materials. According to the manufacturers, they offer adequate characteristics for the fabrication of permanent restorations, however, due to the inconsistency of data in the literature and the smaller number of studies focused on those materials, this *in vitro* comparative study aimed to evaluate the effect of printing layer thickness on degree of conversion (DC), surface roughness (Sa), flexural strength (FS), elastic modulus (E), and Vickers hardness (VHN), of four resins printed at two different layer thickness (50 and 100 μ m). The null hypotheses set is that different layer thicknesses and resins brand will not influence physical and mechanical properties.

2. Material and methods

2.1. Tested materials and experimental design

Four different resins, recommended by manufacturers for temporary fixed restorations and 3D printed digital light processing (DLP) constructed were selected: VarseoSmile Crown Plus (Bego, Bremen, Germany); NexDent C&B MFH (Vertex-Dental B.V., Soesterberg, The Netherlands); Nanolab 3D (Wilcos do Brasil Ltda, Petrópolis, RJ, Brazil); and Resilab 3D Temp (Wilcos do Brasil Ltda, Petrópolis, RJ, Brazil).

A bar measuring 25 $\times$ 2 $\times$ 2 mm following the International Standard Organization (ISO 4049–2019), designed on open-source CAD software (Blender Foundation), then exported as a STL file and sent to slicer software (Anycubic Photon Workshop 3D, Anycubic 3D), where the specimens were placed upon the support and positioned at a 45-degrees printing orientation [23]. The file was then sent to the 3D printer (Anycubic Photon Mono, Anycubic 3D). This is an open-source

affordable 3D printer that works with a 45,000 mW ultraviolet light emitting diodes (LED) (wavelength 405 nm) light-power source through a 104 mm² liquid crystal display (LCD) curing the resin inside the tank layer by layer from the bottom [7,13] with 432.6 mW/mm² irradiance. Before printing the specimens, the resins' exposure times were verified by printing a 10-mm cube, post-processing it and measuring each cube's length, thickness, and height using a digital calliper (Mitutoyo, Tokyo, Japan). After being printed, the specimens were placed in a cure rotary washer machine (Wash & Cure 2.0, Anycubic 3D – 25,000 mW, LED, 30.5 mm², 405 nm, 819.6 mW/mm²), according to the manufacturer. The specimens were washed with 99.5 % p.a. isopropyl alcohol (Lab-synth, Diadema, SP, Brazil) for 5 min and light-cured for 30 min [24]. The bars' supports were then cut, and the specimens underwent metallographic polishing (600 and 1200 grit sandpaper, followed by 0.3 and 0.05 μ m alumina suspension). The bars were printed according to resin brand (4 brands) and layer thickness (50 and 100 μ m), generating eight groups (n = 10). The specimens were randomly allocated within their group. The exposure time was adjusted and finally set when the block was printed at the correct dimension for both layer thickness and resin brand [25].

The resins were agitated before each printing process according to the manufacturer's recommendations. The resins' specifications and printing parameters are described in Table 1.

2.2. Raman spectroscopy

Raman spectroscopy was performed using a Raman spectrophotometer (LabRAM HR Evolution - HORIBA). Software HORIBA Scientific's LabSpec (LabSpec 6 Spectroscopy Suite) is attached to an optical microscope (BX41, Olympus) with an excitation wavelength of 532 nm. The system was calibrated before the test. The specimens were placed on a glass slide, and sites of 20 $\times$ 20 μ m were analyzed at a $\times$ 100-vis objective lens. The spectrums were collected with an integration time of 60 s and six accumulations. The spectrum range was 1380–1813 cm⁻¹ spectral region. In each specimen spectra, the absorption bands heights of the aliphatic and aromatic carbon bonds were measured at 1.638,11 cm⁻¹ and 1.608,08 cm⁻¹, respectively. The DC was determined according to the following Eq. 1.

$$\%DC = 1 - \left[\frac{\frac{1.638,11\text{cm}^{-1}}{1.608,08\text{cm}^{-1}} \text{ polymer}}{\frac{1.638,11\text{cm}^{-1}}{1.608,08\text{cm}^{-1}} \text{ monomer}} \right] * 100 \quad (1)$$

2.3. Confocal laser scanning microscopy

Specimens were placed onto the stage and evaluated using a confocal laser scanning microscope/software (Lext OLS 4000, Olympus). A scanning was performed at 216 $\times$ magnification to obtain a tridimensional surface profile using the roughness average (Sa) parameter. Sa from each specimen (expressed in μ m) was obtained.

2.4. Flexural strength and elasticity modulus

A three-point bending test was performed using a universal testing machine (4411, Instron, Norwood, MA, USA) following the International Standard Organization (ISO 4049, 2019). The specimens were fixed between two supports (20 mm span) with a 3000 N load cell at a crosshead speed of 0.5 mm/min until fracture occurred. A displacement strain deflectometer with a magnetic base for mounting (W-E401-J, Instron) was placed so the tip touched the center of the fractured bar. The flexural strength (FS) was calculated considering the load at fracture and the specimen's dimensions, which were verified using a digital caliper rule. The fracture loads obtained from FS were calculated in megapascal (MPa) using the Eq. 2:

$$\sigma = 3FL/(2bh^2) \quad (2)$$

Where σ is the flexural strength, F is the load at the fracture point, L is the length of the support span, b is the width of the specimen, and h is the thickness of the specimen.

Then the E was determined in gigapascal (GPa) by the Eq. 3:

$$E = FL^3/4bh^3d \quad (3)$$

Where F is the maximum force, L is the distance between the supports, b is the thickness of the specimen, H is the height, and d is the deflection suffered in mm when the force F is applied. The specimens were analyzed under a microscope with 40 x magnification for failure pattern check.

2.5. Vickers microhardness test

All specimens from each group were submitted to a microhardness tester (MicroHardness Tester FM-700, Future Tech, Kawasaki, Japan) to obtain the surface microhardness and reported as Vickers hardness number (VHN). A pyramid-shaped diamond indenter with a specified angle was forced into the surface using a load force of 500 g and a dwell time of 15 s. Each specimen had a line pattern with five indentation points at a 1 mm distance, and the result was reported as the average of indented locations for each specimen.

2.6. Scanning electron microscopy (SEM)

Representative images were obtained using a scanning electron microscope (JEOL-JSM-6510, USA) to identify the surface morphology of these materials. For the SEM morphological analysis each chosen sample was sputter-coated with a 15-nm thick palladium gold layer (SputterCoater MED-020-Bal-Tec). The evaluation was performed with 20 kV and 21–23 mm working distance and 1000x magnification.

2.7. Statistical analysis

Obtained data for DC, Sa, FS, E, and VHN were organized in spreadsheet software (Excel, Microsoft 365 Apps, Microsoft Co.) and tested for normality using the Shapiro-Wilk test, followed by two-way ANOVA crossing resin brand and layer thickness. Tukey test (HSD) was used to determine the differences within groups ($\alpha = 0.05$) in statistical software (Sigmaplot 13.0, Systat Software GmbH, Erkrath, Germany).

3. Results

All obtained data passed the Shapiro-Wilk normality test. Data for all tests are described in Table 2.

3.1. Degree of conversion (DC)

Differences were found for the DC test in resin brand ($p < 0.001$) for all groups printed with 50 or 100 μ m. Layer thickness affected VSC

Table 2
Means $\pm$ standard deviation for Conversion Degree (DC), Surface Roughness (Sa), Flexural Strength (FS), Elasticity Modulus (E), and Vickers Hardness (VHN) considering resin brand and layer thickness factors ($n = 10$).

Layer Thickness (μ m)	VHN (N/mm ²)		E (GPa)		FS (MPa)		Sa (μ m)		CD (%)	
	100	50	100	50	100	50	100	50	100	50
VSC	23.8 $\pm$ 1.9 ^{ab}	27.6 $\pm$ 1.0 ^{ab}	4.03 $\pm$ 0.6 ^{ab}	4.51 $\pm$ 0.5 ^{ab}	134 $\pm$ 7.7 ^{ab}	124 $\pm$ 0.01 ^{ab}	0.27 $\pm$ 0.01 ^{ab}	0.23 $\pm$ 0.03 ^{ab}	55.3 $\pm$ 1.0 ^{ab}	58.1 $\pm$ 1.2 ^{ab}
MFH	15.3 $\pm$ 0.5 ^{cd}	16.8 $\pm$ 0.6 ^{ab}	2.37 $\pm$ 0.3 ^{cd}	2.47 $\pm$ 0.3 ^{cd}	125.1 $\pm$ 5.3 ^{ab}	125.1 $\pm$ 5.3 ^{ab}	0.37 $\pm$ 0.08 ^{cd}	0.28 $\pm$ 0.03 ^{ab}	48.2 $\pm$ 0.6 ^{ab}	50.2 $\pm$ 1.2 ^{ab}
NNL	25.2 $\pm$ 0.2 ^{ab}	27.4 $\pm$ 1.7 ^{ab}	7.09 $\pm$ 0.2 ^{ab}	7.66 $\pm$ 0.7 ^{ab}	144.7 $\pm$ 7.2 ^{ab}	144.7 $\pm$ 7.2 ^{ab}	0.23 $\pm$ 0.03 ^{ab}	0.21 $\pm$ 0.05 ^{ab}	45.4 $\pm$ 1.0 ^{cd}	46.6 $\pm$ 1.7 ^{cd}
RSL	14.8 $\pm$ 0.4 ^{cd}	17 $\pm$ 0.5 ^{ab}	1.9 $\pm$ 0.4 ^{cd}	1.98 $\pm$ 0.1 ^{ab}	124.2 $\pm$ 5.5 ^{ab}	124.2 $\pm$ 5.5 ^{ab}	0.31 $\pm$ 0.06 ^{ab}	0.22 $\pm$ 0.03 ^{ab}	14.2 $\pm$ 1.2 ^{cd}	14.6 $\pm$ 1.0 ^{cd}

The standard deviation is described in parentheses. Different uppercase letters in the columns indicate significant differences between the resins. Different lowercase letters in the lines indicate significant differences between the thickness layer for each test.

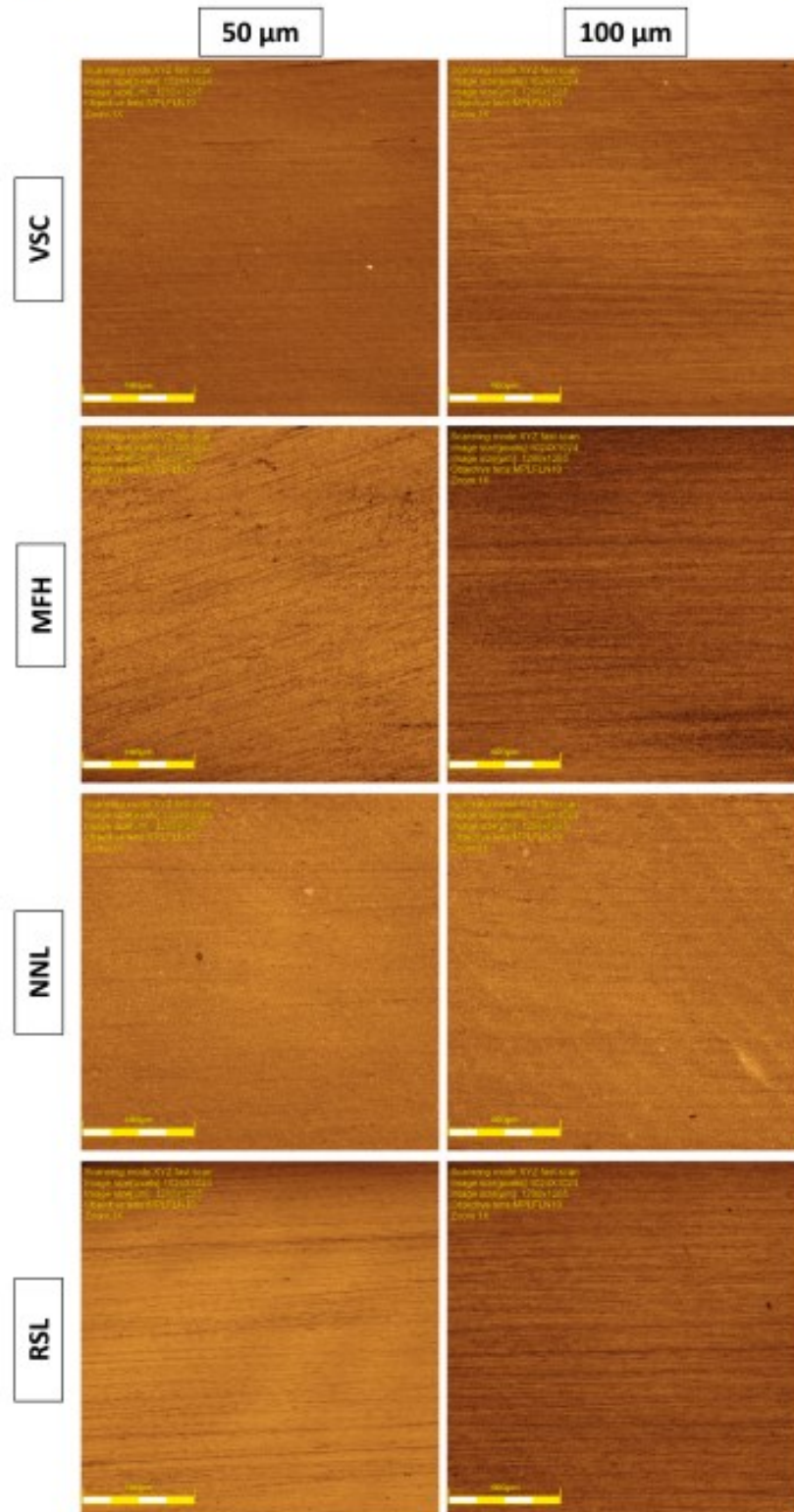


Fig. 1. Polished specimens surface printed with 50 and 100 μm, magnified at 216 x in confocal laser scanning microscopy.

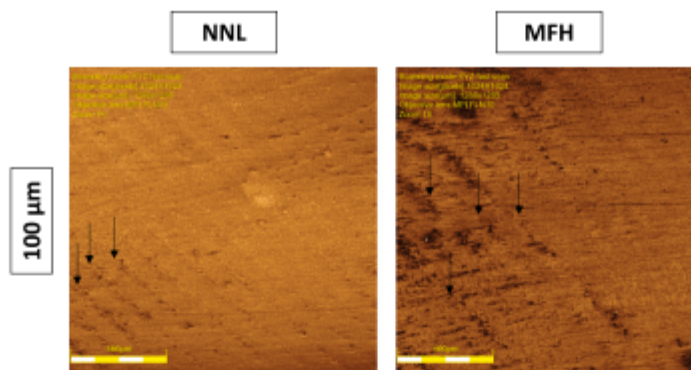


Fig. 2. Printed layer interface bubbles in specimens printed with 100 μm , magnified at 216 x in confocal laser scanning microscopy.

($p = < 0.001$), MFH ($p = 0.001$), and NNL ($p = 0.045$) groups, but did not affect the RSL ($p = 0.488$) group. VSC group printed with 50 μm showed the highest DC, followed by MFH and NNL, respectively. The RSL group presented the lowest DC.

3.2. Surface roughness (Sa) and 3D optical profile

Differences were found for the surface roughness test within the resin brand ($p < 0.001$). MFH group printed with 100 μm showed higher Sa followed by RSL, comparable to VSC. In this case, NNL showed the lowest Sa representing the smoother surface. VSC, NNL, and RSL groups were similar within 50 μm layer thickness. Differences were also found between brands for Sa when printed with 100 μm ($p < 0.001$). NNL showed the lowest Sa, which was the VSC group. Layer thickness ($p < 0.001$) also influenced surface roughness for VSC ($p < 0.001$), MFH ($p < 0.001$), and RSL ($p < 0.001$) groups but did not affect the NNL ($p = 0.379$) group. Three-dimensional optical profile images revealed that specimens printed at 100 μm were rougher than those printed with 50 μm . Printed layers were visible at x 216 magnification for VSC and NNL groups in both layer thicknesses. The RSL group was visible when printed at 50 μm (Fig. 1). NNL and MFH groups showed bubbles in printed layer interfaces for some specimens (Fig. 2).

3.3. Flexural strength (FS) and elasticity modulus (E)

Differences were found for FS in resin brands ($p < 0.001$). The NNL group had the lowest FS. VSC, MFH, and RSL groups were similar in layer thicknesses (50 and 100 μm). Different layer thicknesses also affected VSC ($p = 0.020$), NNL ($p < 0.001$), and RLB ($p = 0.005$) groups but did not affect the MFH group ($p = 0.062$). For E, only differences among resins ($p < 0.001$) were found. The NNL group showed the highest E, followed by VSC, MFH, and RSL. No differences were found for layer thickness ($p = 0.970$).

3.4. Vickers hardness (VHN)

Differences were found in resin brands ($p < 0.001$). VSC and NNL groups had the highest hardness and were similar to each other ($p = 0.889$). At the same time, RSL and MFH groups had the lowest hardness and were similar ($p = 0.910$), considering specimens printed at a 50 μm thickness layer. However, within 100 μm layer thickness, the NNL group showed the highest hardness for VHN, followed by the VSC group, and last, MFH and RSL groups. VHN was also affected by layer thickness in all groups ($p < 0.001$).

3.5. Scanning electron microscopy (SEM)

Representative images from all groups using a scanning electron microscopy revealed that all surfaces presented the printing layers in a uniform sequence, except the RSL group printed with 100 μm , which presented some spread delamination areas and random porosities (pointed out by the white arrow in Fig. 3). Printed layers were visible at x1000 magnification in all samples, except for NNL 50 μm . NNL, MFH, and RSL groups showed some delamination initiation in printed layer interfaces for some specimens (Fig. 3, black arrows). NNL hybrid surface is visible with particles uniformly distributed.

4. Discussion

In the present study, the printer and resins were selected according to chosen availability or indication. This study was a preview effort to evaluate if low-cost and fast-obtained restorations could have appropriate physical and mechanical properties. According to the results, the resin brand and layer thickness differed in most performed tests. Printing time is not precisely halved when the layer thickness is doubled, as a prolonged exposure time to the curing light source is required to cure each layer. This compensation can be decisive in a slight difference between the average degree of conversion percentages. These findings suggest that the degree of conversion has correlations with surface roughness, flexural strength, elasticity modulus, and Vickers hardness, indicating that a higher degree of conversion can lead to smoother surfaces, increased mechanical strength, higher stiffness, and greater material hardness. Additionally, the degree of conversion was low and inconsistent, and it might be related to the need for better post-polymerisation guidelines as it is clearly material-dependent. The layer thickness alone might not be the one influencing these properties, highlighting the importance of considering this factor in 3D printing processes, especially for resins containing particles. There is also an initial layer exposure time that is not mentioned by the manufacturer and can surely influence the performance of these materials.

The groups printed with 50 and 100 μm obtained superior performances compared to all resin compounds for 3D printing investigated in another study [16]. These authors reported that the specimens were light-cured for 30 min [24] to avoid more variables, but properties such as FS and VHN might have been improved by increasing the post-cure time [26]. Higher values were also reached with periods longer than 60 min, as demonstrated for crowns [16].

The three-point bending test is standardized by ISO 4049–2019 for polymer-based restorations in dentistry. Fracture is one of the main reasons for clinical failures of definitive restorations [27]. The minimum required flexural strength for resin materials necessary is 100 MPa. At least four specimens must reach or exceed this value, and

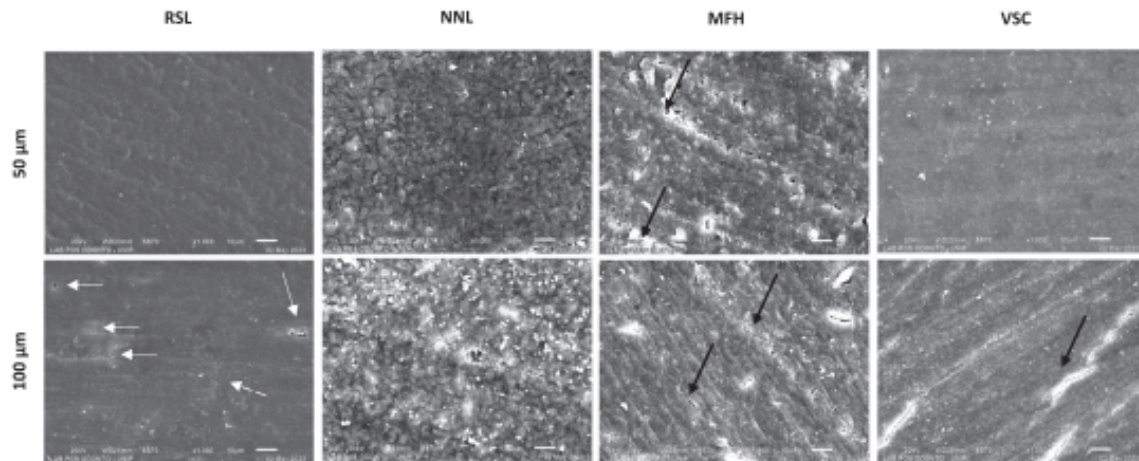


Fig. 3. Representative images of the Scanning Electron Microscopy (SEM) for all resins.

only two may be below it, according to ISO 4049. All specimens, but the NNL group printed at 100 µm thickness layer, reached FS greater than 100 MPa. That group would probably be reproved since it did not get the minimum required resistance providing a future deficient and not long-lasting restoration. The NNL group had the lowest FS in both layer thicknesses. All groups but MFH had their FS decreased when printed at 100 µm compared to 50 µm, but another study found the 100 µm thickness layer to be the highest value in their tested resins for FS [20]. NNL has also shown low FS in another study compared to other tested groups [19].

The elasticity modulus is the ability of the material to resist elastic deformation. Resin brand affects E for both 50 and 100 µm layer thickness. The NNL group had the highest E , followed by VSC, MFH, and RSL. Layer thickness did not affect E , even when it affected the most testes. These values remained similar when specimens were printed with 50 or 100 µm. Although E was similar between different layer thicknesses, the worst results in a thicker layer were found on other performed tests. Although the RSL group was made with temporary restoration resin, with no hybrid filler material added to its composition, it has shown similar FS between VSC and MFH despite its non-expected performance.

Studies have shown that adding fillers in resin composition might increase its physical and mechanical properties [11,12]. Additionally, the morphology of inorganic fillers has a significant influence on fracture strength. Some authors reported that particles with irregular and faceted shapes, such as those observed in the material investigated in this study, present acute angles, preventing mechanical stresses from being distributed more evenly and leading to the formation of cracks [27]. It was possible to visualize in the SEM representative images that the presence of particles, porosities, and different layer thicknesses (that can be more prompt to delamination) can influence the VHN, FS, and E behaviour. However, more studies with more groups comparing filled and non-filled resins are needed. Studies have also shown that the build orientation affects FS and accuracy. The best results for accuracy were found for specimens printed at 45 degrees [23], although they did not evaluate different layer thicknesses. Another study printed crowns and observed that the internal gap volume was smaller with 50 µm. Still, the marginal fit was smaller with 100 µm when studying three-unit prostheses printed at 45°. However, both were clinically acceptable [21]. However, another study found 90 degrees being the best orientation, but did not affect the mechanical properties [15]. A 45-degree orientation was chosen for this study to eliminate another variable, considering those previous studies.

Regarding Vickers hardness, which is the resistance to plastic deformation, groups printed with 50 µm exhibited the highest average from those printed with 100 µm. Therefore, the nanohybrid resin composite for 3D printing investigated in this study showed lower hardness than enamel. This information is extremely relevant, considering the wear of antagonistic natural teeth. The resin also has a lower elastic modulus than the dentine, which may lead to stress accumulation in the tooth's remaining structure. The dissipation of masticatory forces in teeth restored with this material should be the subject of future investigations. This study found lower VHN for the same material NNL compared to another study [25]. Even though the VHN test can be different according to the composition of materials [28,29], it was possible to show that the RSL group showed the lowest VHN. The probable cause lay in its shortage of fillers. This comparison aimed to assess the differences between materials indicated for a definitive restoration and another one that is indicated for provisional restorations. This information endorses that the presence of filling on those resins can benefit their mechanical properties.

Higher hardness is related to lower surface roughness [30], while the impression thickness seems to have no influence [20,22] in those parameters, explaining both the low values for the surface roughness means obtained by the 50 and 100 µm-printed groups and the absence of significant difference between them. The nanohybrid resin-composite for 3D printing is superior in surface roughness to all milling blocks previously tested [30]. Replacement material for the outermost layer of the tooth should ideally have a hardness similar to or less than that of enamel, which is 274.8 (± 18.1) VHV. In contrast, a replacement for the underlying portion should have a modulus of elasticity similar to or greater than enamel, which is 16.5 (± 2.8) GPa [14,31]. Only gold alloys meet these requirements, but due to their high cost and unfavorable aesthetics, they have fallen into disuse [27].

Representative images from all groups, using a scanning electron microscopy confirmed that the RLS group printed with 100 µm was expected to present more defects, such as random placed porosities, which did not happen to the RLS printed with 50 µm (Fig. 3). These porosities could explain its higher Sa. Surprisingly, NNL showed the lowest Sa representing the smoother surface. The low Sa might be generated by the surface roughness parameter choice, as the SEM representative images suggest a rougher surface for both NNL and MFH. As the Sa roughness parameter is an average roughness of the surface, it might be that parameters such as Sy or St would reveal better comparison outcomes as they consider the peaks and valleys onto the surface. At the end, NNL seems to be more uniform than the others that can have their average deviated by porosities (RSL-100 µm) or layer detachments or discontinuities (MFH

and VSC). Regarding the differences between the layer thickness, the representative images were crucial to highlight better surfaces for samples printed with 50 µm layer thickness. Corroborating with the surface roughness results, the images show that the layer thickness difference affected NNL less than the other groups. Similarly, to the confocal analysis, SEM confirmed that specimens printed at 50 µm seems to be a better choice than those printed with 100 µm.

In summary, the physical and mechanical properties of 3D printed restorations can be affected by the layer thickness, which can interfere with the choice of the 3D printing resin for a desired clinical outcome. When considering crowns, either temporary or permanent, the layer thickness is crucial to avoid delamination and porosities, assuring a great adaptation to the surrounding tissues. Further studies are needed in order to determine if those materials are a good choice for clinical practice. Furthermore, additional in vitro studies and clinical trials will be needed to verify the influence of printing parameters on the general properties of printing materials to define the correct indication and safe use of the material in clinical practice.

5. Conclusion

Within the limitations of this comparative in vitro study, in which geometric samples are used instead of real restorations in place and function at the patient's mouth, it could be concluded that the tested resins and layer thicknesses directly influenced the degree of conversion, surface roughness (Sa), flexural strength, and hardness. Therefore, these physical and mechanical properties should be taken into consideration, combined with the surface properties and morphology of these materials, when a successful clinical performance is desired. The elastic modulus of the materials studies is the only property not affected by the layer thickness. On the other hand, the flexural strength increased significantly when a 50 µm layer thickness was considered.

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4.2. Capítulo 2 –

Composition and superficial structure of four 3D-printed resins

Polymers Composites

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Abstract

CAD/CAM technology has transformed dentistry, allowing for precise fabrication of dental restorations. LCD technology enhances intraoral imaging, while DLP technology revolutionizes 3D printing of dental models. This study delves into the pivotal role of layer

thickness, post-cure time, and temperature in 3D printed nanohybrid resins. Four distinct resins were examined for physical properties. Confocal laser scanning microscopy, SEM, and EDS were employed for microstructural analysis. Results revealed significant variations in filler distribution, interaction with the resin matrix, and elemental composition among the resin groups. Understanding these parameters is crucial for optimizing 3D printing outcomes, balancing speed, accuracy, and material characteristics. This in-depth exploration contributes to advancing additive manufacturing technologies, unlocking their full potential in dentistry and beyond.

KEYWORDS

3D Printing, Additive Manufacturing, Particle-filled composite, CAD-CAM.

Highlights

- LCD and DLP technologies elevate imaging and 3D printing for enhanced dental devices.
- Delving into these parameters ensures optimal print outcomes, balancing speed, and accuracy.
- The composition influences the structural integrity and performance of the final product.

1. INTRODUCTION

CAD/CAM (Computer-Aided Design/Computer-Aided Manufacturing) technology has revolutionized dentistry by enabling precise and efficient fabrication of dental restorations such as crowns, bridges, and implants. It allows dentists to digitally scan a patient's oral anatomy, design custom restorations on a computer, and then use CAM to mill or 3D print the final restoration, reducing turnaround time and improving accuracy^{1,2}. LCD (Liquid Crystal Display) technology plays a pivotal role in intraoral cameras and digital radiography systems, providing dentists with high-quality images for diagnosis and treatment planning. DLP (Digital Light Processing) technology, on the other hand, is employed in 3D printing of dental models and orthodontic appliances, offering a layer-by-layer additive manufacturing process that enhances the precision and speed of producing patient-specific dental devices^{3,4}. These technologies collectively empower modern dentistry with advanced tools for better patient care and outcomes.

The implementation of fillers in dentistry has undergone a transformative evolution, reshaping the landscape of material development and utilization in contemporary dental practices. These fillers, characterized by their microscopic dimensions, assume a pivotal role in sculpting the physical, mechanical, thermal, and chemical properties within a spectrum that extends beyond 3D-printed resins. Their introduction into dental materials has marked a paradigm shift, allowing for enhanced structural integrity, improved wear resistance, and heightened aesthetic qualities in various dental applications. As advancements persist in the realm of material science, the strategic integration of fillers continues to define the trajectory of dental innovation, offering practitioners and patients alike a new standard of precision, durability, and customized solutions. This dynamic interplay between fillers and dental materials underscores the ongoing commitment to elevating the standards of care and treatment modalities within the field of dentistry^{5,6}.

3D printed nanohybrid resins have emerged as a groundbreaking innovation in modern dentistry, offering clinicians precise control over the layer thickness during the printing process, allowing for the customization of dental prosthetics with unprecedented accuracy^{2,7}. The choice of layer thickness can significantly impact the mechanical properties and surface finish of the final dental restorations^{1,8-11,11}, ensuring optimal performance and aesthetics. Moreover, post-cure time and temperature play crucial roles in achieving the desired material properties and biocompatibility^{9,12}, ensuring that 3D printed dental devices are safe and durable for clinical use.

The properties and quality of 3D printed resins are significantly influenced by three key parameters: layer thickness, post-cure time, and temperature^{7,9,11-14}. Varying layer thickness can impact the structural integrity and surface finish of printed objects^{11,13}.

Thicker layers may lead to reduced resolution but faster printing, while thinner layers enhance precision but extend print times. Post-cure time, the duration of UV or heat exposure after printing, affects resin cross-linking and final mechanical properties. Temperature plays a pivotal role, affecting resin viscosity, curing speed, and adhesion to build platforms. Controlling these parameters is crucial to achieve optimal print outcomes, balancing speed, accuracy, and material characteristics.

Studying different layer thicknesses, post-cure times, and temperature influences in 3D printed resins is imperative for advancing additive manufacturing technologies. These parameters play a pivotal role in determining the final quality, structural integrity, and performance of 3D printed objects. Experimenting with various layer thicknesses allows for the optimization of print speed and resolution, catering to specific application requirements. Post-cure times significantly impact material properties like strength, flexibility, and durability, crucial for industries ranging from aerospace to healthcare. Moreover, understanding temperature influences aids in achieving precise control over print conditions, preventing issues such as warping and delamination. In sum, delving into these factors empowers researchers and engineers to unlock the full potential of 3D printing, revolutionizing industries, and propelling innovation forward. Thus, the aim of this *in vitro* study is to analyze a different approach for the degree of conversion and to display the microstructure of four 3D printed specimens that were tested for physical and mechanical properties in a previous study ¹³.

2. EXPERIMENTAL DESIGN

2.1. Materials and sample preparation

Four distinct resins, which are recommended by manufacturers for creating temporary fixed restorations and 3D printed digital light processing (DLP) constructions, were chosen. These resins include VarseoSmile Crown Plus from Bego in Bremen, Germany; NextDent C&B MFH from Vertex-Dental B.V. in Soesterberg, The Netherlands; Nanolab 3D from Wilcos do Brasil Ltda in Petrópolis, RJ, Brazil; and Resilab 3D Temp, also from Wilcos do Brasil Ltda in Petrópolis, RJ, Brazil.

To adhere to the International Standard Organization (ISO 4049–2019) guidelines and produce a uniform bar measuring $25 \times 2 \times 2$ mm, open-source CAD software (Blender Foundation) was utilized. The resulting design was then exported as an.STL file and processed through slicer software (Anycubic Photon Workshop 3D, Anycubic 3D). The specimens were oriented at a 45-degree angle for printing ¹⁵. Subsequently, the file was transmitted to the 3D printer (Anycubic Photon Mono, Anycubic 3D), a budget-friendly, open-source device that employed a 45,000 mW ultraviolet light emitting diode (LED)

with a wavelength of 405 nm as its light source. It utilized a 104 mm² liquid crystal display (LCD) to solidify the resin layer by layer from the bottom ^{16,17}, with an irradiance of 432.6 mW/mm². Before printing the specimens, the exposure times for the resins were adjusted by printing a 10-mm cube, post-processing it, and using a digital caliper (Mitutoyo, Tokyo, Japan) to measure its length, thickness, and height ¹³.

After completing the printing procedure, the samples were subjected to a curing rotary washer device (Wash & Cure 2.0, Anycubic 3D). This machine featured a 25,000 mW LED that emitted light at a wavelength of 405 nm, covering an area of 30.5 mm² and delivering an irradiance of 819.6 mW/mm², in accordance with the manufacturer's recommendations. Subsequently, the samples were immersed in 99.5% p.a. isopropyl alcohol (Labsynth, Diadema, SP, Brazil) for a 5-minute cleaning cycle and then exposed to 30 minutes of light curing ¹⁸. The support structures were removed from the bars, and the samples underwent metallographic polishing using sandpaper with grit sizes of 600 and 1200, followed by alumina suspension with particle sizes of 0.3 and 0.05 µm. The bars were fabricated through 3D printing, considering the resin brand (four different brands), resulting in 4 distinct groups, consisting of 10 specimens. The exposure duration was adjusted and concluded when the block was printed to the precise dimensions (Tab 1) ^{13,19}.

Commercial name and Abbreviation	Composition and Shade	Exposure time	layer	Batch N°.
VarseoSmile Crown Plus (VSC)	4'-isopropylidiphenol, ethoxylated and 2-methylprop-2enoic acid. Silanised dental glass, methyl benzoyl formate, diphenyl (2,4,6-trimethyl benzoyl) phosphine oxide, 30–50 wt. %—inorganic fillers (particle size 0.7 µm). Shade A1 dentin	2		600181

NexDent C&B MFH (MFH)		Methacrylic methacrylate inorganic urethane methacrylate oligomers, acrylate monomers, filler, phosphine oxides, pigment, methacrylate monomer, phosphine oxide. Shade N1	1.7	wx044N01
Nanolab (NNL)	3D	Nanohybrid resin (1419, 210102). Shade A1	1.8	2101012
Resilab Temp (RSL)	3D	Unavailable, Shade A1	2	1572

2.2. Raman

Raman spectroscopy was conducted utilizing a Raman spectrophotometer, specifically the LabRAM HR Evolution by HORIBA. The accompanying software, LabSpec 6 Spectroscopy Suite from HORIBA Scientific, was connected to an optical microscope (Olympus BX41) with an excitation wavelength of 532 nm. Prior to the test, the system underwent calibration. Specimens were positioned on a glass slide, and 20 x 20 µm areas were examined using a x100-vis objective lens. Spectra were gathered with an integration time of 60 s and six accumulations within the 1380-1813 cm⁻¹ spectral range. In each specimen's spectra, absorption band heights for aliphatic and aromatic carbon bonds were measured at 1.638.11 cm⁻¹ and 1.608.08 cm⁻¹, respectively. The Degree of Conversion (DC) was determined using a specified equation.

$$\%DC = 1 - \left[\frac{\frac{1.638,11 \text{ cm}^{-1}}{1.608,08 \text{ cm}^{-1}} \text{ polymer}}{\frac{1.638,11 \text{ cm}^{-1}}{1.608,08 \text{ cm}^{-1}} \text{ monomer}} \right] * 100$$

2.3. Confocal laser scanning microscopy

Samples were positioned on the platform and examined with a confocal laser scanning microscope and software (Olympus Lext OLS 4000). Scanning was conducted at a 2160x magnification to generate surface profile.

2.4. Scanning Electron Microscopy (SEM) and dispersive X-ray spectroscopy (EDS)

The mineral component distribution and elemental composition were assessed using energy dispersive X-ray spectroscopy (EDS). The specimens were prepared on stubs, coated with a layer of gold (Au), and examined through a scanning electron microscope (LEO-1430; Carl Zeiss, BW, Oberkochen, Germany) providing MEV images. The areas of interest were magnified 20,000 times, for 30 seconds, with a 15 mm working distance, 20 KV, and the elements' composition and distribution were scrutinized using EDS (Oxford Instruments, England). The concentrations of the following chemical elements by weight were determined: Carbon (C), Oxygen (O), Silicon (Si), Aluminum (Al) and Barium (Ba).

2.5. Data analysis

Obtained data for DC were tabulated and went through Shapiro-Wilk normality test. Groups were submitted to ANOVA Two-Way to compare resins and layer thickness, followed by Tukey (HSD) test to determinate differences among groups ($\alpha=0.05$). Obtained images and data in confocal laser scanning microscopy, Scanning Electron Microscopy (SEM) and dispersive X-ray spectroscopy (EDS) were displayed in the results section.

3. RESULTS

Fig 1 represents Raman spectrums for all resins. Peaks appeared at 1452cm^{-1} indicating formation of aromatic rings after polymerization. Peaks were observed at 1612.3cm^{-1} and 1717.68cm^{-1} especially for VSC and MHF groups representing aliphatic carbon double bond to carbon (C=C) and oxygen (C=O), respectively. Peaks were also observed at 1641cm^{-1} representing unpolymerized methacrylate C=C stretching mode.

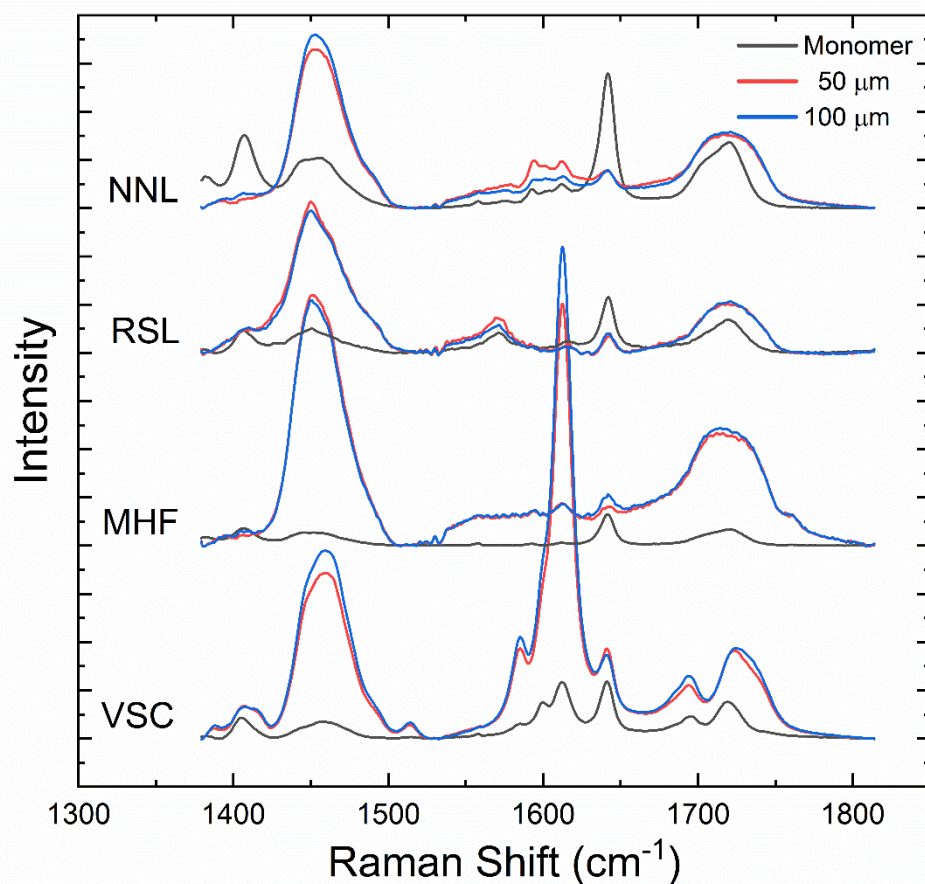


FIGURE 1 Selected Raman spectrum.

Table 2 presents data on the degree of conversion (CD). Resins exhibited statistically significant differences in CD ($p=0.007$). However, there were no significant differences observed between layer thicknesses ($p=0.272$). The MHF group demonstrated the highest CD, followed by NNL and VSC, with no statistically significant differences among them. Conversely, the RSL group displayed the lowest CD value, and it was significantly different from the other groups.

TABLE 2 - MEAN OF CD (%) FOR ALL GROUPS IN TWO DIFFERENT LAYER THICKNESS.

	Layer thickness	
	50	100
VSC	79.5 Aa	83.13 Aa
MHF	91.39 Aa	88.93 Aa

NNL	85.82 Aa	78.68 Aa
RSL	47.01 Ba	33.38 Ba
Uppercase letter means difference among columns. Lowercase letters mean difference between lines ($\alpha=0.05$).		

The images obtained by confocal laser and SEM are displayed on Fig 2. The elemental weight and spectrum acquired is displayed on Fig 3.

The VSC group presented micrometric fillers ranged from 0.2 to 2 μm (Fig 2). There is a high concentration of fillers in the resin's matrix. The fillers present rounded edged, good interaction with the resin matrix, and good distribution. It contains Silicon (7.89%) and Bario (6.90) glass particles (Fig 3).

The MFH group presented micrometric fillers ranging from 0.15 to 4 μm . There is a low concentration of fillers in the matrix. The fillers are slightly irregular with rounded edges. There are large spaces of organic matrix between the fillers. The fillers have a good interaction between the fillers and the resin matrix (Fig 2). It contains Silicon (0.73%) and Aluminum (0.34%) glass particles (Fig 3).

The NNL group presented irregular fillers ranging from 0.25 to 3 μm . There is a high concentration of irregular and sharp edges filler in the matrix. The fillers have a pour interaction with the matrix. There are large spaces of resin matrix without fillers (Fig 2). It contains Silicon (8.16%), Bario (7.97), and Aluminum (2.44%) glass particles (Fig 3).

The RSL group showed a small number of nanometric particles disperse in the matrix (Fig 2). The filler is visible in the confocal but not so delimited in SEM at 2160X increase. It contains Silicon (2.65%) (Fig 3).

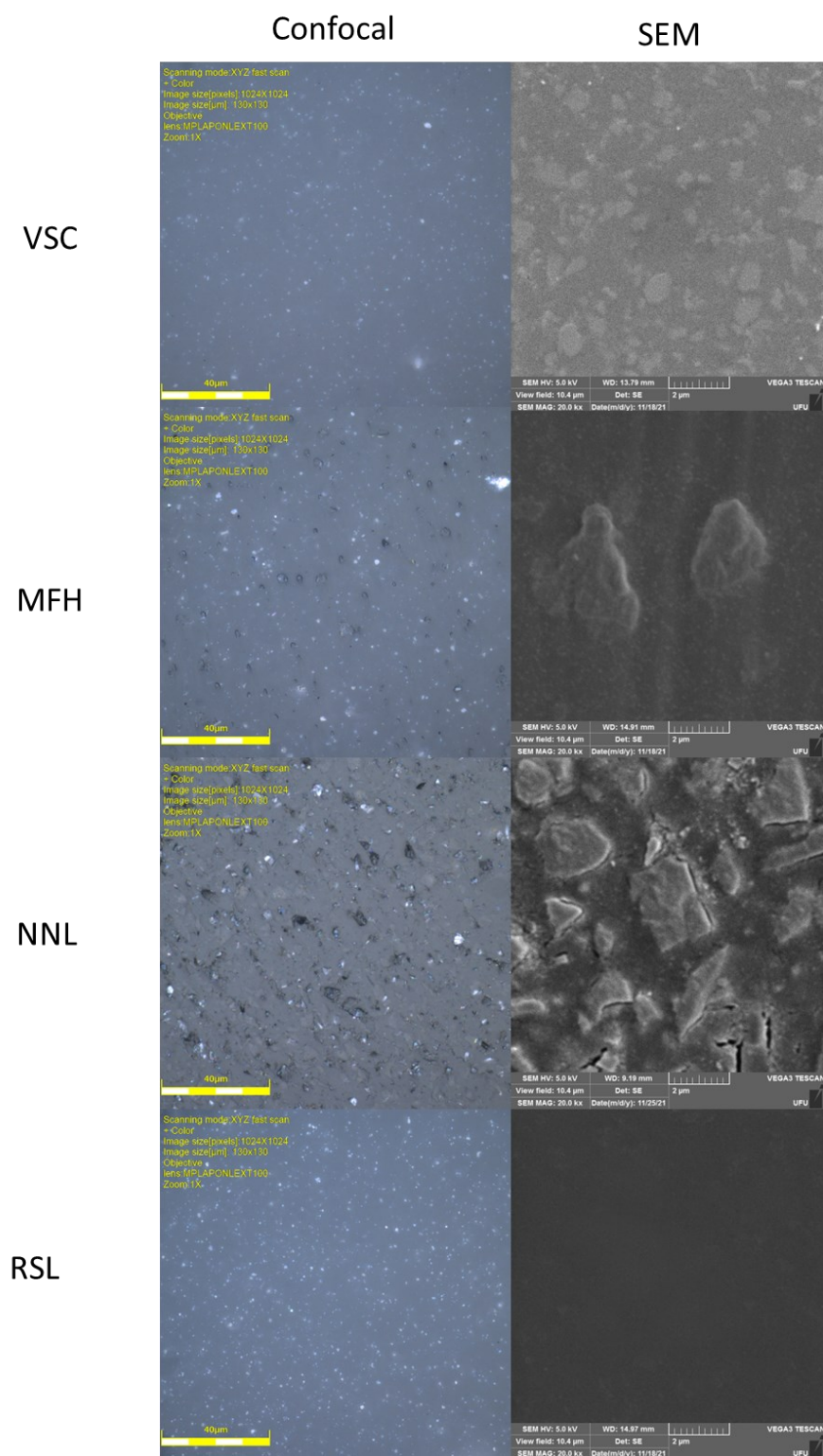


FIGURE 2 Confocal laser and SEM images showing fillers sizes and distribution within the matrix.

EDS Profile

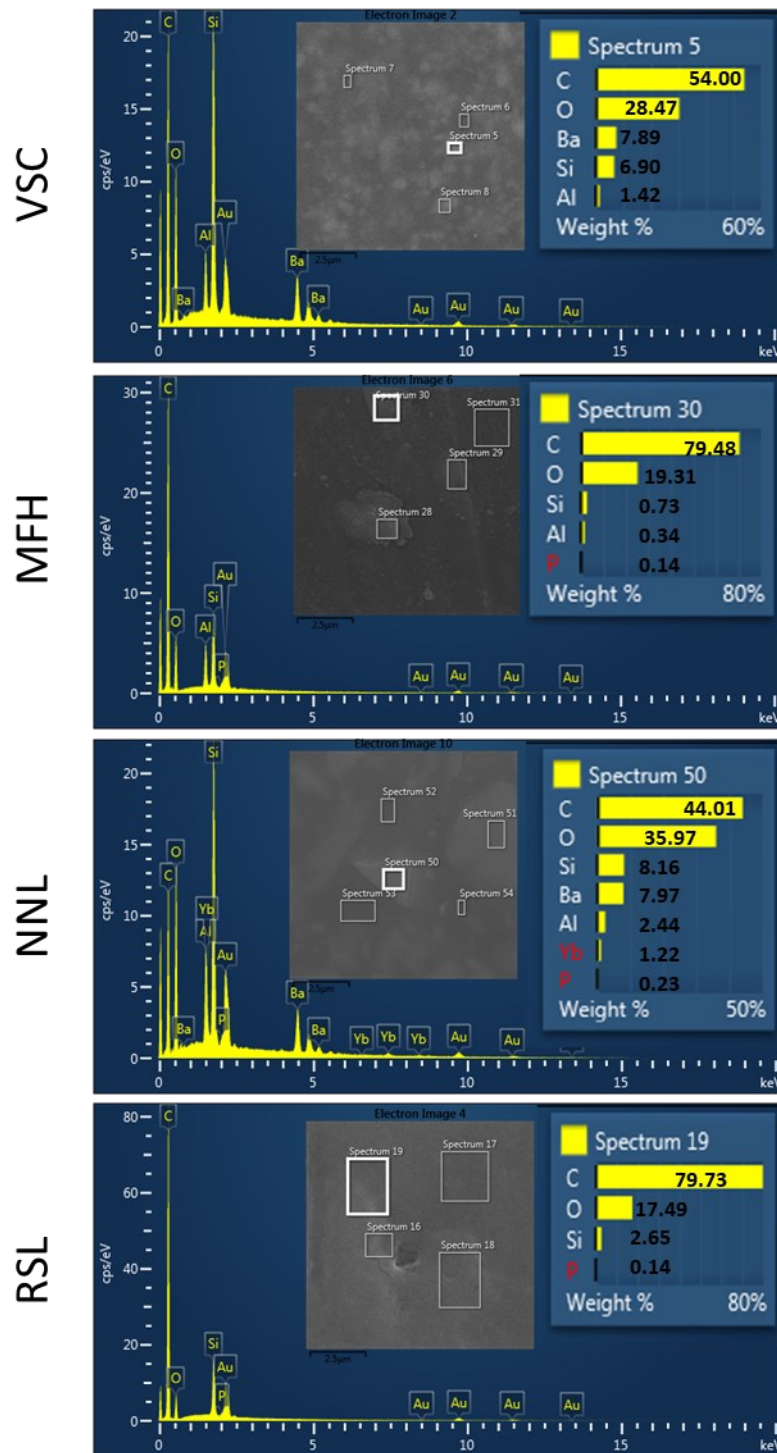


FIGURE 3 EDS scanning of the resins focusing especially on the fillers, when they were visible.

4. DISCUSSION

This study aims to comprehensively evaluate the chemical and surface properties of four previously examined resins. In these following analyses, the detailed examination using confocal laser scanning, SEM, and EDS not only reveals the microstructural intricacies but also lays bare the elemental composition, offering a comprehensive understanding of the materials at play. Each resin group showcases unique characteristics, from micrometric fillers and their distribution to the nature of interaction within the resin matrix.

A study⁵ delved into the characterization of various CAD/CAM materials (BC, TC, CS, GB, SB, LU) using SEM and EDX analysis. The microstructure of these materials varied significantly, with different shapes and sizes of fillers. For instance, BC and TC contained small irregular-shaped fillers, CS had smaller evenly distributed fillers, and GB featured relatively larger irregular-shaped fillers. SB and LU presented unique filler compositions, including silicon dioxide and zirconium silicate. The EDX spectra confirmed the elemental composition of the fillers, highlighting variations in Si, O, Ba, Al, and Zr content among the materials. The mechanical properties assessed in the referred study, including hardness (HM), Vickers hardness (HV), elastic modulus (EIT), and indentation creep (CIT), demonstrated significant differences among the materials. GB exhibited the highest HM, HV, and EIT values, indicating superior mechanical strength. LU followed closely, showcasing substantial mechanical properties. The correlation analyses revealed interesting relationships, with HM and HV strongly positively correlated and both showing a significant positive correlation with EIT. Notably, CIT exhibited a significant negative correlation with HM, HV, and EIT, suggesting that materials with higher mechanical strength are less prone to indentation creep.

Another study⁶ state that the correlation between the inorganic filler percentage and the mechanical characteristics was highly evident, exerting a substantial influence on the resin's mechanical properties. The most significant correlation was observed in the regression analysis between Flexural Strength (FS) values and the volume percentage of inorganic filler. The inclusion of hybrid inorganic fillers in certain material compositions affirmed enhanced mechanical properties.

In this study, the wt% found in the present results might also have influenced the properties of the resins from the previous study¹³. There might be a relationship between wt%, shape, and size as found in a few studies^{5,6}. Overall, the combination of microstructural analysis and mechanical testing in these studies provides valuable insights into the role of fillers in influencing the performance of 3D-printed dental resins. The observed variations in filler characteristics among different materials seemed to

follow a proportion between the wt% of fillers with the mechanical properties. This also contribute to their distinct mechanical behaviors, emphasizing the importance of the right composition and proportions within fillers seeking to optimize the properties of this class of dental restorative materials.

This study did not analyze a wide range on Raman spectra. A pick of analyze close to 600cm^{-1} could have showed more about the bond connections between the fillers and the polymeric matrix^{20,21}. Another aspect that should be taken in consideration is the sharp peaks at 1723.56 cm^{-1} corresponded to C=O on the ester group as found in another study for a SLA resin²², and DC is made on a relative basis by comparing the vibration bands of the unpolymerized methacrylate C=C stretching mode at 1640 cm^{-1} to the aromatic C=C mode at 1610 cm^{-1} ²³.

Fillers also have been used in different applications through Dentistry. A study²⁴ introduce silver-loaded mesoporous silica nanoparticles, showcasing how specific fillers enhance both mechanical and antimicrobial properties in 3D-printed denture base resin. Novel experiments explored fluorapatite glass-ceramics via stereolithography 3D printing, emphasizing how filler composition influences the durability and mechanical performance of printed objects²⁵. Prompts to scrutinize the effect of composition, fabrication mode, and aging on mechanical properties of temporary materials in prosthodontics, highlighting the enduring impact of filler composition and structure over time. As well as investigate various printing parameters affecting accuracy in 3D-printed partial denture frameworks, revealing the intricate relationship between precision and filler-related aspects^{2,10,11,26-28}.

Moreover, our study reveals distinctive properties in the filler shapes among the four resin groups, signaling a scarcity of comprehensive research in this domain. This underscores the ongoing evolution of modern dentistry, suggesting trajectory toward substantial advancements in the realm of these resins.

5. CONCLUSIONS

As this exploration is conclude, it becomes evident that delving into the composition and structure of 3D printed resins is not just an academic pursuit but a gateway to unleashing the full potential of additive manufacturing in dentistry. The composition, fillers and structure seed to have influence on resins properties. Armed with this knowledge, researchers and engineers stand poised to push the boundaries of innovation, ensuring that the future of dental technology is characterized by precision, durability, and, above all, the continual improvement of patient care.

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DATA AVAILABILITY STATEMENT

Data will be provide as requested.

Conflict of interest

The author(s) declared no potential conflicts of interest concerning this article's research, authorship, and publication.

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4.3. Capítulo 3 –

Clinical Article - PLOS ONE

Survival rate of implant-supported screw-retained 3D-printed single-crowns restorations: a prospective 1-year follow-up cohort study

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ABSTRACT

Statement of the problem: The digitally fabricated crowns may be an alternative for provisional crown under dental implants. However, the limited resistance of the print materials continues to be a concern regarding the use of 3D-printed resin as a provisional material for implants supported crowns.

Objectives: This clinical trial aimed to access the survival of implant-supported screw-retained single-crowns 3D-printed restorations through digital workflow.

Methods: A total of 33 patients received 76 single unit implant-supported screw-retained printed crowns placed in posterior area. Digital impressions were taken with an Intraoral Scanner. Titanium (Ti) base abutments were placed on implants. Digital impressions were imported to a dental Computer-Aided Design software, and the crowns' designs were obtained. The crowns were cemented to the Ti-base using a resin dual cement followed by its placement in the mouth and occlusal adjustments. The patients were followed for a year. The data were submitted to the Kaplan-Meier test to analyze the survival rates evolution during the follow-up and the chances of failures in each period of evaluation ($\alpha=.05$)

Results: The overall crown survival rate was determined to be 24.77% (19) at 6 months and 17.19% (13) at 12 months period. Almost all the failures were related with the fractures of the restoration (63 cases), and abutment screw loosening (2 cases). Both cases of screw loosening present the restoration fractured after 1 year of follow-up.

Conclusion: The 3D-printed crowns exhibited a notably low rate of survival. Substantial enhancements in the 3D-printing crown fabrication process are imperative to achieve higher rates of survival and improved clinical outcomes.

Keywords: 3D Printing; CAD-CAM; Clinical Trial; Single Crown; Survival; Hybrid resin.

INTRODUCTION

Additive manufacturing (AM) processes represent the latest advancement in Computer Aided Design (CAD) file prototyping within the field of dentistry.[1,2] In this approach, a stereolithography file (.stl file) is generated, and ultraviolet light is employed to photopolymerize the voxels in resin for 3D printing generating prosthetics restorations.[3] This innovative method offers cost savings, with approximately 300 single crowns being producible from one liter of resin, compared to the requirement for individual blocks in milling systems.[4–6]

The biomechanical properties of long-standing resinous compounds for 3D printing are deemed suitable, particularly for temporary restorations without an inorganic matrix. These resins exhibit a modulus of elasticity akin to self-polymerizing acrylic resin and perform comparably to bis-acrylic resin in terms of maximum stress resistance before fracture.[7–9] However, the introduction of an inorganic matrix all well a proper post curing process can modify material properties, enhancing both flexural resistance, modulus of elasticity, and hardness in the printed resins. This adjustment serves to prevent excessive load transfer to the remaining tooth structures as well as surface wear.[10–13] Less is known about the behavior of the use of those resins as temporaries to rehabilitate implants.

Titanium (Ti) base abutments play a pivotal role in the success of dental restorations. These abutments serve as the intermediary components connecting dental implants to prosthetic restorations. The choice of material for implant abutments significantly influences the mechanical properties of the final crowns. Titanium, renowned for its biocompatibility and favorable mechanical characteristics, is often preferred for abutment fabrication. The mechanical properties of the abutment material, such as its modulus of elasticity and hardness, directly impact the overall stability and longevity of the crown.[14–16]

Considering these findings, questions arise regarding the performance of those restorations in the mouth environment. The survival of implant-supported restorations plays a significant role in the clinical outcome. Little is known about the behavior of 3D-printed resins applied in those restorations.[8,17,17–26] The aim of this study was to evaluate the survival rates of

the implant-supported screw-retained 3D-printed provisional single-crowns restorations after one-year of follow-up.

MATERIAL AND METHODS

Study design

This study is a continuation of a randomized double-blinded clinical trial that evaluated conical connections of implants placed in two different levels from the crest. This study was approved by the human research ethics committee of the Federal University of Uberlandia, Minas Gerais, Brazil between January 2021 and January 2022 (#5.142.350). The study protocol was published in the Brazilian Registry of Clinical Trials (ReBEC) (registration number U1111-1273-1182) available at <https://ensaiosclinicos.gov.br/rg/RBR-9qvwvyw>.

When recruited, all participants were duly informed about the research and signed a clear and informed consent form according to Resolution 510/16 of the National Health Council and in accordance with the Declaration of Helsinki. The STROBE Checklists for cohort study was followed. Eligibility for the trial extended to patients who met the inclusion and exclusion criteria and had previously experienced successful implant therapy.

Table 1 – Inclusion and exclusion criteria
Inclusion criteria
1) Age between 18 and 70 years old; 2) Need for bilateral unitary rehabilitation with implants in the maxilla or mandible; 3) Sufficient bone availability for installation of the conventional-sized implant; 4) Good systemic health.
Exclusion criteria
1) Smokers and ex-smokers; 2) Diabetics; 3) Patients who are chronic users of medications (eg. Bisphosphonates, Immunosuppressants, anti-inflammatories) or pathologies that alter bone metabolism (eg. Osteoporosis; Diabetes); 4) Patients who chronically use anti-inflammatories and antibiotics; 5) Sufferers of bruxism; 6) Alcoholics; 7) Chemical

addicts; 8) Pregnant women or those who wish to become pregnant in the next year; 9) History of radiotherapy treatment in the head and neck region.

To calculate the sample size, the peri-implant bone level was used as the primary variable. A study that compared the peri-implant bone level after 8 months in implants with a Morse cone platform installed at the bone level and subcrestally that supported lower protocol type prostheses demonstrated the expected mean standard deviation for the analysis of peri-implant bone loss was 0.49 mm.[27] Establishing the β power at 0.90 and the α at 0.05 and a clinically significant difference of 0.50 mm between the groups, 12 patients were needed to receive implants in the maxilla and 12 patients to receive implants in the mandible, to carry out this study. However, anticipating patient losses during follow-up, we propose the additional treatment of 3 patients per group (25% of the sample) to avoid loss of statistical power in longitudinal analyses. A total of 33 patients were recruited.

Patients with maxillary or mandibular bilateral tooth loss were selected to rehabilitation in posterior area with implants placement followed by abutment installation and 3D-printed crown cementation. The restorations were analysed at the baseline, 6, and 12 months. The Presence/absence of technical complications (i.e., complications related to superstructures, such as loss of retention and ceramic/veneer fracture) of the crowns was set as the outcome.

Surgical procedure and groups

Regarding the surgical procedure. After performing the local anesthesia technique, a full-thickness mucoperiosteal flap was opened to expose the ridge. The milling procedure was performed under abundant irrigation with saline solution and in accordance with the implant manufacturer's recommendations. Two Drive® type implants (Neodent, Curitiba, Brazil) were installed in a randomized manner, one of which was installed at bone level and the other was installed 2 mm subcrestally. Randomization was performed by applying a randomization table that was followed at the time of implant installation. These implants have a diameter of 3.5 and a length between 8 – 10 mm. The implant platform selected was the conventional Morse conical type. When installing the implants, the primary stability of the implants was

measured using the insertion torque and healing abutments (Neodent, Curitiba, Brazil) were placed to avoid reopening surgery.

After insertion of the implants, the surgical bed was sutured with 5.0 nylon threads (Ethicon, Johnson & Johnson). Amoxicillin (500mg) for 7 days, Nimesulide (100mg) for 5 days and sodium dipyrone (500mg) for 3 days for oral consumption were prescribed to all patients during the postoperative period. Additionally, a mouthwash based on 0.12% chlorhexidine digluconate were prescribed for 14 days. The sutures were removed after 14 days.

Prosthetic procedures

After 4 weeks of the surgical procedure, gigital impressions were performed with an intraoral scanner (VIRTUO VIVO, STRAUMAN). Scanbodies (Neodent, Curitiba, Brazil) screwed directly from the implant platform were placed in position to digitally transfer the position of the implants to the design software (exocad, GmbH, Germany). Then the crowns were designed by an experiment operator regarding minimum thickness, screw channel and aesthetics.[21,28] The final file (.stl) were sent to the 3D printer where the crowns were printed using a hybrid resin (Varseo Crown Smile Plus, Bego) following the manufacturer's recommendations. The healing abutments were changed for the restorations supported by conical abutments (Neodent Curitiba Brazil) were installed with an undertorque of 10N so that could make no harm to the stability of the implant. The prostheses were screwed type to enable removal during implant evaluation.

The resin is recommended by its manufacturer for permanent fixed restorations. VarseoSmile Crown Plus by Bego is a biocompatible, high-strength resin with a tooth-colored appearance. The specifications can be found in Table 2.

Table 2 – Resin, composition, exposure time in seconds, shade, and batch.

Commercial name	Composition	Exposure	Shade	Lot. No.
VarseoSmile Crown Plus	4'-isopropylidiphenol, ethoxylated and 2-methylprop-2enoic acid.	2 seconds	A1 dentin	600181

Silanized dental glass, methyl benzoyl
formate, diphenyl (2,4,6-
trimethylbenzoyl) phosphine oxide,
30–50 wt. %—inorganic fillers
(particle size 0.7 μm)

The design that resulted was then saved as an STL file and processed through slicer software, specifically the Anycubic Photon Workshop 3D and Anycubic 3D. The objects were positioned at a 45-degree angle for the printing process.[29] Following this, the file was sent to a 3D printer, the Anycubic Photon Mono, which is an affordable open-source device. This printer utilized a 45,000 mW ultraviolet light emitting diode (LED) with a wavelength of 405 nm as its light source. It also featured a 104 mm² liquid crystal display (LCD) to solidify the resin layer by layer from the bottom,[30,31] with an irradiance of 432.6 mW/mm². Before printing the crowns, the exposure times for the resins were adjusted by printing a 10-mm cube, which was then post-processed. Measurements of its length, thickness, and height were taken using a digital caliper (Mitutoyo in Tokyo, Japan).[12,32]

Upon completion of the printing process, the crowns were subjected to a curing rotary washer device, the Wash & Cure 2.0 by Anycubic 3D. This machine was equipped with a 25,000 mW LED that emitted light at a wavelength of 405 nm, covering an area of 30.5 mm² and delivering an irradiance of 819.6 mW/mm², in accordance with the manufacturer's recommendations. Subsequently, the crowns underwent a 5-minute cleaning cycle in 99.5% p.a. isopropyl alcohol from Labsynth in Diadema, SP, Brazil, and were then exposed to 30 minutes of light curing, as indicated in reference.[12,33] Finally, the support structures were removed from the crowns, and the specimens underwent polishing (Jiffy, Ultradent). The crowns were sandblasted in the intaglio, cemented using a universal self-adhesive cement (RelyX U200, 3M ESPE) on their respective titanium bases (Neodent Curitiba Brazil) as a luting agent, and placed in the mouth for proximal and occlusal adjustments and polishing.

Statistical Analysis

The Sigma Plot Software was used to access the survival rates. The data were submitted to the Kaplan-Meier test to analyze the survival rates evolution during the follow-up and the chances of failures in each period of evaluation. All tests were applied with a 95% confidence level.

RESULTS

A total of 33 patients, comprising 22 females and 11 males within an age range of 24 to 70, were meticulously selected from the Dentistry Hospital of the Federal University of Uberlandia in Minas Gerais, Brazil. They met the inclusion criteria without exhibiting any signs or symptoms that would warrant exclusion (Fig. 1).

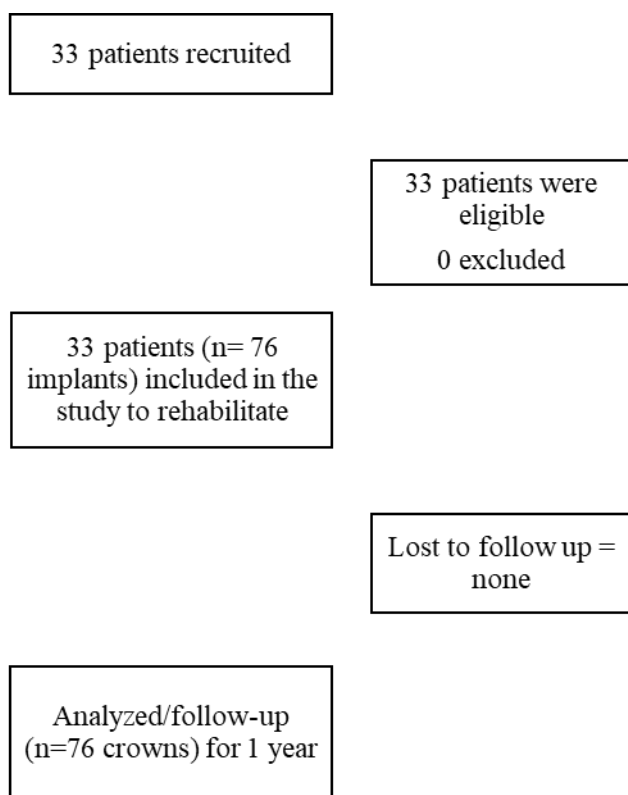


Fig 1. **STROBE Flow-chart.** Flow-chart describing the selection of participants/crowns.

Collectively, 76 implants, abutments, and single crowns were bilaterally placed in the posterior region, encompassing premolars and molars. An example of crow placed and adjusted can be found in Figure 2.

The overall crown survival rate was determined to be 24.77% (19) at 6 months and 17.19% (13) at 12 months period (Figure 2). Almost all the failures were related with the fractures of the restoration (63 cases), and abutment screw loosening (2 cases). Both cases of screw loosening present the restoration fractured after 1 year of follow-up.



Fig 2. **Crown example.** Crown placed and adjusted.

DISCUSSION

New generations of resins are available in modern dentistry such as the one used in this study. Regardless it is not specified in the manufacture's indication, it was considered that such a material could be used as a long-term temporary screw-retained crown. The employment of ceramic fillers in 3d-printed resins improved the material properties.[2,8] Relying on that, this study was conducted to assess the performance of provisional restorations through a digital workflow immediately load technic.

Factors as occlusal overload, trauma, poor crown design, material choice, abutment, inadequate cementations can lead to crown fractures. [14,16,34] In this study, bruxism was part of the exclusion criteria, which implies that individuals with a history of bruxism were not included in the research, likely to minimize the potential impact of teeth grinding on the study's outcomes. None of the participants related to trauma during the follow up. The crowns' design was executed by an experienced operator, ensuring the precision and quality of the crown's structural [28] and aesthetic characteristics. The material of choice was carefully tested in an in vitro study. Regardless the study's limitations, the material's properties showed promisor results in a possible application for crowns restorations. Its

Flexural Strength was 124 MPa, the Elasticity Modulus was 4.51 GPa, and the Vickers Hardness was recorded at 27.8 VHN.[12] A systematic review showed that, in general, 3D-printed provisional crown and fixed dental prosthesis resins exhibit enhanced mechanical properties, including fracture strength, flexural strength, elastic modulus, peak stress, and wear resistance, when contrasted with traditional and CAD/CAM milled provisional resin materials.[8] More clinical studies should be addressed to access the 3d-printed resins behavior in mouth environment.

Ideally, the substitute material for the outermost layer of the tooth should exhibit a hardness comparable to or lower than enamel, recorded at 274.8 VHV. Conversely, a replacement for the underlying portion should possess a modulus of elasticity akin to or greater than enamel (16.5 GPa), in attempt to decrease vertical wear of materials or tooth structures.[35,36] While gold alloys fulfill these criteria, their diminished popularity can be attributed to their elevated cost and unfavorable aesthetic attributes.[37]

Crowns dislodgement is a common problem related in cemented resin restorations.[17] This study did not present this complication. This might be due to that a careful surface treatment were performed followed by silanization.[25] The same cement was used to avoid variability, but more studies are needed to access the influence of cementing and bonding of those materials to titanium substrates.

Two distinct implant shapes were positioned at two varying bone levels during installation, but neither influenced on implant rate survival in this study. Both implants feature comparable internal conical connections and Ti-base abutments. The pivotal role of abutment material in restoration success is underscored in this context.[17,33,38] The observed low survival rate in this study suggests a potential correlation with material property disparities between the abutment and the crown. The Ti-base, characterized by a high elasticity modulus, contrasts with the resin, which exhibits properties more like dentin. This distinction could have implications for stress accumulation and the propagation of fractures. One of those studies [17] exposed clinical trials that had high survival rate in general. One study included was implant supported.[15] The same study had only 14% of survival rate for the printed crowns. Another study showed that [20] The fracture resistance of screw-retained implant-

supported interim crowns is affected by manufacturing procedures and tooth type. Milled specimens demonstrated superior fracture resistance in comparison to the groups produced through DLP (Digital Light Processing) additive manufacturing. The investigation's findings prompt consideration of the interplay between abutment and crown materials in optimizing restoration outcomes.

In such circumstances, 3D printing could potentially serve as a provisional restoration when applied for a short period. This approach offers the advantage of a digital workflow,[6] ensuring convenience during the initial phase of tissue healing. Subsequently, the final version can be fabricated using a more robust and durable material for long-term placement.[9,38] In this study, the restorations were analyzed at 6 and 12 months from baseline. However, more clinical trials are needed to better determinate a precise range of period which would be considered safe to employ those restorations on Ti-base type abutments.

A potential limitation of the study lies in its omission of a control group featuring an alternative type of well-established restoration. The clinical conditions posed a notable challenge for the material, particularly given the use of a titanium abutment instead of a dentin or enamel substrate. Another potential hurdle for the material was the placement of the restorations in the posterior region, where functional loads tend to be higher. A serious investigation about patient historic regarding Tinnitus or Temporomandibular disorders should have been done to improve the exclusion criteria. Considering these aspects, there exists the possibility that the material could have exhibited improved performance under different circumstances.

While the utilization of fillers in hybrid 3D-printed resins may enhance their properties, further enhancements are required to bolster their resistance for enabling their application in screw-retained restorations for long-term restorations. In this study immediately after the experimental crowns' failure, the final restorations were milled and installed to avoid damage or loss to surrounded tissues. Moreover, additional research studies are warranted to delve deeper into this subject matter.

CONCLUSIONS

Within the confines of this study, the utilization of screw-retained 3D-printed crowns exhibited a notably low rate of survival. This suggests that employing these crowns in single rehabilitations may yield suboptimal success rates. Substantial enhancements in the 3D-printing crown fabrication process are imperative to achieve higher rates of survival and improved clinical outcomes.

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5. Conclusões

Ao final desta tese podemos concluir que, o grau de conversão, a rugosidade superficial (Sa), a resistência à flexão e a dureza foram diretamente influenciados pelas resinas testadas e pelas espessuras das camadas. A síntese dessas propriedades físicas e mecânicas, juntamente com as propriedades superficiais e a morfologia, foi crucial para alcançar um desempenho clínico bem-sucedido. Curiosamente, o módulo elástico dos materiais estudados permaneceu inalterado pela espessura da camada, enquanto um aumento significativo na resistência à flexão foi observado ao empregar uma espessura de camada de 50 µm.

Destaca-se que uma exploração aprofundada da composição e estrutura das resinas impressas em 3D vai além da curiosidade acadêmica, sendo a chave para desbloquear todo o potencial da fabricação aditiva na odontologia. Essa nova compreensão capacita

pesquisadores e engenheiros a impulsionar a inovação, garantindo que o futuro da tecnologia odontológica seja marcado por precisão, durabilidade e, acima de tudo, o contínuo aprimoramento do cuidado ao paciente.

Além disso, a utilização de coroas impressas em 3D parafusadas revelou uma taxa de sobrevivência notavelmente baixa, indicando que sua aplicação em reabilitações únicas pode resultar em taxas de sucesso não correspondentes a um material que proporciona restaurações de longa duração. Torna-se evidente a necessidade de melhorias substanciais no processo de fabricação de coroas impressas em 3D, visando alcançar taxas de sobrevivência mais elevadas e melhores resultados clínicos em futuras aplicações.

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