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# Evaluation of the mechanical properties of different materials for manufacturing occlusal splints


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**Abstract:** This study aimed to compare the mechanical properties of various occlusal plate materials by analyzing surface roughness, Knoop microhardness, flexural strength, and modulus of elasticity. Fifty samples were prepared and classified as SC (self-curing acrylic resin), WB (heat-cured acrylic resin), ME (acrylic resin polymerized by microwave energy), P (resin print), and M (polymethylmethacrylate polymer block for computer-aided design/computer-aided manufacturing). The data were analyzed using a one-way analysis of variance and Tukey's honestly significant difference test. Surface roughness was the same in all groups. The surface hardness of group M was statistically superior. The samples from groups P and M had higher flexural strength than other samples. The modulus of elasticity of group SC was statistically lower than that of other groups. The mechanical properties of the materials used to make the occlusal plates differed, and group M achieved the best results in all analyses. Therefore, clinicians must consider the material used to manufacture long-lasting and efficient occlusal splints.



**Keywords:** Bruxism; Occlusal Splints; Mechanical Tests.

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## Introduction

Bruxism is a group of disorders involving the temporomandibular joints (TMJs), masticatory muscles, which are primarily responsible for TMJ movement, and related structures characterized by the squeezing or grinding of teeth due to jaw immobilization or projection.[1-3] This event can occur while sleeping, as rhythmic (creaking) or non-rhythmic (squeezing) dental contact or while awake as repetitive or sustained dental contact and static or dynamic jaw contraction.[3,4] Occlusal splints are typically used to treat temporomandibular disorders symptoms and to prevent the harmful effects of bruxism in the stomatognathic system, particularly sleep bruxism, such as muscle and dental pain and dental elements fractures.[5,6]

In the literature, the mechanism of action of occlusal splints needs to be better established.[7] Some studies attribute therapeutic success to occlusal modification, which reduces bruxism effects.[8] Others refer to shifting the condyle position to achieve a more stable and higher load distribution in the TMJ.[9] However, there are no concerns due to the lack of uniformity among studies.[7]

For this therapy, occlusal splints can be made with conventional acrylic resins (self-curing, heat-curing, or microwave-polymerized acrylic resins), polymethylmethacrylate (PMMA) polymers made with a computer-aided design/computer-aided manufacturing (CAD/CAM) system, or materials made with 3D printers.[10] During parafunctional habits, the materials are constantly subjected to high occlusal effort, which can reach 785 N.[11] They must have adequate occlusal stability to withstand applied loads and the oral environment without changing their mechanical properties.[6,12]

With the advancement of digital technologies, new materials for the fabrication of occlusal splints are becoming available, and their mechanical properties may differ from those of conventional acrylic resins. Because of improved materials and fabrication methods, studies have reported that these new occlusal splint fabrication methods, such as printed resin and milled blocks in CAD/CAM, are efficient. However, to improve and favor long-term success for clinicians, it is critical to evaluate the efficacy of these new materials.[10]

This study aimed to compare the mechanical properties of various materials used to manufacture occlusal splints by analyzing the surface roughness, Knoop microhardness, flexural strength, and modulus of elasticity. The null hypothesis predicted that there would be no difference in the mechanical properties of the different materials tested.

## Methodology

According to ISO 20795-1, 50 samples were made with 64 × 10 × 3.3 mm (± 0.2 mm) dimensions, based on the material and method used to produce the occlusal plates (Table 1). The sample was drawn from a previous study.[13]

### Preparation of samples

Four 64 × 10 × 3.3 mm matrices (Smart Dent Bio Bite Splint; Smart Dent, Sao Carlos, Brazil) were printed on a 3D dental printer (Miicraft Ultra Series; Smart Dent, Sao Carlos, Brazil) as models for the inclusion of the muffles using special type IV plaster (Elite Dental Stone; Zhemarck, Badia Polesine, Italy) and laboratory condensation silicone (Reflex Lab; Yller Biomaterials, Pelotas, Brazil) for manufacturing the samples in the following groups: self-curing acrylic resin (SC), heat-cured acrylic resin (WB), and acrylic resin polymerized by microwave energy (ME). After the plaster crystallized, the muffles were opened, the matrices were removed, and the mold was obtained, which was filled with resins from SC, WB, and ME that were manipulated according to the manufacturers' recommendations.

In the SC group, the monomer and polymer were manipulated, inserted into the muffle molds, and polymerized for 20 min in a pressure cooker with 20 pounds of compressed air as recommended by the manufacturer. In the WB group, the manipulated resin was polymerized in a hot water bath at 70°C for 30 min and, subsequently, at 100°C for 1 hour and 30 min. In the ME group, the resin was manipulated and polymerized using microwave energy in a 900 W oven for 20 min at 20% power and then for 5 min at 60% power.

Group resin print (P) was manufactured in a virtual project using specific software (Exocad Dental CAD; Align Technology, San Jose, USA) and printed with resin (Smart Dent Bio Bite Splint; Smart Dent, Sao Carlos, Brazil) at an angle of 90° and 50 μm layer thickness on a dental 3D printer (Miicraft Ultra Series; Smart Dent, São Carlos, Brazil) and underwent post-processing with isopropyl alcohol for 5 min and exposure to UV light for 10 s. Group M samples were prepared from an experimental PMMA resin block (acrylic resin manipulated and polymerized at a temperature of 120°C and a pressure of 80 pounds of nitrogen) and milled using a milling machine (VHS S1) from the same virtual project used for group P.

All samples were finished and polished with sandpaper grains of 150, 220, 400, 600, 800, and 1000 (Microcut; Buehler, Lake Bluff, Illinois). After polishing, all samples were stored for 24 h in distilled water at 37 °C. Mechanical analyses were carried out.

**Table 1.** Description of the materials used to make the study samples.

| Group | Material | Method of manufacture | Trademark |
|---|---|---|---|
| SC | Self-curing acrylic resin | Self-curing | Jet® |
| WB | Heat-cured acrylic resin | Polymerized by water bath | Classic® |
| ME | Heat-cured acrylic resin | Polymerized by microwave energy | VipiWave® |
| P | 3D printing resin | Print | SmartDent Bite Splint® |
| M* | Polymethylmethacrylate (PMMA) block | Milling | PMMA block not sold |

*Made from a mixture of polymer and monomer and polymerized at a temperature of 120 °C and a pressure of 80 pounds of nitrogen

### Knoop microhardness

Knoop microhardness values were determined by applying a 25-g load to a microhardness device (HMV-2T; Shimadzu Corp., Kyoto, Japan) for 10 s. For each sample, three measurements were recorded for each sample.[14]

### Surface roughness (Ra)

A roughness meter was used to calculate the Ra (portable roughness meter SJ-411; Mitutoyo, Suzano, Brazil). Each sample was placed in the center of the apparatus, and the profilometer's measuring tip was focused on its surface. A reading was taken at random in the center of the specimen. Two parallel readings to the right and left of the center were taken, and the average was calculated after these three readings. Ra values (the arithmetic mean of Ra) were measured with a 300 μm sweep lasting 12 s.[15] The initial values were in angström (Å) and were converted to the nanometric scale (nm).

### Strength and flexural modulus

Each sample was flexed on the universal testing machine (EMIC model DL 3000; EMIC, Sao Jose dos Pinhais, Brazil) for the three-point flexural strength and modulus of elasticity test at a constant speed of 5 mm/min until a fracture occurred.[16] Flexural strength and modulus of elasticity were measured in MPa.

### Data analysis

One-way analysis of variance (ANOVA) was used to determine statistically significant differences between groups for surface roughness, Knoop microhardness, flexural strength, and modulus of elasticity. Tukey's honestly significant difference test was used to compare variables with statistical significance. All statistical analyses were done using statistical software (SPSS Statistics 17.0; SPSS Inc., Chicago, USA). A p-value $< 0.05$ was considered statistically significant.

## Results

Table 2 shows that the one-way ANOVA test showed a statistically significant difference in Knoop hardness, flexural strength, and flexural modulus. Table 3 shows all groups' mean values and standard deviations based on the test and the Tukey test results. When compared to other groups, group M and group P have the highest and lowest microhardness values, respectively. Regardless of the polymerization method, there was no significant difference between conventional acrylic resins. Groups P and M had higher mean values in the flexural strength tests; no significant differences were found between groups P and M. However, there was a significant difference in flexural strength between groups SC, WB, and ME. The SC group had lower modulus of elasticity values than the other groups. The milled resin showed superior mechanical properties in all tests.

## Discussion

The study's null hypothesis was partially accepted because the Ra test showed no statistically significant differences among the groups tested. However, the mechanical properties of the evaluated materials varied in the other tests.

Occlusal plate uniformity contributes to the patient's oral health and longevity.[17] A previous study reported that a Ra value of <0.2 μm does not affect the number of microorganisms or their

**Table 2.** One-way ANOVA results of surface roughness, microhardness, flexural strength, and modulus of elasticity tests.

| ANOVA | Sum of squares | df | Mean square | F | p-value |
|---|---|---|---|---|---|
| Surface roughness | | | | | |
| Type of resin | 0.016 | 4 | 0.004 | | |
| Error | 0.135 | 45 | 0.003 | 1,295 | 0.286 |
| Total | 0.150 | 49 | | | |
| Knoop hardness | | | | | |
| Type of resin | 678,872 | 4 | 169,718 | | |
| Error | 153,856 | 45 | 3,419 | 49,639 | < 0.001 |
| Total | 832,728 | 49 | | | |
| Flexural strength | | | | | |
| Type of resin | 40,245,761 | 4 | 10,061.440 | | |
| Error | 9,193,007 | 45 | 204,289 | 49,251 | < 0.001 |
| Total | 49,438,768 | 49 | | | |
| Flexural modulus | | | | | |
| Type of resin | 17,056,720.7 | 4 | 4,264,180.18 | | |
| Error | 11,895,232.3 | 45 | 264,338,495 | 16,132 | < 0.001 |
| Total | 28,951,953.0 | 49 | | | |

**Table 3.** The mean values (standard deviation) and Tukey test results for the tests showed a statistically significant difference in the one-way ANOVA.

| Tests | Groups | | | | |
|---|---|---|---|---|---|
| | SC | WB | ME | P | M |
| Surface roughness (μ m) | 0.08 (0.05)* | 0.09 (0.06)* | 0.07 (0.05)* | 0.15 (0.08)* | 0.1 (0.02)* |
| Knoop hardness (kgf/mm²) | 20.35 (1.14) A | 21.33 (1.08) A | 19.45 (1.43) A | 12.6 (3.29) B | 24.95 (1.32) C |
| Flexural strength (MPa) | 37.96 (4.97) A | 43.6 (8.25) A | 68.60 (14.74) B | 94.80 (20.05) C | 111.13 (17.59) C |
| Flexural modulus (MPa) | 1,251.35 (664.86) A | 2,634.41 (619.19) B | 2,665.26 (409.94) B | 2,365.39 (539.23) B | 2,915.22 (193.47) B |

Means followed by the same capital letter on the line do not differ at the 5% level of significance ($p < 0.05$) by the Tukey's honest standard deviation test. *There is statistically insignificant difference in the one-way ANOVA.

pathogenicity.[18] The Ra test revealed no statistically significant differences between groups in this study. The variation ranged from 0.07 μm for group ME to 0.15 μm for group M. Another comparative study reported differences between heat-cured acrylic resin and microwave-cured acrylic resin groups; when compared to self-curing acrylic resin, the latter had higher Ra values than the others.[19] Because of the amount of residual monomer in self-curing resin, it facilitates the formation of pores and impairs the mechanical properties of this group.[20]

The mean Ra value of 0.1 μm found in this study for milled PMMA samples was similar to that found in another study, which found a value of 0.192 μm for the same variable.[10] Because there is no standardization in polishing, the roughness variable is quite inconsistent in the literature, resulting in divergent mean values.[16] The results of this study showed that Ra is standardized using the polishing technique, regardless of the material used to manufacture the occlusal plates.

The Knoop hardness test analyzes the microhardness of various materials using a tool with a diamond tip.[21] These data describe the material's resistance to forces, which is critical for occlusal splints that receive a high force load in function.[22] In this study, group M had a higher microhardness than the other groups. In previous studies, milled PMMA samples yielded similar and favorable results. [23] These blocks are industrially polymerized at high temperatures and pressures, resulting in improved chemical, mechanical, and aesthetic properties.[24] There was no significant difference compared to conventional acrylic resins, which contradicts the previous study.[25] The heat-curing resin group had a higher hardness. Polished samples can explain this distinction in water, which reduces the hardness of these heat-curing resins due to the water sorption phenomenon.[25,26]

Meanwhile, because the additional polymerization that this material underwent compensated for the water sorption phenomenon, the hardness of self-curing resins increased during this mechanical polishing process.[26,27] A previous study reported that printed resins had lower hardness values than milled and conventional acrylic resins [28]. These findings could be explained by water storage, which reduces the hardness of printed materials[29] with high water uptake capacity after manufacturing.[30]

The fracture resistance of a sample is referred to as its flexural strength.[31] In this study, the results were statistically similar between group P and group M and higher than those of the other groups. Milled PMMA samples had higher flexural strength than printed samples[32], but this difference was not statistically significant in this study. Although there was no statistical difference, the PMMA block fabrication method reduced the formation of pores and errors compared to the printed samples group.[30] A previous study reported that the acrylic resins polymerized by microwave (group ME) performed better than other acrylic resins.[33] Although there was no statistical difference between the microwave-polymerized acrylic resins and other conventional acrylic resins, the microwave-polymerized acrylic resins had higher flexural strength values.[33] Similar results may have occurred between groups SC and WB because pressure is used in the curing process in group SC, which can improve the fracture resistance of this resin due to less pore formation and overestimate its properties compared to other studies.[34]

A high modulus of elasticity allows the material to better resist the forces applied to it, which is essential for manufacturing occlusal plates subject to forces >785 N.[11] The modulus of elasticity was similar between groups WB, ME, P, and M and was statistically higher than that of group SC. According to this study. The mechanical properties of self-curing resin samples are worse in most analyses (hardness, flexural strength, and elastic modulus) because this material contains more residual monomer, which affects their mechanical properties.[20]

The polymerization method of samples made with self-curing acrylic resin was one of the study's limitations. The manufacturer recommends that polymerization be performed in a pressure cooker with 20 pounds of compressed air for 20 min. Most studies only performed polymerization on the bench; hence, compared to other studies, this work may have overestimated the mechanical properties of the self-curing acrylic resin.[33] Another limitation can be found in the sample polishing sequences. Metal polishing sandpaper granulations of 150, 220, 400, 600, 800, and 1000 were used to finish the samples in this study. However, other studies recommend mechanical polishing in a vise with pumice paste, lime powder, a soft brush, and a felt cone. [18] Another limitation is that important methodologies were not carried out, such as degree of conversion, scanning electron microscopy analyses, color stability, and others. Finally, few studies have compared the mechanical properties of acrylic resins based on the polymerization method. Therefore, additional studies are required to provide strong evidence for the findings of this study.

## Conclusion

According to the results of this study, there was a difference in the mechanical properties of the materials used to manufacture occlusal splints, with milled resin outperforming the others in analysis.

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