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Original Article

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Flexural resistance of 3D printing resin compared to conventional acrylic resins employed to build occlusal bite splints

Resistência flexural de uma resina para impressão 3D comparada a resinas acrílicas convencionais empregadas para confecção de placas estabilizadoras de mordida

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Resumo

Introdução: com o avanço tecnológico dentro da odontologia, as resinas fotopolimerizáveis para impressão tridimensional (3D) se tornaram uma alternativa para a fabricação de dispositivos interoclusais. **Objetivo:** o presente trabalho teve como objetivo analisar a resistência flexural de uma resina para impressão tridimensional comparada com resinas acrílicas convencionais (quimicamente ativada e termicamente ativada), sob a influência da termociclagem. **Material e método:** foram confeccionados 60 corpos de prova, que foram distribuídos aleatoriamente em seis grupos experimentais (n=10), de acordo com a resina utilizada (resina acrílica ativada quimicamente, resina acrílica ativada termicamente e resina para impressão 3D) e com o tratamento recebido (controle e termociclagem). Os corpos de prova foram submetidos ao ensaio de flexão de três pontos para determinação da resistência flexural. **Resultado:** a análise dos dados demonstrou que o fator material (<0.0001) e o fator termociclagem (p=0.0096) influenciaram a resistência flexural, entretanto, a interação entre os dois fatores não (p=0.9728). **Conclusão:** deste modo podemos concluir que a resina para impressão 3D apresentou desempenho inferior às resinas acrílicas, especialmente quando submetida a termociclagem.

Descritores: Resinas para impressão tridimensional; resinas acrílicas; placas estabilizadoras.

Abstract

Introduction: with the technological advance in dentistry, light-polymerized three-dimensional (3D) printing resins had become an alternative for the manufacture of occlusal splint splints. **Objective:** the present study aimed to analyze the flexural strength of a resin for 3D printing compared to conventional acrylic resins (chemically activated and thermally activated), under the influence of thermocycling. **Material and method:** 60 specimens were made, which were distributed in six experimental groups (n = 10), according to the resin employed (chemically activated acrylic resin, thermally activated acrylic resin and 3D printing resin) and the treatment received (control and thermocycling). The specimens were submitted to flexural strength by the three-point flexural test. **Result:** data analysis showed that the material factor (<0.0001) and the thermocycling factor (p = 0.0096) influenced flexural strength, however, the interaction between the two factors did not (p = 0.9728). **Conclusion:** it was concluded that 3D printing resins presented the lowest flexural resistance to acrylic resins, especially when submitted to thermocycling.

Descriptors: 3D printing resins; acrylic resins; occlusal bite splint.

INTRODUCTION

The significant technological advance in digital dentistry, mainly in three-dimensional printing (3D), provided new options to the workflow, reducing time and production cost, however keeping acceptable precision levels to solve different therapeutic approaches[1].

Digital light processing (DLP) 3D printing uses light-polymerization method, where the 3D printing machine displays one single image of each layer in the whole platform simultaneously. The precision of the object obtained varies according to the type of 3D printing[2]. Moreover, the DLP method was reported as more precise than other types of 3D printers[3].

The literature reports several 3D printing applications, like in maxillofacial reconstruction[4], planning and interventions in implantology[5], planning in orthognathic surgeries[6], orthodontic appliances (braces)[7], metal frameworks for removable partial dentures[8], fixed partial dentures[9], study and work models[2], and stabilization bite splints[10].

Occlusal bite splints therapy is commonly used to treat temporomandibular disorders and prevent dental wear[11]. Polymethyl methacrylate (PMMA) resins are widely employed to manufacture this device[12]. An efficient alternative that presents precision and interesting cost-benefit is the use of 3D printing equipment to obtain occlusal bite splints. Production of occlusal bite splints with 3D printing provides more precise treatment planning, is time saving and have more predictable outcomes[13].

One of the most studied properties of materials is flexural resistance, usually assessed with the three-point flexural test, which determines the load supported by the material investigated. This test determines tensile stress, compressive stress, and shear stress of a bar when submitted to a load[14].

There is in the literature a gap in the understanding of the properties of materials used for 3D printing, particularly with regard to flexural resistance. Thus, the present work aimed at assessing flexural resistance of a 3D printing resin, compared to conventional acrylic resins, and thermocycling effects on them. The null hypothesis tested was that there would be no differences in the flexural resistance of both resins in the control group and thermocycling group.

METHODOLOGY

Materials

Two types of acrylic resins were selected, a chemically actived acrylic resin (CAAR) (VipiFlash, Vipi Indústria, Comércio, Exportação e Importação de Produtos Odontológicos Ltda, Pirassununga, SP, Brasil), and a thermally actived acrylic resin (VipiCril Plus, Vipi Indústria, Comércio, Exportação e Importação de Produtos Odontológicos Ltda, Pirassununga, SP, Brasil). A 3D printing resin indicated for the manufacturing of occlusal bite splints (Yller Cosmos Splint Incolor, Yller Biomateriais, Pelotas, RS, Brazil) was employed.

Acrylic Resin Specimens Manufacturing

Sixty specimens were produced in beam shape (65.0×10.0×3.3 mm) (±0.2 mm), according to ISO 20795-1 standard. The acrylic resin specimens were produced using stainless steel matrix with four cavities shaped as rectangular beams.

For the manufacture of chemically activated acrylic resin (CAAR), the matrix was isolated with water based lubricant. Then the CAAR was handled according to the manufacturer's recommendations. As the plastic phase was reached, the resin was positioned inside the matrix, and manual pressure was performed with thick glass plate. The resin excess was removes with Lecron spatula. Full polymerization of the resin was waited in order to remove it.

For thermally activated acrylic resin specimens (TAAR), the matrix was isolated with water based lubricant (KY, Dailus, Embu das Artes, SP, Brazil) poured with wax 7 (Lysanda, São Paulo, SP, Brazil) molten inside the matrix cavities. Then the wax molds were removed and placed in metallic muffle for conventional polymerization. For such, the muffles were isolated with water based insulating solution and filled with type III stone plaster (Asfer Indústria Química Ltda., São Caetano do Sul, SP, Brazil). Three wax molds were positioned over it with at least 1 cm distancing. Zetaplus condensation silicone wall technique (Zhermack, Badia Polesin, RO, Italy) was chosen to facilitate cleaning and polishing of the specimens. The counter-muffle was filled with type III stone plaster and positioned in the hydraulic press, then submitted to 1,250 Kgf load. Wax removal occurred shortly after, with boiling water for 5 minutes.

After wax removal, isolation of the plaster present in the muffle was made with alginate isolating solution (CEL-LAC SS White Artigos Dentários Ltda, Rio de Janeiro, RJ, Brasil). TAAR was handled according to the manufacturer guidance, and deposited on the plastic phase over the spaces obtained in the silicone wall, and then a cellophane paper rectangle was positioned to close the muffle. A preliminary pressing was performed with 1000 Kgf pressure, and after the muffle opening the cellophane paper and excess material were removed. The muffle was closed again and submitted to 1250 Kgf pressure, and 20 minutes passed before polymerization.

Conventional polymerization was performed immersing the muffle in aluminum pan with 3 liters of cold water. Initially, the stove flame was kept positioned in low heat for 30 minutes, and then the flame was augmented to boil for 90 minutes. The muffles were opened after cooling, and specimens in TAAR were removed.

CAAR and TAAR specimens were finished and polished. The rougher were removed with tungsten drill. Then polishing was performed with hand sander under constant irrigation, using a sequence of three water sandpapers in the following granulation order: #400, #600 and #1200. At the end of the process all specimens were measured with digital caliper (Mitutoyo Sul Americana, Suzano, SP, Brazil) to verify the dimensions, and then kept in distilled water for 30 days, until the start of the flexural resistance test.

Obtention of 3D Printing Resin Specimens

The specimens (n=20) were virtually drawn in three-dimensional manipulation software (Meshmixer; Autodesk Inc) following the matrix pre-established measures. The file generated, in .STL format, was then sent to the 3D printer (Phrozen Tech Co. Ltda, Hsinchu, Taiwan) and printed in light-polymerized resin at 90-degree angle. Once the printing was completed, they underwent cleaning process to remove the surface resin with ultrasound bath for 2 minutes in isopropyl alcohol and then mechanical removal with brush was performed. As they were dry, the polymerization process was concluded by placing them in post-cure equipment for 5 minutes. Based on the dimensions of this calibration block, adjustments were made to the time of exposure to light of the cure layers.

Study Groups

The specimens were randomly distributed across groups, respecting control and thermocycling groups. Table 1 presents the study groups.

Table 1. Study groups according to type of resin and treatments.

Resin	Treatment	Group	n = (60)
CAAR	Control	Chemically activated resin control (Cc group)	10
	Thermocycling	Chemically activated resin thermocycled (Ct group)	10
TAAR	Control	Thermally activated control (Tc group)	10
	Thermocycling	Thermally activated resin thermocycled (Tt group)	10
3D print	Control	3D printed resin control (Pc group)	10
	Thermocycling	3D printed resin thermocycled (Pt group)	10

Thermocycling

Ct, Tt and Pt groups' samples were subject to thermocycling for 10000 cycles, with temperatures ranging from 5°C to 55°C, and time of permanence of six seconds in each water tank, after 30 days of immersion.

Flexural Resistance

The three-point flexural test was used to determine the samples' flexural resistance. The tests were executed with a universal testing machine (Biopdi, São Carlos, Brazil). Distance of 50 mm was kept between supports and the load was applied in the core of the specimen. The test was performed with a 100 N load cell, at constant speed of 5 mm/min, until rupture. Flexural resistance was obtained by the formula: $\sigma = 3FI/2\ bh^2$, where F is maximum load in Newton; I is the distance between supports, that is, 50mm; b is the specimen width, and h is the specimen height.

Statistical Analysis

Data normality was verified by Shapiro-Wilk test. Variance analysis (ANOVA) with two factors (material and thermocycling), followed by Tukey test, were used to compare flexural resistance [MPa] across groups. The significance level adopted was 5% and data processing was performed using the software Graphpad Prism 7.0.

RESULT

Table 2 and Figure 1 presents mean, standard deviation, confidence interval (95%) data, and minimum, maximum, and median value of the flexural resistance of the groups analyzed.

Table 2. Mean, standard deviation, confidence interval (95%), and minimum, maximum, and median value of the flexural resistance [MPa] of the groups analyzed

Group	Mean	Standard deviation	Confidence interval (95%)	Minimum value	Median	Maximum value
Cc	120.20	14.90	109.50 - 130.80	91.73	122.20	136.80
Ct	110.90	14.62	100.40 - 121.30	92.45	112.00	134.30
Tc	140.50	17.87	127.70 - 153.30	106.50	144.90	160.60
Tt	129.00	16.16	117.40 - 140.50	104.10	130.40	157.00
Pc	80.67	14.87	70.03 - 91.30	61.92	77.40	107.00
Pt	70.49	9.85	63.45 - 77.54	56.27	71.32	88.45

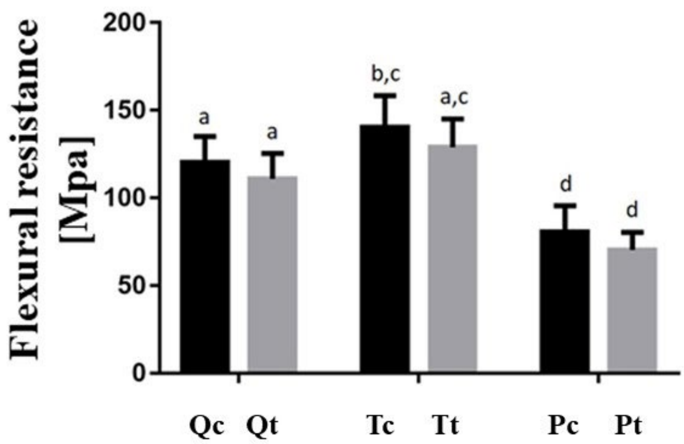

Figure 1. Graph of the mean flexural resistance obtained in the different study groups.

Different letters indicate statistically significant difference (p<0.05) between groups. Values expressed as mean + standard deviation.

The analysis of data demonstrated that the material factor (<0.0001) and the thermocycling factor (p=0.0096) influenced the flexural resistance, however, the interaction of the two factors did not (p=0.9728).

DISCUSSION

The present work analyzed the flexural resistance of a 3D printing resin, compared to resins used conventionally for the manufacture of occlusal bite splints (CAAR and TAAR). Control and thermocycling groups were established to also assess the influence of thermocycling in these acrylic resins. According to the results, both material and thermocycling influenced the results, which rejects the null hypothesis tested.

Occlusal bite splints are important therapeutic resource in the treatment of TMDs, because they create stable occlusal contacts with the antagonist teeth, producing a better relation of the articular disc with the mandibular condyle, where a more harmonic relationship can reduce muscular strain[15]. To manufacture these devices acrylic resin is used, and more recently CAD/CAM and 3D printing resins[9,16,17]. Reports of appliance break are not uncommon, due to fall or material wear. For this reason, flexural resistance is a highly important parameter, because it determines the resistance of a material to the forces that can cause its fracture or deformation[18]. The test was made based on ISO 20795-1 standard for prosthetic polymers.

The literature has explored, in some studies, the behavior of material used for 3D printing in Dentistry. In this regard, understanding materials properties is necessary for their validation as therapeutic option. A comparative study involving 6 conventional resin brands and 3D printing resins observed difference in the values of flexural strength, with conventional resins presenting significantly higher values compared to 3D printing resins[10]. However, these characteristics are not related only to the manufacturing technique, but also to the composition of each product, as show in the study by Prpić et al.[19], where in the flexural strength test the nano-acrylic 3D resin specimens did not fracture with maximum load of 117.2 MPa, while those of acrylic 3D resin were the first with 75 MPa, obtaining values significantly inferior to those of conventional resins, which ranged from 88.3 MPa to 104.9 MPa, according to the brand. In the present study, 3D printing resins was employed, which explains flexural resistance values similar to those found in the previously mentioned study.

Lutz et al.[20] addressed the behavior of three resins used for the manufacture of stabilization bite splints; one is CAD/CAM milling resin, the other for printing and one conventional TAAR. The devices were analyzed as to their resistance to fracture with or without chewing cycle. In that study, the splints manufactured by three-dimensional printing proved to be more susceptible to wear and less resistant to fracture than those milled or conventionally manufactured. The authors also suggested that the splints manufactured by the 3D printing method should be used for short time in the oral cavity, and that new materials should be found for the manufacturing of splints.

Another factor analyzed in these studies is the mechanical change that printing resins suffer with ageing, and it was reported that through artificial ageing test this materials tend to have their flexural properties affected, with reduction in strength and flexural module values, which is in accordance with the results found in our study[9,21].

Different 3D printers and materials have been used in Dentistry, including selective laser sintering (SLS), thermal inkjet (TIJ), and fused deposition modeling (FDM)[22]. For the present study, a commercially available SLA printer was used with a light-sensitive polymer, polymerizing layer by layer using a laser with wave length of 405 nm to 23 ± 2 C. The resin contained methacrylate and phosphine oxide, suitable for intra-oral use in a fully polymerized state.

Moreover, the production of an oral device by 3D printing process can reduce costs and expenses and improve the treatment precision. When combined with oral scanning, which can be quickly made, lower costs can be expected compared to the conventional manufacturing technique[23,24]. The adjustments of these splints are faster, which favor the professional productivity[25]. However, as reported in this work, printing resins were less resistant to forces in the flexural resistance test, which can compromise the appliance durability, and produce less wear on antagonist teeth[12].

CONCLUSION

Despite the growing adoption of the method of manufacture of occlusal bite splints by 3D printing, the resin employed in this study presented unsatisfactory performance, particularly when subject to thermocycling. This result supports the idea that the use of these splints should be temporary, with a shorter time of use; however, due to differences in the literature, new studies should be conducted.

REFERENCES

1. Abduo J, Lyons K, Bennamoun M. Trends in computer-aided manufacturing in prosthodontics: a review of the available streams. Int J Dent. 2014;2014:783948. http://dx.doi.org/10.1155/2014/783948. PMid:24817888.

2. Murugesan K, Anandapandian PA, Sharma SK, Kumar MV. Comparative evaluation of dimension and surface detail accuracy of models produced by three different rapid prototype techniques. J Indian Prosthodont Soc. 2012 Mar;12(1):16-20. http://dx.doi.org/10.1007/s13191-011-0103-8. PMid:23449946.

3. Hazeveld A, Slater JJH, Ren Y. Accuracy and reproducibility of dental replica models reconstructed by different rapid prototyping techniques. Am J Orthod Dentofacial Orthop. 2014 Jan;145(1):108-15. http://dx.doi.org/10.1016/j.ajodo.2013.05.011. PMid:24373661.

4. Fernandes N, van den Heever J, Hoogendijk C, Botha S, Booysen G, Els J. Reconstruction of an extensive midfacial defect using additive manufacturing techniques. J Prosthodont. 2016 Oct;25(7):589-94. http://dx.doi.org/10.1111/jopr.12487. PMid:27123959.

5. Cheng A, Humayun A, Cohen DJ, Boyan BD, Schwartz Z. Additively manufactured 3D porous Ti-6Al-4V constructs mimic trabecular bone structure and regulate osteoblast proliferation, differentiation and local factor production in a porosity and surface roughness dependent manner. Biofabrication. 2014 Oct;6(4):045007. http://dx.doi.org/10.1088/1758-5082/6/4/045007. PMid:25287305.

6. Shujaat S, Costa O Sr, Shaheen E, Politis C, Jacobs R. Visual and haptic perceptibility of 3D printed skeletal models in orthognathic surgery. J Dent. 2021 Jun;109:103660. http://dx.doi.org/10.1016/j.jdent.2021.103660. PMid:33848559.

7. Al Mortadi N, Jones Q, Eggbeer D, Lewis J, Williams RJ. Fabrication of a resin appliance with alloy components using digital technology without an analog impression. Am J Orthod Dentofacial Orthop. 2015 Nov;148(5):862-7. http://dx.doi.org/10.1016/j.ajodo.2015.06.014. PMid:26522047.

8. Nakata T, Shimpo H, Ohkubo C. Clasp fabrication using one-process molding by repeated laser sintering and high-speed milling. J Prosthodont Res. 2017 Jul;61(3):276-82. http://dx.doi.org/10.1016/j.jpor.2016.10.002. PMid:27825561.

9. Reymus M, Fabritius R, Keßler A, Hickel R, Edelhoff D, Stawarczyk B. Fracture load of 3D-printed fixed dental prostheses compared with milled and conventionally fabricated ones: the impact of resin material, build direction, post-curing, and artificial aging-an in vitro study. Clin Oral Investig. 2020 Feb;24(2):701-10. http://dx.doi.org/10.1007/s00784-019-02952-7. PMid:31127429.

10. Berli C, Thieringer FM, Sharma N, Müller JA, Dedem P, Fischer J, et al. Comparing the mechanical properties of pressed, milled, and 3D-printed resins for occlusal devices. J Prosthet Dent. 2020 Dec;124(6):780-6. http://dx.doi.org/10.1016/j.prosdent.2019.10.024. PMid:31955837.

11. Reichardt G, Miyakawa Y, Otsuka T, Sato S. The mandibular response to occlusal relief using a flat guidance splint. Int J Stomatol Occlusion Med. 2013;6(4):134-9. http://dx.doi.org/10.1007/s12548-013-0093-8. PMid:24273617.

12. Kurt H, Erdelt KJ, Cilingir A, Mumcu E, Sülün T, Tuncer N, et al. Two-body wear of occlusal splint materials. J Oral Rehabil. 2012 Aug;39(8):584-90. http://dx.doi.org/10.1111/j.1365-2842.2012.02301.x. PMid:22486490.

13. Reyes-Sevilla M, Kuijs RH, Werner A, Kleverlaan CJ, Lobbezoo F. Comparison of wear between occlusal splint materials and resin composite materials. J Oral Rehabil. 2018 Jul;45(7):539-44. http://dx.doi.org/10.1111/joor.12636. PMid:29663496.

14. Donovan TE, Hurst RG, Campagni WV. Physical properties of acrylic resin polymerized by four different techniques. J Prosthet Dent. 1985 Oct;54(4):522-4. http://dx.doi.org/10.1016/0022-3913(85)90425-1. PMid:3862809.

15. Mazzeto MO, Hotta TH, Mazzetto RG. Analysis of TMJ vibration sounds before and after use of two types of occlusal splints. Braz Dent J. 2009;20(4):325-30. http://dx.doi.org/10.1590/S0103-64402009000400011. PMid:20069257.

16. Benli M, Gümüş BE, Kahraman Y, Gökçen-Rohlig B, Evlioğlu G, Huck O, et al. Surface roughness and wear behavior of occlusal splint materials made of contemporary and high-performance polymers. Odontology. 2020 Apr;108(2):240-50. http://dx.doi.org/10.1007/s10266-019-00463-1. PMid:31612354.

17. Wedekind L, Güth JF, Schweiger J, Kollmuss M, Reichl FX, Edelhoff D, et al. Elution behavior of a 3D-printed, milled and conventional resin-based occlusal splint material. Dent Mater. 2021 Apr;37(4):701-10. http://dx.doi.org/10.1016/j.dental.2021.01.024. PMid:33648744.

18. Astudillo-Rubio D, Delgado-Gaete A, Bellot-Arcís C, Montiel-Company JM, Pascual-Moscardó A, Almerich-Silla JM. Mechanical properties of provisional dental materials: a systematic review and meta-analysis. PLoS One. 2018 Feb;13(2):e0193162. http://dx.doi.org/10.1371/journal.pone.0193162. PMid:29489883.

19. Prpić V, Schauperl Z, Ćatić A, Dulčić N, Čimić S. Comparison of mechanical properties of 3D-Printed, CAD/CAM, and conventional denture base materials. J Prosthodont. 2020 Jul;29(6):524-8. http://dx.doi.org/10.1111/jopr.13175. PMid:32270904.

20. Lutz AM, Hampe R, Roos M, Lümkemann N, Eichberger M, Stawarczyk B. Fracture resistance and 2-body wear of 3-dimensional-printed occlusal devices. J Prosthet Dent. 2019 Jan;121(1):166-72. http://dx.doi.org/10.1016/j.prosdent.2018.04.007. PMid:30647000.

21. Väyrynen VO, Tanner J, Vallittu PK. The anisotropicity of the flexural properties of an occlusal device material processed by stereolithography. J Prosthet Dent. 2016 Nov;116(5):811-7. http://dx.doi.org/10.1016/j.prosdent.2016.03.018. PMid:27312654.

22. Hoy MB. 3D printing: making things at the library. Med Ref Serv Q. 2013;32(1):93-9. http://dx.doi.org/10.1080/02763869.2013.749139. PMid:23394423.

23. Grauer D. Quality in orthodontics: the role of customized appliances. J Esthet Restor Dent. 2021 Jan;33(1):253-8. http://dx.doi.org/10.1111/jerd.12702. PMid:33410248.

24. Fung L, Brisebois P. Implementing digital dentistry into your esthetic dental practice. Dent Clin North Am. 2020 Oct;64(4):645-57. http://dx.doi.org/10.1016/j.cden.2020.07.003. PMid:32888514.

25. Salmi M, Paloheimo KS, Tuomi J, Ingman T, Mäkitie A. A digital process for additive manufacturing of occlusal splints: a clinical pilot study. J R Soc Interface. 2013 Apr;10(84):20130203. http://dx.doi.org/10.1098/rsif.2013.0203. PMid:23614943.

CONFLICTS OF INTERESTS

The authors declare no conflicts of interest.

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