UNIVERSIDADE DE SÃO PAULO

FACULDADE DE ODONTOLOGIA DE BAURU

OSCAR OSWALDO MARCILLO TOALA

# Mechanical properties of CAD-CAM blocks for base denture prosthesis after chemical disinfection protocols

# Propriedades mecânicas dos blocos CAD-CAM para base de dentadura após ciclos de desinfecção química

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Tese constituída por artigos apresentada a Faculdade de Odontologia de Bauru da Universidade de São Paulo para obtenção do título de Doutor em Ciências no Programa de Ciências Odontológicas Aplicadas, na área de concentração Reabilitação Oral

Orientador: Prof. Dr. Vinicius Carvalho Porto

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# ERRATA

**FOLHA DE APROVAÇÃO**

## DEDICATÓRIA

Este trabalho foi produto de muitos anos de esforço e dedicação, formado em 2009, quando formei da faculdade e comecei a busca de uma Odontologia diferente, baseada na ciência e direcionada pela aplicabilidade clínica.

Em primeiro lugar, dedico este trabalho a Deus, só com ele foi possível resolver muitos desafios e problemas, assim como alegrias e emoções. Só Ele sabe que acredito que tudo tem um significado na vida e nada acontece por acaso.

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*“A educação é o passaporte para o futuro, amanhã pertence a quem se prepara hoje”.*

***Malcom X***

**RESUMO**

A inovação dos procedimentos computadorizados levou a confecção de blocos de poli-metilmetacrilato (CAD/CAM PMMA blocos) para base dentadura, monstrando ótimas propriedades mecânicas e biológicas, uma melhor adaptação, e procedimentos com reduzido numero de atendimentos. No entanto, os protocolos de desinfecção são necessários com o intuito de remover o biofilme na superfície protética. O efeito destes desinfetantes é muito discutido na literatura mostrando diversos efeitos sobre as propriedades mecânicas e superficiais das resinas em função da concentração, tempo de imersão, e tipo de solução. O objetivo deste trabalho foi avaliar o efeito a curto e longo prazo de soluções desinfetantes nas propriedades mecânicas e superficiais da resina CAD/CAM PMMA para base de dentadura. As resinas testadas foram VIPI Gum Block (CAD/CAM PMMA) (VIPI) e VIPI Cril Plus (Convencional PMMA)(VIPI) e as soluções desinfetantes foram: Grupo controle: Água deionizada; H1= Hipoclorito de sódio 1%; H05= Hipoclorito de sódio 0,5%; e C2= Gluconato de clorexidina 2%. Foram confeccionados 140 corpos de prova (12x12x3mm) direcionada para microdureza (KHN) e rugosidade (Ra) (n=10); e 280 corpos de prova (65x10x3 mm), direcionados para resistência Flexural (RF) e módulo de elasticidade (ME) (n=10). Cada ciclo de desinfecção representava 10 minutos em cada solução e os tempos avaliados foram: 0 (inicial), 14, 30, 130 e 260 ciclos. Os testes estatísticos para KHN e Ra foi ANOVA medidas repetidas e, posteriormente ,o teste de Tukey HSD com nível de significância 5%. Para a RF e ME, a estatística empregada foi ANOVA 3 criterios e teste de Tukey para comparações entre grupos, adotando um nível de significância de 5%. O primeiro trabalho avaliou o efeito a curto prazo das soluções desinfetantes sobre as propriedades superficiais da resina. Os valores Ra não mostraram diferença significante das resinas quando expostas nas soluções durante o período avaliado ($p>0,05$). No entanto, na KHN a CAD/CAM PMMA mostrou-se superior à convencional quando imersa em todas as soluções ($p<0,05$) em todos os tempos ($p<0,05$). O segundo artigo avaliou o efeito ao longo prazo das imersões em soluções desinfetantes da resina CAD/CAM. Nas propriedades superficiais, a KHN mostrou diferença significante no tipo de resina ($p<0,000$), tempo ($p=0,002$) e a interação solução*resina ($p<0,000$). A Ra mostrou uma diferença significante no tipo de solução ($p=0,007$). Na RF, a resina foi determinante no resultado em Mpa ($p=0,001$), o tempo foi outro fator relevante

(p=0,032), e a interação solução*resina (p=0,008). No ME, os fatores relevantes foram: resina (p=0,001), tempo (p=0,032), e solução*resina (p=0,008). A resina CAD/CAM PMMA mostrou valores iniciais superiores na KHN e RF, a Ra e ME semelhante à resina Convencional PMMA. No entanto, quanto maior a exposição (ciclos) da resina às soluções desinfetantes, os testes de KHN, RF e ME mostraram valores superiores da resina Convencional PMMA com diferença significante. Dentro das limitações deste estudo, a resina CAD/CAM PMMA mostrou propriedades favoráveis de acordo com cada experimento realizado e as soluções desinfetantes (H1, H05 e C2) não afetaram negativamente a resina ao longo do tempo.
Palavras-chave: Desenho assistido por computador (CAD). Manufatura assistida por computador (CAM). Poli metil metacrilato (PMMA). Base de dentadura

## ABSTRACT

**Mechanical properties of CAD/CAM blocks for base denture prosthesis after chemical disinfection protocols**

The innovation of computerized procedures led to the manufacture of polymethylmethacrylate blocks (CAD/CAM PMMA blocks) for denture base, showing excellent mechanical and biological properties, better adaptation, and reduced number of attendances. However, disinfection protocols are necessary in order to remove the biofilm on the prosthetic surface. The effect of these disinfectants is widely discussed in the literature, showing several effects on the mechanical and surface properties of resins depending on the concentration, immersion time, and type of solution. The objective of this work was to evaluate the short and long term effect of disinfectant solutions on the mechanical and surface properties of CAD/CAM PMMA resin for denture base. The tested resins were VIPI Gum Block (CAD/CAM PMMA) (VIPI) and VIPI Cril Plus (Conventional PMMA) (VIPI) and the disinfectant solutions were: Control group: Deionized water; H1 = 1% sodium hypochlorite; H05 = 0.5% sodium hypochlorite; and C2 = 2% chlorhexidine gluconate. One hundred and forty specimens were made (12x12x3mm) for microhardness (KHN) and roughness (Ra) tests ($n = 10$); and 280 specimens (65x10x3 mm), for Flexural Strength (FS) and Flexural Modulus (FM) ($n = 10$). Each disinfection cycle represented a 10 minutes immersion in each solution and the evaluated times were: 0 (initial), 14, 30, 130 and 260 cycles. The statistical tests for KHN and Ra were repeated-measures ANOVA and, subsequently, the Tukey HSD test with a significance level of 5%. For FS and FM, the statistics used was 3-Way ANOVA and Tukey's test for multiple comparisons, adopting a significance level of 5%. The first work evaluated the short-term effect of disinfectant solutions on the surface properties of the resin. The Ra test showed no significant difference in resins when exposed to the solutions during the evaluated period ($p > 0.05$). However, the KHN test showed that CAD/CAM PMMA was superior to conventional when immersed in all solutions ($p < 0.05$) at all times ($p < 0.05$). The second article evaluated a long-term effect of CAD/CAM PMMA resin immersed in the solutions. In surface properties, KHN showed a significant difference in the type of resin ($p < 0.000$), time ($p = 0.002$) and the solution * resin interaction ($p < 0.000$). The Ra showed a significant difference in the type of solution ($p = 0.007$). In RF, the resin was decisive in the result in Mpa ($p = 0.001$), the time was another relevant factor ($p = 0.032$), and the

solution*resin interaction (p = 0.008). In the ME, the relevant factors were: resin (p = 0.001), time (p = 0.032), and solution * resin (p = 0.008). The CAD/CAM PMMA resin showed higher initial values in KHN and FS, Ra and FM similar to the conventional PMMA resin. However, the greater the exposure (cycles) of the resin to disinfectant solutions, the KHN, FS and FM tests showed higher values of the conventional PMMA resin with a significant difference. Within the limitations of this study, the CAD/CAM PMMA resin showed favorable properties according to each experiment performed and the disinfectant solutions (H1, H05 and C2) did not negatively affect the resin over time.
Keywords: Computer-aided design (CAD). Computer-aided manufacturing (CAM). Poly methyl-methacrylate (PMMA). Base denture.

## LISTA DE ABREVIATURA E SIGLAS

| | |
|---|---|
| PMMA | Poli Metil Metacrilato |
| CAD | Desenho assistido por computador |
| CAM | Manufatura assistida por computador |
| KHN | Microdureza Knoop |
| Ra | Rugosidade |
| µm | Micrometro |
| Mpa | Megapascal |
| CD | Complete denture (dentadura) |
| DS | Denture Stomatitis (Estomatitis) |
| *C. albicans* | *Cândida albicans* |
| SDJ | Saudi Dental Journal |
| JPD | Journal of Prosthetic Dentistry |
| ANOVA | Analysis of Variance |
| HSD | Honestly Significance Difference |

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# 1 Introduction

# 1 INTRODUCTION

The introduction of computer-aided design (CAD) and computer-aided manufacturing (CAM) in dentistry has helped the clinicians indicate a new presentation of dental materials with better mechanical, physical and biological properties, as well as reduced appointments.[1,2,3] Even though the implant therapy has been recognized as an excellent alternative for complete, partial, or single replacement of tooth and related-structures, complete dentures (CD) are still a treatment option for edentulism when the patient is not suitable for implant therapy due to a compromised health condition, financial limitations or phycological factors. [1] Since 1937, the poly-methyl methacrylate (PMMA) have been used for the fabrication of CD in the majority of cases except patients with allergy or hospitalized condition. [1,4,5] The PMMA is a synthetic thermoplastic polymer composed by the reaction of methyl-methacrylate monomers: [1] the interaction of powder (microspheres of pre-polymerized PMMA, benzoyl peroxide and pigments) and liquid (monomer, cross-link agents, plasticizers and stabilizers compounds). [6,7,8] The PMMA can be classified according to the polymerization process: Chemical polymerization, which is initiated by the reaction of a tertiary amine; and Heat polymerization, which includes a thermal bath with or without pressure, and microwave polymerization. [7] In the last decades, pre-polymerized blocks have been introduced that could be milled based on a CAD/CAM project. [1,2,3] The PMMA is widely accepted in many fields of dentistry, it could be indicated for temporary crowns, surgical guides, occlusal appliances, and CD. [1,7]

One of the critical tasks for CD wearers is the adequate cleansing of the prosthesis, mainly the inner surface that directly contacts the patient´s mucosa. [1,9,10] A poor hygiene would lead to microbial adherence and superficial colonization of the prosthetic device, and facilitate a mucosa alteration known as Denture Stomatitis (DS). [1] DS is a multifactorial condition, frequently associated to *Candida albicans* development within the PMMA, and could migrate to the oral mucosa. [9,10] Researches have appointed that mechanical removal of microorganisms (brushing) is the best hygiene method removing the adhered plaque on the acrylic resin. [3] However, some patients might experience limited motor skills and would need an additional mechanism for cleansing, such as chemical solutions or physical disinfection. [9,10] Additionally, literature detailed one problem related to this pathogen (*Candida albicans*), which could be allocated in the resin a depth of 631μm [11]; making imperative the use of an associated mechanism for the correct cleansing and disinfection of the CD. [10]

Chemical disinfection have been categorized as a fast, low cost, and secure protocol of decontaminating the base denture. [10] But, there is no consensus about the best solution in terms of composition, concentration, time of immersion, and the deleterious effect of the mechanical and surface properties generated after continuous disinfection. [10] The most common solutions used in dentistry are sodium hypochlorite (varying from 0,5 to 2,5%), chlorhexidine gluconate (2 or 4%), peracetic acid and vinegar; and the immersion time would vary from 10 minutes to 8 hours disinfection cycle. [9,10,12] Other approaches included the microwave disinfection (physical disinfection), application of coating (cyanoacrylates or related-coatings) and photodynamic therapy, all of them, trying to reduce the microbial colonization and harmless disinfection on mechanical properties of the PMMA. [1,13,14] Current literature referred that the chemical solution would disinfect the irregularities on the resin microtopography (peaks and valleys) whereas the brushing might not have access, and the ability to penetrate in the PMMA matrix. [9,12] The previous statement confirmed the need for studying the effect of continuous exposure of PMMA to chemical disinfection solutions on the superficial characteristics and mechanicals aspects.

The CAD/CAM technology facilitate a new possibility to deliver a CD, which could mill the base denture from CAD/CAM PMMA block and, subsequently, fix pre-fabricated teeth, or produce a complete denture (teeth and base) from monoblock pucks. [6] Maeda et al. (1994) published the first paper of a CD fabricated by CAD/CAM technology using a 3D lithography machine through an additive process. [6] Therefore, a new wave of researches have been carried on to identify the benefits, limitations, and advantages of this material (CAD/CAM PMMA) under certain conditions: thermal cycling, coffee staining, water storage, and mechanical, biological, optical and surface properties. [8,15] According to literature, one of the main advantages of CAD/CAM PMMA blocks is the manufacturing condition under high temperature and controlled pressures, producing a dense polymer with a low monomer release rate and porosity. [6] This condition might produce a resin with higher mechanical and superficial characteristics, even higher than conventional PMMA. [16] Many papers have demonstrated that CAD/CAM PMMA did have higher microhardness values and a smoother surface than conventional ones, as well as higher initial flexural properties and after an accelerated thermal aging protocol. [2,3,16] However, the effect of chemical disinfection on these characteristics of CAD/CAM PMMA has not yet been studied.

Based on these statements, the objectives of the present study were to evaluate the flexural and surface properties of CAD/CAM PMMA blocks after chemical disinfection during a short and long-term analysis. The first null hypothesis was that the flexural properties and superficial characteristic of CAD/CAM PMMA resin have no difference to Conventional PMMA. The second null hypothesis was that CAD/CAM PMMA resin is not affected by chemical solutions through time.

# 2 Articles

# 2 ARTICLES

The present research allowed the drafting, discussion and production of two manuscripts, which have been submitted to the journal detailed:

1. Does chemical disinfection affect the superficial properties of CAD CAM resin blocks?. Saudi Dental Journal. **SDENTJ_2020_418**. Proof document in Annex 1
2. Does continuous chemical disinfection affect mechanical properties of CAD/CAM PMMA. Journal of Prosthetic Dentistry. **JPD Draft.** Proof document in Annex 2

## 2.1 ARTICLE 1 Does chemical disinfection affect the superficial properties of CAD CAM resin blocks

**TITLE:**

Does chemical disinfection affect the superficial properties of CAD CAM resin blocks?

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**ABSTRACT:**

Complete dentures are being fabricated by computer-aided design and computer-aided manufacturing (CAD CAM) showing high mechanical and superficial properties. The purpose of this study was to evaluate the effect of chemical disinfection on the superficial roughness (Ra) and Knoop hardness (KHN) of a CAD CAM resin block after 14 and 30 immersion cycles. Quadrangular specimens (12x3mm) were divided into 2 groups: Control Group (n=10)(heat and pressure controlled polymerization, Vipi Cril Plus, VIPI®) and a CAD CAM group (n=10)(pre-polymerized resin pucks, Vipi GUM, VIPI®). The immersion solutions were Control Group (deionized water), H1 (Sodium hypochlorite 1%) and C2 (chlorhexidine gluconate 2%). The immersion cycles were evaluated according to: Baseline (0 cycles), T1 (14 cycles) and T2 (30 cycles). Measurements were applied on a contact profilometer (Roughness, Ra) and a hardness tester (Knoop microhardness, KHN). The results were analyzed using a 3-way ANOVA and a Tukey HSD pos hoc test ($p=0.05$). Roughness: At Baseline, the CAD CAM (0,17±0,02$\mu$m) showed no difference to conventional (0,18±0,01$\mu$m) resin. At T2, CAD CAM resins exposed to CG and H1 showed a reduction on Ra values, with significant difference among the solutions ($p<0,00$), groups ($p<0,00$), and their interaction with time ($p<0,01$). Microhardness: CAD CAM resin showed higher value (20,3±0,5 KHN) than conventional resin (18,6±0,5 KHN). CG and H1 did not affect KHN values ($p>0,05$) for both resins, but there was a significant difference between groups ($p<0,00$), time ($p<0,00$) and time*solution ($p<0,00$). However, the C2 reduced the KHN values for both resins at T1, and it was restored at T2. Disinfection solutions (H1 or C2) did not affect adversely roughness or hardness of the CAD CAM resin. Both tested materials demonstrated values above minimal clinical requirements.

*Key words:* Computer-aided design, Computer-aided manufacturing, base denture, disinfection, microhardness, roughness

## 1. INTRODUCTION

In the last years, even with the implant-retained or screwed therapy (Saeed et al., 2020), complete dentures (CD) are still an indicated procedure to restore dental and associated structures in edentulism (Papadiochou and Polyzois, 2018). The main material is the poly-methyl-methacrylate (PMMA) and its application for dental purposes has been reported since 1937 (Papadiochou and Polyzois, 2018). The PMMA has many advantages: dimensional stability, biocompatibility, adequate mechanical properties, good superficial characteristics, cleansable, low cost, easy manipulation, low monomer release percentage and easy repair (Papadiochou and Polyzois, 2018; Perea-Lowery et al., 2020; Saeed et al., 2020). This material could be indicated in many fields such as CD, baseliners, provisional restorations, occlusal and surgical appliances (Saeed et al., 2020).

The oral environment is a difficult survival task for dental materials due to the conditions they have to overcome: temperature changes, disinfection protocols, pH values, biological adherence and occlusal forces (Silva et al., 2008; Schwindling et al., 2014). Based on these challenges, as the acrylic resin aged, it should be frequently cleaned and disinfected, to prevent Denture Stomatitis, a mucosal pathology that compromises denture wearers (Silva et al., 2008; Schwindling et al., 2014; Papadiochou and Polyzois, 2018).

According to literature, mechanical cleansing such as brushing or ultrasonic devices could remove the majority of adhered biofilms (Saeed et al., 2020). But they would not reach penetrated microorganisms (*C. albicans*: 631 $\mu$m) within the resin (Latib et al., 2018). Literature has established a need for a complementary cleansing procedure that could effectively remove fungal cells from the irregularities and surface topography (Papadiochou and Polyzois, 2018; Latib et al., 2018; Saeed et al., 2020). Chemical disinfection, microwave disinfection, coatings, and photodynamic therapy have been addressed to fulfill this objective (Silva et al., 2008; Schwindling et al., 2014; Papadiochou and Polyzois, 2018).

In general terms, repeated disinfection protocols would generate an aging effect leading to a negative outcome on its physical properties (Silva et al., 2008; Schwindling et al., 2014). Based on this fact, one of the cleansing protocols is the immersion in chemical solutions in different concentrations such as sodium hypochlorite, chlorhexidine, vinegar and peracetic acid, but chemical solution interacting with the base denture might initiate an adverse mechanical or superficial change (Schwindling et al., 2014). Literature is not clear about the solution´s concentration, time exposure, and disinfection intervals (Schwindling et al., 2014). However, the unpleasant interaction would enhance the mechanical reservoir for oral pathogens (higher roughness values) or diminish its resistance to masticatory cycles (lower hardness and flexural strength values), affecting the survival rate of the prosthesis (Schwindling et al., 2014; Latib et al., 2018). Available literature showed that two of the main solutions with higher control of biofilm colonization are: 1% sodium hypochlorite and 2% chlorhexidine gluconate against *C. albicans* and other bacterial species (Silva et al., 2008; Hashizume et al., 2015).

Computer-aided design and computer-aided manufacturing (CAD-CAM) materials have been widely applied to replace the partial or complete absence of oral-related structures (Papadiochou and Polyzois, 2018; Perea-Lowery et al., 2020; Arslan et al., 2018; Javena Mihajlo et al., 2018). In 1994, Maeda et al., introduced the first study of CAD-CAM technology applied to complete dentures through an additive process using a 3-D lithography machine.

Since its dental application, many papers have addressed advantages when using this technology within many aspects such as a low number of appointments, better fit, superior mechanical and physical properties and fewer teeth movement (Javena Mihajlo et al., 2018). PMMA CAD-CAM denture blocks are fabricated under high controlled pressure and heat resulting in a condensed resin puck, minimal shrinkage, porosity or free monomer release (Arslan et al., 2018; Javena Mihajlo et al., 2018; Perea-Lowery et al., 2020; Saeed et al., 2020). Its application has shown remarkable adaptation, higher mechanical and superficial values and, consequently, low count biofilm adherence (Arslan et al., 2018; Javena Mihajlo et al., 2018; Alp et al., 2019; Perea-Lowery et al., 2020; Saeed et al., 2020). Roughness provides information about superficial irregularities, plaque accumulation, patient discomfort and high staining rate (Ayaz et al., 2015; Panariello et al., 2015; Arslan et al., 2018; Javena Mihajlo et al., 2018; Al-Dwairi et al., 2019; Murat et al., 2019; Perea-Lowery et al., 2020; Saeed et al., 2020). It has been established that initial Ra values under the roughness threshold of 0,2 $\mu$m makes the surface clinically acceptable (Ayaz et al., 2015; Panariello et al., 2015). Hardness would provide a characteristic of the density of the material and its resistance to wear (Schwindling et al., 2014; Panariello et al., 2015; Javena Mihajlo et al., 2018) and how it would resist to an indentation or permanent penetration (Schoeffle et al., 2019; Perea-Lowery et al., 2020).
Even though these CAD-CAM blocks have been tested under conventional (Ayaz et al., 2015) and coffee (Alp et al., 2019) thermocycling, the roughness values have remaining stable during the evaluated time (Ayaz et al., 2015; Alp et al., 2019). Unfortunately, there is still no data about the behavior of CAD-CAM resin blocks under continuous disinfection in roughness and microhardness values.
The purpose of this *in vitro* study was to evaluate superficial roughness and microhardness, of CAD-CAM denture blocks after continuous disinfection. Two null hypotheses were established: 1) CAD-CAM resin blocks have similar values than Conventional PMMA; and 2) CAD-CAM resin blocks are not affected by chemical disinfection solutions.

## 2. MATERIALS AND METHODS

### 2.1. SAMPLE PREPARATION

Ten specimens were fabricated for each resin (**Table 1**). For the conventional resin group, ten silicon patter (Zeta Labor, Zhermark SPa, Italy) (12x12x3,5mm) were obtained from a stainless steel matrix with constant pressure (5KgF). The molds were flasked in stone gypsum and the acrylic resin was packed according to fabricant specifications (**Table 1**). Therefore, the specimens were deflasked and excesses were removed. For the CAD-CAM group, the specimens were kindly supplied by VIPI®, milled into the final dimensions. The specimens were polished both sides using a 600 and 1200-silicon grid carbide paper under constant irrigation in a multiple device polisher (ER 27000; Erios, Sao Paulo, SP, Brazil) for 25 seconds with 120gr-vertical load (Silva et al., 2016). The Ra standardization was established according to 0,2 $\mu$m under a contact profilometer Marsurf XCR 20 (Mahr Metrology, Mahr Metering Systems GmbH, Göttingen, Germany) (Schoeffle et al., 2019). After polishing, the specimens were ultrasonically cleaned and were stored at 37ºC for 48 hours according to ISO 1567:1988 (International Organization for Standardization Specification 1567, 1988) (Neppelenbroek et al., 2005; Silva et al., 2016).

TABLE A

2.2. ROUGHNESS TEST

The experiment was held on a contact profilometer Marsurf XCR 20 (Mahr Metrology, Mahr Metering Systems GmbH, Göttingen, Germany) obtaining five horizontal lectures with 5 mm distance, a 0,8mm wavelength and 0,5 mm/s speed within a 1 mm distance between each recording. Therefore, the mean of peak-to-valley distances was calculated by a software MarWin (Mahr Metering Systems GmbH, Göttingen, Germany) (Pinto et al., 2010).

MICROHARDNESS TEST

A microhardness tester HMV-2000 (Shimadzu Corporation, Tokyo, .Japan) was used and the results were executed by a software C.A.M.S. (Computer Assisted Microhardness System, Newage Testing Instruments Inc, United States). The selected hardness value was the Knoop (KHN), determined by a diamond pyramidal shape test point under vertical static load (25 gr) for 10 seconds under a 40x magnification. Three indentations were recorded within a distance of 500 $\mu$m and an average value was calculated for each specimen (Pinto et al., 2010).

2.3. DISINFECTION PROTOCOL

Chemical disinfection solutions, brand and immersion time are displayed in **Table 2**. The disinfection cycle was established as a 10 minutes immersion at room temperature (Pinto et al., 2010; Schwindling et al., 2014; Silva et al., 2016). Therefore, the periods were: Baseline (0 cycles), T1 (14 cycles) and T2 (30 cycles).

TABLE B

2.4. STATISTICAL ANALYSIS

The analysis was performed on IBM SBSS Statistics v25.0 program (IBM Corp, New York, United States) using a 3-way analysis of variance (ANOVA) and the Tukey Honestly Significant Difference (HSD) pos hoc test, all tests were applied with a significant level of 5%.

## 3. RESULTS

3.1. Roughness Test

The roughness of CAD/CAM resins showed a variation different from the solution affecting each resin in different ways. According to the 3-way ANOVA, there was an interaction between the time, the solution, the group and all of them together (see **Table4**). Descriptive statistics and the Tukey HSD pos hoc test showed that CAD/CAM resin immersed in H1 increased its Ra at T1, but at T2 was restored to baseline; however it was significant lower than conventional PMMA at the end of the experiment. C2 did not affect both tested resins though time with no significant different between them ($p>0,05$). On the other hand, CG (deionized water) reduced Ra of CAD/CAM resin at T2 (0,16 $\mu$m) being significant different to Conventional PMMA (0,21 $\mu$m)

TABLE C

TABLE D

3.2. Microhardness test

According to the 3-way ANOVA test, there was a significant difference of the tested resins and the time also influenced the KHN values of the resins (see **Table6**). In the descriptive statistics, CAD/CAM resin showed a higher value than Conventional resin during the whole experiment. However, in C2 were observed an interaction that negatively affected both resins at T1, but at T2 those values were restored to Baseline.

TABLE E

TABLE F

# 4. DISCUSSION

According to the present results, CAD CAM resin showed a superior KHN value and similar Ra values than conventional resin. Therefore, first hypothesis was partially accepted. As chemical disinfection was held, tested resins showed a different behavior according to each test and among the solutions: CG and H1 reduced surface roughness and did not affect microhardness values, however, C2 did not affect Ra but the KHN was affected through time. The second hypothesis was partially accepted.

4.1. Roughness Test

Roughness is a property based on the adequate polishing and the maintenance of a stable superficial polymeric structure (Schwindling et al., 2014). In the present study, the roughness was established under the criteria of 0,2 $\mu$m threshold for Candida colonization (Schwindling et al., 2014), receiving the same protocol to maintain its clinical acceptance: Conventional (0,19±0,04$\mu$m) and CAD-CAM (0,17±0,04$\mu$m). However, no significant difference was found in the groups at baseline.

In terms of chemical disinfection, this protocol would initiate an internal reaction of the resin working as an initiator, plasticizer and promoting free monomer or it could be an absorption of the aqueous disinfectant solution making the resin softer altering the polymeric network and its physical and mechanical properties (Schwindling et al., 2014; Panariello et al., 2015). However, there is no consensus about the characteristics of the chemical disinfectants: concentration, type of solution, exposure time and temperature (Neppelenbroek et al., 2005; da Silva et al., 2011; Fernandes et al., 2013; Schwindling et al., 2014). Previous researches have reported that no damage to the surface using 1% sodium hypochlorite was observed (Fernandes et al., 2013; Paranhos et al., 2013). Probably one the differences was the exposure time with an overall of 60 minutes immersion (Fernandes et al., 2013). Another study tested a base denture resin with a 60h immersion with no difference in surface roughness (Paranhos et al., 2013). When testing chlorhexidine, some authors did not find an alteration on the roughness values when a heat polymerized resin was submitted to 2% chlorhexidine gluconate under the same protocol (Machado et al., 2012). Within this scenario, higher exposure time would create a degradation of the polymeric chains or the absorption enhancing the superficial alterations (Schwindling et al., 2014). Exposing the acrylic resin to three different solutions 0,5 and 1% sodium hypochlorite and 0,12% sodium polymetaphosphate with a longer immersion protocol (60 days), the authors found a significant difference in the superficial roughness after this prolonged time (Davi et al., 2010). This fact was also confirmed by a recent study, a daily disinfection (8 hours) for consecutive 183 days was conducted, and this continuous immersion protocol did create higher Ra values on the acrylic resin (Procopio et al., 2018).

In our research, C2 did not affect the superficial roughness of both resins, CAD-CAM and Conventional, through time; whereas the H1 and CG created a smoother surface at the end of the experiment in the CAD CAM resin ($p<0,05$), and they did not affect Ra on Conventional resin. The reason for these values could be explained by the polymerization method in high temperatures and pressure, making a more homogeneous polymer (Fernandes et al., 2013; Schwindling et al., 2014) with lower residual monomer (Fernandes et al., 2013; Schoeffle et al., 2019) and reducing pore formation leading to an enhance surface property (Fernandes et al., 2013; Schoeffle et al., 2019). Therefore, none of the chemical solution used in the present study negatively affected the surface roughness of the CAD CAM resin.

## 4.2. Microhardness Test

Hardness values are important because of its significance in terms of resistance to wear and density properties (Perea-Lowery et al., 2020). This research revealed that CAD-CAM resins have superior values (20.30±0,50 KHN) when compared to conventional resin (18,60±0,50 KHN) ($p<0,000$), but both resins were above the specification 15 Knoop for clinical acceptance (Goiato et al., 2013). The results are coincident with other studies (Al-Dwairi et al., 2019) where CAD-CAM resins showed superior hardness values: Avadent (20,60±0,33 KHN) and Schütz (19,80±1,08 KHN) than the control group (18,09±0,31 KHN). However, another paper revealed that CAD-CAM resins demonstrated a significant reduction when stored in water at 37ºC for 30 days with a variation in their hardness value properties when compared to conventional polymerized resins (Perea-Lowery et al., 2020).

Conventional acrylic resins would experiment a degradation procedure when immersed in aqueous solutions and a detrimental response would be exerted on its mechanical characteristics (Schwindling et al., 2014). A significant reduction was observed in the hardness value when immersed in sodium hypochlorite and perborate solutions also with a 10 minutes immersion protocol (Neppelenbroek et al., 2005). Another study also reported a decrease in KHN values with the significant statistical difference compared to Baseline (21.13±0,88 KHN) after 45 (18,66±0,81 KHN) and 90 cycles (18,66±0,52 KHN) when immersed on 1% hypochlorite solution and combined with brushing (20,15±0,78 KHN) (Panariello et al., 2015). Chemical cleansing is necessary whereas brushing could not effectively remove plaque (Schwindling et al., 2014).

However, this is the first study evaluating CAD-CAM resin over repeated chemical immersions and showed no significant difference. Comparing the present study, probably hardness of the CAD-CAM resin exposed to CG and H1 did not reduce their values because of the homogenous polymer produced by an effective cross-link reaction (Fernandes et al., 2013; Schwindling et al., 2014) leading to a higher degree of conversion (Fernandes et al., 2013; Schoeffle et al., 2019), making difficult the migration of the disinfectant within the polymeric chains. However, C2 did have a variation reducing the KHN of both resins at T1. Probably, the type solution, its composition, the pH and more immersion cycles could explain the different effect on the microhardness for both resins.

## 5. CONCLUSIONS

Within the limitations of the present research, CAD-CAM resin blocks could be safely disinfected regardless of the chemical solutions with no negative alterations of its superficial characteristics. It´s highly recommended other mechanical tests as well as increased immersion cycles.

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# 7. TABLES

## 7.1. TABLE A

| Resin | Brand | Polymerization | Protocol |
| --- | --- | --- | --- |
| Conventional base denture | VIPI Cril Plus (VIPI Indústria, Comércio, Exportação e Importação de Produtos Odontológicos, Pirassununga, SP) | Heat and pressure | 1st stage: 90ºC-60p; 2nd stage 120ºC-60p |
| CAD-CAM base denture | VIPI Block Gum (VIPI Indústria, Comércio, Exportação e Importação de Produtos Odontológicos, Pirassununga, SP) | Pre-polymerized block | Milled |

**Table A**. Testes resins and their respective polymerization protocol according to fabricant.

## 7.2. TABLE B

| Group | Periods | Solution | Brand | Immersion |
|---|---|---|---|---|
| Control Group | Baseline | Deionized water | Produced inlab (Biochemistry department) | 10 min |
| H1 | T1 (14 cycles) | 1% Sodium hypochlorite | Solução de Milton. Asfer Indústria Química Ltda. Santa Maria, SP, Brazil | 10 min |
| C2 | T2 (30 cycles) | 2% Chlorhexidine gluconate | Riohex 2%, Rioquímica indústria Farmacéutica. São Jose do Rio Preto, SP, Brazil | 10 min |

**Table B**. Chemical solution and their respective immersion/cycle relationship

## 7.3. TABLE C

| Solution | RESIN | Baseline | T1 | T2 |
|---|---|---|---|---|
| | | mean ± sd | mean ± sd | mean ± sd |
| CG | CONVENTIONAL PMMA | 0,18 ± 0,01 **Aa** | 0,19 ± 0,01 **Aa** | 0,21 ± 0,01 **Aa** |
| | CAD/CAM PMMA | 0,17 ± 0,02 **Aa** | 0,18 ± 0,02 **Aa** | 0,16 ± 0,01 **Ab** |
| H1 | CONVENTIONAL PMMA | 0,19 ± 0,01 **Aa** | 0,20 ± 0,01 **Aa** | 0,20 ± 0,01 **Aa** |
| | CAD/CAM PMMA | 0,17 ± 0,02 **Aa** | 0,20 ± 0,03 **Ba** | 0,16 + 0,01 **Ab** |
| C2 | CONVENTIONAL PMMA | 0,18 ± 0,02 **Aa** | 0,17 ± 0,03 **Aa** | 0,18 ± 0,01 **Aa** |
| | CAD/CAM PMMA | 0,16 ± 0,02 **Aa** | 0,15 ± 0,02 **Aa** | 0,16 ± 0,02 **Aa** |

**Table C**. Roughness and descriptive statistics (values are expressed in $\mu$m). Different capital letters represent significant difference through time, while lower case letters represent comparison between the resin. sd (standard deviation), CG (deionized water), H1 (1% sodium hypochlorite), C2 (2% chlorhexidine gluconate), Baseline (0 cycles), T1(14 cycles) and T2(30 cycles)

## 7.4. TABLE D

| | SS | Df | MS | F | p |
|---|---|---|---|---|---|
| SOLUTION | 0,011 | 2 | 0,006 | 17,285 | **0,000** |
| GROUP | 0,019 | 1 | 0,019 | 58,674 | **0,000** |
| SOLUTION*GROUP | 0,001 | 2 | 0,000 | 1,280 | 0,286 |
| TIME | 0,001 | 2 | 0,001 | 1,909 | 0,153 |
| TIME*SOLUTION | 0,005 | 4 | 0,001 | 4,448 | **0,002** |
| TIME*GROUP | 0,003 | 2 | 0,002 | 5,433 | **0,006** |
| TIME*SOLUTION*GROUP | 0,004 | 4 | 0,001 | 3,338 | **0,013** |

**Table D**. Roughness test. Three-way ANOVA and Tukey Honestly Significance Difference (HSD). SS (Sum Square), Df (degree of freedom), MS (Mean square), F (f Factor), *p* (significance difference)

## 7.5. TABLE E

| Solution | RESIN | Baseline | T1 | T2 |
|---|---|---|---|---|
| | | **mean ± sd** | **mean ± sd** | **mean ± sd** |
| CG | CONVENTIONAL PMMA | 18,2 ± 0,7 **Aa** | 18,0 ± 0,3 **Aa** | 18,1 ± 0,2 **Aa** |
| | CAD/CAM PMMA | 20,4 ± 0,4 **Ab** | 20,2 ± 0,7 **Ab** | 20,3 ± 0,8 **Ab** |
| H1 | CONVENTIONAL PMMA | 18,6 ± 0,6 **Aa** | 18,4 ± 0,2 **Aa** | 18,1 ± 0,3 **Aa** |
| | CAD/CAM PMMA | 20,3 ± 0,5 **Ab** | 19,7 ± 0,9 **Ab** | 19,5 ± 0,6 **Ab** |
| C2 | CONVENTIONAL PMMA | 18,9 ± 0,3 **Aa** | 17.8 ± 0,5 **Ba** | 18,2 ± 0,5 **ABa** |
| | CAD/CAM PMMA | 20,1 ± 0,6 **Ab** | 18,8 ± 0,9 **Bb** | 20,1 ± 0,9 **ABb** |

**Table E**. Microhardness and descriptive statistics (values are expressed in KHN). Different capital letters represent significant difference through time, while lower case letters represent comparison between the resin. sd (standard deviation), CG (deionized water), H1 (1% sodium hypochlorite), C2 (2% chlorhexidine gluconate), Baseline (0 cycles), T1(14 cycles) and T2(30 cycles)

# 7.6. TABLE F

| | SS | Df | MS | F | p |
|---|---|---|---|---|---|
| SOLUTION | 1,59 | 2 | 0,79 | 1,600 | 0,214 |
| GROUP | 126,13 | 1 | 126,13 | 252,14 | **0,000** |
| SOLUTION*GROUP | 6,18 | 2 | 3,09 | 6,18 | **0,004** |
| TIME | 10,57 | 2 | 5,29 | 18,34 | **0,000** |
| TIME*SOLUTION | 8,64 | 4 | 2,16 | 7,49 | **0,000** |
| TIME*GROUP | 1,20 | 2 | 0,60 | 2,09 | 0,129 |
| TIME*SOLUTION*GROUP | 1,94 | 4 | 0,48 | 1,68 | 0,159 |

**Table F**. Microhardness test. Three-way ANOVA and Tukey Honestly Significance Difference (HSD). SS (Sum Square), Df (degree of freedom), MS (Mean square), F (f Factor), *p* (significance difference)

## 2.2 ARTICLE 2 – Does continuous chemical disinfection affect mechanical properties of CAD/CAM PMMA

Does continuous chemical disinfection affect mechanical properties of CAD/CAM PMMA

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**ABSTRACT:**

**State of the problem**: Complete dentures fabricated by computer-aided design and computer-aided manufacturing (CAD/CAM) have shown higher mechanical properties when compared to conventional base denture resins, but there is no evidence of its performance after repeated disinfection immersions.

**Purpose**: The purpose of this paper was to analyze the effect of consecutive disinfection immersions on physical properties of CAD/CAM base denture blocks.

**Materials and Methods**: Two groups of base denture resins were tested: Heat-polymerized (VipiCryl, VIPI®) and milled blocks (VipiGum, VIPI®). The specimens were designed into quadrangular (12x3mm) (n=40) and rectangular (64x10x3,3mm) (n=240) specimens. Specimens were stored in water for 48 hours. Therefore, they were immersed in the disinfection chemical solutions: CG (control group, deionized water), H1 (sodium hypochlorite 1%), H05 (sodium hypochlorite 0,5%) and C2 (Chlorhexidine 2%). Each disinfection cycle represented a weekly disinfection process (10 min immersion). The immersion periods represented: baseline (0 cycles), 2.5 years (130 cycles) and 5 years (260 cycles). The analysis was based on the Roughness (Ra), Microhardness alterations (KHN), Flexural strength (FS) and Flexural Modulus (FM). The applied statistical tests were a 3-way ANOVA and Tukey HSD Pos Hoc Test were applied for all experiments, significance level of 5%.

**Results:** CAD/CAM PMMA showed higher flexural properties: flexural strength ($p=0,001$) and flexural modulus ($p<0,000$), than conventional PMMA. Microhardness KHN ($p<0,000$) was superior than conventional PMMA, but the chemical solution affected all resin in the surface roughness ($p=0,007$), values were under the 0,20 µm threshold for microbial adherence.

**Conclusions**: Within the limitations of this study, the CAD/CAM PMMA blocks can be safely disinfected without a negative effect on flexural and superficial properties.


**CLINICAL IMPICLATIONS**

Chemical disinfection for complete dentures is a reliable procedure to prevent Candida colonization on the acrylic surface, but no available data on CAD/CAM PMMA blocks. The present research showed superior mechanical properties for CAD/CAM PMMA, and chemical solutions can be safely used for long-term disinfection.

**INTRODUCTION**

Denture cleaning is imperative for maintaining the general health of edentulous patients. Denture base and reline materials present a rough and porous surface which favors the adhesion of microorganisms (bacteria and fungi), and consequently the formation of biofilm and denture plaque [1, 2]. C*andida albicans* species, is a major factor in the etiology for denture stomatitis: an opportunistic infection frequently seen in denture wearers [3]. Oral microorganisms can still be a risk factor for respiratory tract infections, gastrointestinal infections and chronic pulmonary obstruction diseases [4, 5]. Hence, denture cleaning and disinfection routine is fundamental for preventing diseases among denture wearers and the maintenance of a healthy oral environment.

The cleaning and removal of prosthesis plaques can be carried out by mechanical or chemical means. Mechanical cleaning is a cheap and common method that includes brushing using water, toothpaste or soap and ultrasound treatment [6]. However, the elderly and individuals with motor or mental disorders may present limited performance [7]. Chemical methods are fast, easy and low cost procedures and are summarized by the immersion of the prostheses in different chemical solutions in different concentrations, such as hypochlorite, peroxides, enzymes, acids or in detergents [8]. These solutions can reach within the inner irregularities of the acrylic base, which is difficult to effectively clean using mechanical methods [6]. There are reports proving the sodium hypochlorite solution efficiency over several microbial strains [8] and even on microorganisms allocated to a depth of 3 mm on acrylic resin irregularities [9].

Preferably, the cleaning and disinfection procedures cannot cause damage to the physical and mechanical characteristics of denture base resins, however, it has been reported that the roughness [10], microhardness [11], hardness [12, 13], flexural strength [14] and color stability [15] may undergo changes with chemical disinfection.

Coming with the development of computer-aided design and computer-aided manufactured (CAD/CAM) technology in the fabrication of complete dentures, currently, a pre polymerized CAD/CAM polymethylmethacrylate (PMMA)-based block has been presented by manufacturers to overcome the challenges exposed in resins traditionally used in complete dentures [16-18]. CAD/CAM PMMA are industrially polymerized under standardized conditions at great heat and pressure providing a highly condensed resin block with superior fit and strength [18], minimal shrinkage and residual monomer release [19] and better bio-hygienic condition (through its hydrophobic properties) [18, 20]. Since its introduction, the CAD/CAM

PMMA block have undergone substantial investigations on its mechanical properties comparing to heat polymerized acrylic resins [18, 19, 20, 21, 22, 23]. Studying superficial characteristics of acrylic resins, as roughness and microhardness, might help to understand its density and the resistance to wear of the material [2], how the superficial roughness would be altered against thermal, chemical or biological challenges [18]. Kattadivil et al., (2015) concluded the importance of testing the flexural strength of CAD/CAM PMMA blocks in patients with heavier functional loads and experienced continuous denture fractures [20].

Despite the promising performance of this material described in the literature, no research has been undertaken to investigate the side effects of chemical disinfection procedures on mechanical properties of CAD/CAM PMMA blocks. The purpose of this in vitro study was to evaluate the effect of continuous disinfection on CAD CAM denture blocks mechanical properties. Two null hypothesis were established: 1) CAD CAM denture blocks would show equal mechanical behavior than conventional resin in the 4 tests (microhardness, roughness, flexural strength and elasticity module); 2) CAD CAM denture blocks would not be affected by chemical disinfection solutions.

## MATERIALS AND METHODS

### Specimens

Two PMMA acrylic resins from VIPI (Vipi Indústria, Comércio e Importação de Produtos Odontológicos) were tested for flexural and surface properties. For each resin, a total of 120 specimens were produced for flexural strength and modulus analysis, and 40 specimens for microhardness and surface roughness evaluation. Then, the specimens were randomly and equally divided (n=10) according to the solution tested (2% chlorhexidine, 0.5% hypochlorite, 1% hypochlorite and deionized water) and the disinfection stages: baseline (T0), 130 cycles (T1) and 260 cycles (T2). Data of the materials composition and polymerization protocol are present in Table 1.

**Table 1.**

### CAD/CAM PMMA

CAD/CAM specimens were obtained from pre-polymerized PMMA pucks (Vipi Block Gum, Vipi Indústria, Comércio e Importação de Produtos Odontológicos) with dimensions of 98.5 (diameter)×25mm (thickness). For this, the PMMA pucks were cutted using a precision sectioning saw machine (IsoMet 1000, Bueller) and then subjected to a polishing protocol with silicone carbide papers (grits 120, 400, 600 and 800) to the final dimensions: 64×10×3.3mm for flexural properties (according to ISO 20795-1) [23] and 12×12×3mm for microhardness and surface roughness [24]. After, the specimens were immersed in distilled water at 37ºC for 48h ± 2 [14] (Q316M5, QUIMIS Aparelhos Científicos LTDA) prior to the disinfection cycles and evaluations.

**Conventional heat polymerized PMMA**

For Vipi Cril Plus (Vipi Indústria, Comércio e Importação de Produtos Odontológicos) specimens, condensation silicone patterns Zetalabor, (Zhermack, Badia Polesine) were initially produced by compressing the material into a metallic matrix between two glass plates [25]. The patterns were conventionally invested in metallic flasks (Mac Artigos odontológicos e prótese Ind. E Com. LTDA) using type III dental stone (Gesso – Rio), according to the manufacturer's instructions, and pressed in a hydraulic press (Dental Importação e Exportação LTDA) at 0.5 t during the setting time of the stone [25].

The resin was handled according to the manufacturer's instructions (Table 1), invested in the doughty stage and kept under a load of 1 ton for 2 hours, as recommended by the manufacturer. After, the specimens were conventionally polymerized (Equipamentos VRC, VRC Soluções Tecnológicas LTDA), using a suggested polymerization protocol by the manufacturer, and deflasked after bench cooling at room temperature. Lastly, the specimens were subjected to the same polishing protocol to the abovementioned dimensions and immersed in distilled water at 37ºC for 48 ± 2 prior to the procedures [14, 23, 26].

**Chemical disinfection**

The specimens were subjected to a simulated disinfection protocol in four different solutions: 2% chlorhexidine (RioHex 2%, Rioquímica infústria Farmacéutica, São Jose do Rio Preto, SP, Brazil), 0.5% hypochlorite (Líquido de Dakin, Asfer Indústria Química Ldta), 1% hypochlorite (Solução de Milton, Asfer Indústria Química Ldta) and deionized water (control). According to the group, except for baseline groups, the specimens were immersed in each solution, with an immersion period of 10 minutes representing 1 cycle. Therefore, 130 and 260 cycles were performed, simulating 10 minutes of chemical disinfection [26]. Information about chemical solutions are listed on table 2.

**Table 2.**

**Flexural properties (three-point bending test)**

The flexural strength (FS) analysis was performed using a universal testing machine (Kratos K2000MP, Kratos). Each specimen was placed upon two cylindrical supports with a 50mm gap between each other [14]. Then a vertical load, at a crosshead speed of 5mm/min, was applied at the middle point of the specimen (according to ISO 20975-1) until its fracture, and the maximum load was recorded [14]. The FS was calculated using the following formula: FS = $3PL/2bd^2$, where "P" corresponds to the applied force (N) at the highest point of the load-deflection curve, "L" is the span length (50mm), "b" and "d" are, respectively, the width (10mm) and height (3mm) of the specimen [14, 23].

The flexural modulus (FM) was also calculated using the following formula: $E= PL^3/4Ybd^3$, where "E" is the flexural modulus, "L" is the span length (50mm), "b" the width (10mm) and "d" the height of the specimen. Lastly, "Y" is the recorded deflection corresponding to a certain load for a point on a straight-line segment on the load-deflection curve [23].

For both acrylic resins, groups were evaluated at three stages: baseline, after 130 and 260 cycles of chemical disinfection.

**Microhardness and surface roughness**

Knoop microhardness analysis was performed using a microdurometer HMV-2000 (Shimadzu Corporation). Three indentations were made in each specimen (one on each side and the third on the middle) and, under a 25-g load for 10 seconds, and the final Knoop microhardness (KHN) was obtained through the arithmetic mean of the three indentations [27-29].

Surface roughness was obtaining using a contact profilometer Marsurf XCR20 (Mahr Metrology). In this analysis, each specimen was subjected to three readings with a measuring length of 5.5mm, at 0.5mm/s and with a cut-off filter of 0.8mm. The final surface roughness of the specimen was determined by the average of these readings [14].

**Statistical analysis**

For flexural properties, the statistical analysis were a 3-Way ANOVA and a Tukey Honestly Significant (HSD) pos hoc test with a significance level of 5%. For microhardness and surface roughness, the statistical analysis were a repeated measures ANOVA and a Tukey HSD pos hoc test with a significant level of 5%.

## RESULTS

**Flexural Properties**

Flexural Strength

**Table 3 and Table 4.**

The Three-way ANOVA showed a significant difference when analyzing the Group (p=0,001) and Time (p=0,032) variables. Therefore, the Tukey HSD test in table 3 demonstrated that all CAD/CAM PPMA blocks showed a higher values (122,4±12,2 MPa) than Conventional PMMA (98,7±11,7) (p<0,05) at Baseline. However, the interaction Solution*Group showed a significant difference (p=0,008). The results in table 3 and 4 represent that CAD/CAM PMMA showed superior values in FS than Conventional PMMA, and the chemical solution did not affect the resin through time.

Flexural modulus

**Table 5 and Table 6.**

In the Flexural Modulus analysis, there was a significant difference within the resins (p<0,000), and through time (p=0,009). These results showed that FM varied through time in all CAD/CAM PMMA blocks and showed higher values than Conventional PMMA at T2 (p<0,05) independent from the chemical solution (solution p=0,308 and their interaction p>0,05) (Table 6). The interaction Solution*Group (p=0,026) demonstrated a significant effect of all chemical solution on the tested resin. The results in table 5 and 6 showed that there was no statistical difference between the resin at baseline, however, the disinfectant solutions increased the FM values at the end of the experiment with significant difference.

**Microhardness and surface roughness**

Microhardness

**Table 7 and Table 8.**

The present results did show a significant difference on the type of resin (group: p<0,000) with a mean= 20,32±0,7 KHN for CAD/CAM PMMA blocks and 18,54±0,6 KHN for Conventional PMMA at Baseline. However, the interaction solution*group did have a significant difference (p>0,000); as shown in table 7: CAD/CAM PMMA blocks did not express a significant difference in H05 and C2; whether CG and H1 showed a reduction of microhardness values when immersed in the tested solutions. Time was also a factor that showed a significant difference (p=0,002), as well as, its interaction with solution (p=0,045) and group (p<0,000) (Table 8). As shown in table 7, during the experiment (periods), CAD/CAM PMMA blocks showed a reduction in values at T1 and stabilized at the end of the experiment (T2). But, Conventional PMMA showed similar values at Baseline and T1, but the values increased at T2. These results expressed that the more immersion, the higher interactions with different behavior in both resins.

Surface Roughness

**Table 9 and Table 10.**

The repeated measures ANOVA test did show a significant difference when analyzing the type of solution (*p*=0,007) with no interaction between the groups or the time (Table 10). However, when applying the Tukey HSD in the variable: Solution (Table 9), we could see that CAD/CAM PMMA block was affected when the H1 (1% sodium hypochlorite) with an increase of Ra values (B: 0,17±0,04µm; T1:0,19±0,03µm; T2: 0,19±0,03µm), and C2 (2% chlorhexidine gluconate) with a decrease in Ra values (B: 0,18±0,03µm; T1: 0,18±0,04µm; T2: 0,17±0,04µm). The CG (deionized water) and H05 (0,5% sodium hypochlorite) did not show a statistical significance when immersion was applied.

## DISCUSSION

According to the present results, CAD/CAM PMMA showed better mechanical behavior than conventional PMMA in FS (p=0,001), FM (p<0,000) and KHN (p<0,000), therefore, the first null hypothesis was partially rejected. The second null hypothesis was partially accepted because the solution was significant relevant in the Ra values (p=0,007) and in FM the CAD/CAM PMMA resin was affected through time showing higher values at T2, whereas the solution in FS (p=0,600) and KHN (p=0,070) was not relevant in the properties of the resin.

### Flexural Properties

Flexural properties are important to understand the behavior of the resin under certain force simulating the intraoral high functional loads during mastication and parafunction [14, 23]. A previous study showed that CAD/CAM PMMA resin higher values for FS (146,6±6,6 MPa) and FM (3816,7±44,3) when compared to Injection and Compression resins with a significant difference (p<.001) [23]. As the FS is considered an important parameter of the mechanical properties of acrylic resin, it is also related by the degree of conversion during the polymerization process [14, 23]. On the contrary, it has been reported that FS of CAD/CAM PMMA blocks were no consistent among three brands and a Conventional PMMA resin was reported to have superior FS values than CAD/CAM group [30]. The FM represents the materials rigidity, which is analyzed by the deformation the resin undergo before fracture [23, 30]. However, all CAD/CAM PMMA resins showed a greater extension from preload before fracture, which means that thinner bases might be used and a stable occlusion would be expected from a denture base resistant to deformation [30]. Our results showed an initial higher flexural strength of CAD/CAM PMMA resin (122,4±12,2MPa) and an equal FM (2899,1±401,5MPa) than Conventional PMMA. According to the ISO 20795-1 for denture base polymers [14], the acrylic resin should have no less than 65MPa in the 3-point flexural test; and all tested resins passed the stated requirement (Conventional PMMA=97,7±11,7MPa).

Testing the aging effect on PMMA resins helps to understand clinical survival when exposed to moisture and temperature through the thermal cycling test [23], but since the chemical disinfection is important to control microbial colonization [31], to know the effect of continuous immersion in these solutions is mandatory. In general terms, disinfection generates stress on the conventional PMMA resins and have been reported no consensus of the effects on its mechanical properties [14, 31-33]. Some researches have concluded that low exposure to chemical solution had no significant difference on the FS when the PMMA was immersed in 1H [31], but, as the immersion time increased, 1H showed a significant reduction over time [32]. Through literature, CAD/CAM PMMA resins have shown higher FS values before/after thermal aging procedures [14], but there is a variation within commercially available brands [23, 34]. This is the first study evaluating the effect of repeated disinfection on CAD/CAM PMMA resin, and our results showed that the chemical solutions did not affect the flexural strength of CAD/CAM PMMA resin (p=0,600) but there was a significant difference between resins (p=0,001) and the interaction Solution*resin (p=0,008). In the FM results, solutions increased values of CAD/CAM PMMA resin at the end of the experiment (T2)

(CAD/CAM=3048±475,6MPa; Conventional PMMA=2717,3±408,2MPa), whereas the Conventional PMMA´s groups were not affected. Probably, the cross-linking agents, a reduced residual monomer, the polymerization condition (temperature and pressure) could have produced an enhanced polymeric network

**Microhardness and surface roughness**

A controlled polymerization (high temperature and pressure) of the PMMA block would produce an enhanced polymer with better resistance to wear and density properties [29]. According to the ADA specifications, PMMA as a base denture material should have, at least, 15 Knoop [29] to be considered as clinically acceptable. Another factor related to the surface properties is the polishing technique, an adequate protocol could prevent the retain of microbial stains and microorganisms, as well as, preventing critical staining [1, 2]. In literature, Al-Dwairi et al. (2019), reported that two CAD/CAM PMMA resins did have higher surface hardness (p<0,00) and surface roughness (p<0,00) than conventional PMMA [22]. The CAD/CAM PMMA resins, tested in the previous research, had means for Avadent of 20,60±0,33 Vickers (VHN) and Tizian-Schütz was 19,80±1,8 VHN, while conventional PMMA showed VHN=18,09±0,31 [22]. Additionally, Ra has a significant difference among the PMMA blocks: Avadent (0,16±0,03µm) and Tizian-Schütz (0,12±0,02µm), however the roughness for conventional PMMA was 0,22±0,07µm [22]. Arslan et al, (2018) tested the effect of thermocycling aging on flexural strength and surface properties (contact angle and Ra) of CAD/CAM PMMA-based polymers [14]. This paper showed that Ra did not have significant difference among the three CAD/CAM (M-PM Disc=0,21±0,07µm; AvaDent Puck Disc=0,22±0,06µm; Polident Pink CAD/CAM Disc=0,26±0,09µm) resins and the control group (p>0,05) [14]. After thermal cycling, Arslan et al. also concluded that there was no significant difference in roughness values and the results were closed to the 0,2µm threshold [14]. The present research showed higher KHN initial values for CAD/CAM PMMA blocks at baseline (20,32±0,8) than Conventional PMMA (18,54±0,6) with significant difference (p<0,000). The superior microhardness values could be explained by the difference in the manufacturing process resulting in a homogenous polymer, and low levels of residual monomers with higher degree of conversion [22, 35]. On the other hand, Perea-Lowery et al. (2020)[30] compared three CAD/CAM PMMA resins to Conventional PMMA, and showed that Conventional PMMA had the highest microhardness mean values. They also observed a variation among the CAD/CAM PMMA blocks before and after water storage, and highlighted the unknown polymerization process and how the cross linking occurs in the PMMA block. In terms of surface roughness, our results showed a Ra value of 0,17±0,02 μm for CAD/CAM PMMA and no difference among resin (p=0,126) [30]. This fact could be justified by a different acquisition of the specimens in the present methodology, the blocks were cut using a diamond disc and received a standardized polishing with silicon carbide papers.

The chemical disinfection has been reported to negatively affect the microhardness and surface roughness values of conventional PMMA [29]. Goiato et al. (2013) conclude that microhardness of acrylic base denture reduces over time, and thermal as well as disinfection procedures, decreased the microhardness of all acrylic resins [29]. They found that a conventional PMMA: Lucitone 550 (L) and QC-20 (QC) (Dentsply) was affected according to the chemical solution: 1% H (L=19,87±0,5 to 18,56±0,26 KHN; QC=19,23±0,24 to 16,47±1,02 KHN); and 4% CHX (L=19,79±0,54 to 18,53±0,31; QC=19,19±0,32 to 16,04±0,71 KHN) [29]. Neppelenbroek et al. (2005), concluded that chemical solutions did affect the resin by decreasing the Vicker Hardness (VHN) of conventional PMMA (rapid polymerization protocol): 1% H= Lucitone 550 (17,33±2,0 to 16,05±1,90 VHN) and QC-20 (9,16±2,18 to 7,90±1,65 VHN); and 4% CHX= Lucitone 550 (16,75±1,27 to 15,16±1,23) and QC-20 (8,28±1,75 to 7,84±1,22) [13] . According to our results, there was a different interaction between the solution and the resins, therefore, all chemical solutions slightly reduced the KHN values of CAD/CAM PMMA resin. However, the interaction on conventional PMMA showed that low concentration (H05 and C2) of the chemical solutions did not affect the KHN values, whereas the CG and H1 showed higher values in this group of resins, with statistical difference. Differing from Neppelenbroek et al. (2015) [13] and Goiato et al. (2013) [29], where the chemical solutions decrease the microhardness values, probably the total time of exposure and the polymerization protocol would explain the difference in these results.

Literature explains that disinfection protocols might affect the resin over time and chemical characteristics by softening or degrading the surface [29]. However, a high condensed polymer could not be affected by the properties of the solutions, but an acid solutions (pH) could affect the polymer network [36]. In the present research, the solutions (H05 and C2) with pH close to 7 (neutral) did not affect the microhardness and slightly reduced the Ra of both tested resins over time. After the disinfection protocol, all resins were above ADA specifications (15) [29] and below the Ra threshold (0.2μm) [14].

## CONCLUSIONS

CAD/CAM PPMMA resin were not negatively affected by the chemical solutions and showed superior values than Conventional PMMA in all tests. Both resins´ values are above clinical acceptance, though.

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## TABLES

Table 1

| Resin | Brand | Polymerization | Protocol | Composition |
|---|---|---|---|---|
| Conventional heat polymerized PMMA | Vipi Cril Plus (VIPI®) | Heat and pressure | 1st stage: 90ºC-60p<br>2nd stage: 120ºC-60p | Powder: Polymethylmethacrylate, Benzoyl-Peroxide.<br>Liquid: Methylmethacrylate, EDMA (crosslink) |
| CAD/CAM PMMA block | Vipi Block GUM (VIPI®) | Pre-polymerized block | N/I | Methyl Polymethacrylate, Biocompatible pigments, EDMA and Fluorescent |

**Table 1.** Acrylic resins, brands, polymerization protocol and composition. N/I: not informed by fabricant. Data drawn from VIPI® (Vipi Indústria, Comércio e Importação de Produtos Odontológicos, Pirassununga, SP, Brazil)

Table 2

| Group | Chemical solution | Brand | pH |
|---|---|---|---|
| Control Group | Deionized water | -- | 6,1 |
| H1 | 1% sodium hypochlorite | Solução de Milton. Asfer Indústria Química Ltda. | 11,4 |
| H05 | 0,5% sodium hypochlorite | Líquido de Dakin. Asfer Indústria Química Ltda. | 8,4 |
| C2 | 2% chlorhexidine gluconate | Riohex 2%, Rioquímica indústria Farmacéutica. | 5,3 |

**Table 2.** Chemical solutions and its characteristics.

Table 3

| Solution | RESIN | Baseline | T1 | T2 | mean + sd |
|---|---|---|---|---|---|
| | | mean + sd | mean + sd | mean + sd | |
| CG | CONVENTIONAL PMMA | 98.0 + 13.4 | 101.8 + 7.3 | 100.5 + 10.0 | **100.1 + 10.2 B** |
| | CAD/CAM PMMA | 122.9 + 18.2 | 121.5 + 11.7 | 125.2 + 7.6 | **123.2 + 12.5 A** |
| H1 | CONVENTIONAL PMMA | 99.4 + 10.3 | 112.4 + 15.6 | 97.7 + 10.1 | **103.1 + 12.0 B** |
| | CAD/CAM PMMA | 126.4 + 10.3 | 128.9 + 20.4 | 129.3 + 12.2 | **128.2 + 14.3 A** |
| H05 | CONVENTIONAL PMMA | 97.1 + 13.4 | 104.0 + 10.7 | 104.9 + 14.0 | **102.0 + 12.7 B** |
| | CAD/CAM PMMA | 123.5 + 9.9 | 125.8 + 17.1 | 125.1 + 8.6 | **124.8 + 11.9 A** |
| C2 | CONVENTIONAL PMMA | 96.2 + 9.5 | 113.7 + 11.6 | 108.4 + 12.6 | **106.1 + 11.2 B** |
| | CAD/CAM PMMA | 117.0 + 10.4 | 120.9 + 9.0 | 117.9 + 13.7 | **118.6 + 11.0 A** |
| **mean + sd** | **CONVENTIONAL PMMA** | **97.7 + 11.7 a** | **108.0 + 11.3 b** | **102.8 + 11.7 a** | **Solutions** |
| | **CAD/CAM PMMA** | **122.4 + 12.2 a** | **124.3 + 14.5 a** | **124.4 + 10.5 a** | **Periods** |

**Table 3.** Flexural strength and its descriptive statistics: mean and standard deviation (sd). Different capital letters represent the difference between resins. Lower-case letters represent different through time. Values are represented by MPa. CG: deionized water, H1: 1% sodium hypochlorite, H05: 0,5% sodium hypochlorite, C2: 2% chlorhexidine gluconate.

Table 4

| | SS | Df | MS | F | p |
|---|---|---|---|---|---|
| SOLUTION | 361786 | 3 | 120595 | 0.624 | 0.600 |
| GROUP | 2205873 | 1 | 2205873 | 11.406 | **0.001** |
| SOLUTION*GROUP | 2339770 | 3 | 779923 | 4.033 | **0.008** |
| TIME | 1350561 | 2 | 675280 | 3.492 | **0.032** |
| TIME*SOLUTION | 1641375 | 6 | 273563 | 1.415 | 0.210 |
| TIME*GROUP | 719675 | 2 | 359827 | 1.861 | 0.158 |
| TIME*SOLUTION*GROUP | 589223 | 6 | 98204 | 0.508 | 0.802 |

**Table 4.** Three-Way ANOVA results for the Flexural Strength values. SS (Sum Squares), Df (Degree of freedom), MS (Mean Squares), F, and *p* (p value)

Table 5

| Solution | RESIN | Baseline | T1 | T2 | mean ± sd |
|---|---|---|---|---|---|
| | | mean ± sd | mean ± sd | mean ± sd | |
| CG | CONVENTIONAL PMMA | 2978.6 ± 375.7 | 3208.9 ± 589.0 | 2659.8 ± 456.6 | **2949.1 ± 473.8 A** |
| | CAD/CAM PMMA | 2917.5 ± 361.1 | 2955.9 ± 378.7 | 2664.7 ± 540.9 | **2846.1 ± 426.9 A** |
| H1 | CONVENTIONAL PMMA | 2781.1 ± 458.9 | 2841.1 ± 294.8 | 2687.5 ± 404.8 | **2769.9 ± 386.2 B** |
| | CAD/CAM PMMA | 3027.4 ± 507.8 | 3318.0 ± 373.5 | 3308.8 ± 450.9 | **3218.0 ± 444.1 A** |
| H05 | CONVENTIONAL PMMA | 2799.5 ± 517.9 | 2759.1 ± 400.8 | 2823.6 ± 521.2 | **2794.0 ± 480.0 B** |
| | CAD/CAM PMMA | 2781.7 ± 465.6 | 3172.4 ± 573.7 | 3169.4 ± 507.0 | **3041.2 ± 515.5 A** |
| C2 | CONVENTIONAL PMMA | 2784.2 ± 376.1 | 2963.4 ± 451.6 | 2698.3 ± 250.0 | **2815.3 ± 359.2 B** |
| | CAD/CAM PMMA | 2869.6 ± 271.6 | 3050.6 ± 410.2 | 3049.8 ± 403.6 | **2990.0 ± 361.8 A** |
| **mean ± sd** | **CONVENTIONAL PMMA** | **2835.8 ± 432.2 a** | **2943.1 ± 434.1 a** | **2717.3 ± 408.2 a** | **Solutions / Periods** |
| | **CAD/CAM PMMA** | **2899.1 ± 401.5 a** | **3124.2 ± 434.0 b** | **3048.2 ± 475.6 b** | |

**Table 5.** Flexural modulus and its descriptive statistics: mean and standard deviation (sd). Different capital letters represent an interaction solution*group with statistical difference. Lower-case letters represent difference during the time. CG: deionized water, H1: 1% sodium hypochlorite, H05: 0,5% sodium hypochlorite, C2: 2% chlorhexidine gluconate.

Table 6

| | SS | Df | MS | F | p |
|---|---|---|---|---|---|
| SOLUTION | 557.0 | 3.0 | 186.0 | 1.2 | 0.308 |
| GROUP | 26098.0 | 1.0 | 26098.0 | 169.6 | **0.000** |
| SOLUTION*GROUP | 1449.0 | 3.0 | 483.0 | 3.1 | **0.026** |
| TIME | 1488.0 | 2.0 | 744.0 | 4.8 | **0.009** |
| TIME*SOLUTION | 765.0 | 6.0 | 127.0 | 0.8 | 0.549 |
| TIME*GROUP | 733.0 | 2.0 | 366.0 | 2.4 | 0.095 |
| TIME*SOLUTION*GROUP | 591.0 | 6.0 | 99.0 | 0.6 | 0.698 |

**Table 6.** Three-Way ANOVA results for the Flexural Modulus values. SS (Sum Squares), Df (Degree of freedom), MS (Mean Squares), F, and *p* (p value)

Table 7

| Solution | RESIN | Baseline | T1 | T2 | mean $\pm$ sd |
|---|---|---|---|---|---|
| | | mean $\pm$ sd | mean $\pm$ sd | mean $\pm$ sd | |
| CG | CONVENTIONAL PMMA | 18.77 $\pm$ 0.4 | 19.52 $\pm$ 0.9 | 19.56 $\pm$ 0.7 | **19.28 $\pm$ 0.7 BC** |
| | CAD/CAM PMMA | 20.07 $\pm$ 0.7 | 19.36 $\pm$ 0.4 | 19.09 $\pm$ 0.5 | **19.51 $\pm$ 0.5 AB** |
| H1 | CONVENTIONAL PMMA | 18.60 $\pm$ 0.7 | 18.97 $\pm$ 0.4 | 19.59 $\pm$ 0.7 | **19.05 $\pm$ 0.6 C** |
| | CAD/CAM PMMA | 20.33 $\pm$ 1.0 | 19.20 $\pm$ 0.6 | 19.66 $\pm$ 0.8 | **19.73 $\pm$ 0.8 AB** |
| H05 | CONVENTIONAL PMMA | 18.64 $\pm$ 0.6 | 18.10 $\pm$ 0.4 | 18.40 $\pm$ 0.5 | **18.38 $\pm$ 0.5 D** |
| | CAD/CAM PMMA | 20.46 $\pm$ 0.7 | 19.59 $\pm$ 0.4 | 19.73 $\pm$ 0.4 | **19.93 $\pm$ 0.5 A** |
| C2 | CONVENTIONAL PMMA | 18.16 $\pm$ 0.9 | 18.15 $\pm$ 0.6 | 18.78 $\pm$ 0.3 | **18.36 $\pm$ 0.6 D** |
| | CAD/CAM PMMA | 20.42 $\pm$ 0.6 | 19.82 $\pm$ 0.4 | 19.73 $\pm$ 0.4 | **19.99 $\pm$ 0.5 A** |
| **mean $\pm$ sd** | **CONVENTIONAL PMMA** | **18.54 $\pm$ 0.6 a** | **18.69 $\pm$ 0.6 a** | **19.08 $\pm$ 0.6 b** | **Solutions** |
| | **CAD/CAM PMMA** | **20.32 $\pm$ 0.8 a** | **19.49 $\pm$ 0.4 b** | **19.55 $\pm$ 0.5 b** | **Periods** |

**Table 7.** Microhardness and its descriptive statistics: mean and standard deviation (sd). Tukey Significant Honestly Difference (p<0,05). Capital letter represents a significant difference among solution, lower-case letter represents significant difference through the period. CG: deionized water, H1: 1% sodium hypochlorite, H05: 0,5% sodium hypochlorite, C2: 2% chlorhexidine gluconate, Baseline, T1 (130 cycles), T2 (260 cycles).

Table 8

| | SS | df | MS | F | p |
|---|---|---|---|---|---|
| SOLUTION | 3.15 | 3 | 1.05 | 2.5 | 0.070 |
| GROUP | 62.15 | 1 | 62.15 | 145.7 | **0.000** |
| SOLUTION*GROUP | 20.96 | 3 | 6.99 | 16.4 | **0.000** |
| TIME | 4.78 | 2 | 2.39 | 6.7 | **0.002** |
| TIME*SOLUTION | 4.69 | 6 | 0.78 | 2.2 | **0.045** |
| TIME*GROUP | 18.38 | 2 | 9.19 | 25.9 | **0.000** |
| TIME*SOLUTION*GROUP | 3.80 | 6 | 0.63 | 1.8 | 0.105 |

**Table 8.** Repeated measure ANOVA results for the Microhardness values. SS (Sum Squares), Df (Degree of freedom), MS (Mean Squares), F, and *p* (p value).

Table 9

| Solution | RESIN | Baseline | T1 | T2 | mean + sd |
|---|---|---|---|---|---|
| | | mean + sd | mean + sd | mean + sd | |
| CG | CONVENTIONAL PMMA | 0.19 + 0.04 | 0.17 + 0.02 | 0.15 + 0.02 | **0.15 + 0.03 B** |
| | CAD/CAM PMMA | 0.17 + 0.01 | 0.16 + 0.04 | 0.18 + 0.03 | **0.17 + 0.03 A** |
| H1 | CONVENTIONAL PMMA | 0.19 + 0.03 | 0.16 + 0.02 | 0.19 + 0.02 | **0.18 + 0.02 B** |
| | CAD/CAM PMMA | 0.17 + 0.04 | 0.19 + 0.03 | 0.19 + 0.03 | **0.18 + 0.03 C** |
| H05 | CONVENTIONAL PMMA | 0.19 + 0.01 | 0.17 + 0.02 | 0.16 + 0.02 | **0.17 + 0.02 B** |
| | CAD/CAM PMMA | 0.17 + 0.02 | 0.17 + 0.04 | 0.16 + 0.03 | **0.17 + 0.03 A** |
| C2 | CONVENTIONAL PMMA | 0.20 + 0.02 | 0.20 + 0.04 | 0.19 + 0.05 | **0.20 + 0.04 A** |
| | CAD/CAM PMMA | 0.18 + 0.03 | 0.18 + 0.04 | 0.17 + 0.04 | **0.18 + 0.04 B** |

**Table 9.** Surface Roughness and its descriptive statistics: mean and (sd) standard deviation. Tukey HSD: alpha=0,05, Error: Between MS=0,00102, df=72: Letter different than A means a significant difference of the chemical disinfectant. CG: deionized water, H1: 1% sodium hypochlorite, H05: 0,5% sodium hypochlorite, C2: 2% chlorhexidine gluconate, Baseline, T1 (130 cycles), T2 (260 cycles).

Table 10

| | SS | Df | MS | F | p |
|---|---|---|---|---|---|
| SOLUTION | 0.013238 | 3 | 0.004413 | 4.321 | **0.007** |
| GROUP | 0.002450 | 1 | 0.002450 | 2.399 | 0.126 |
| SOLUTION*GROUP | 0.006190 | 3 | 0.002063 | 2.020 | 0.119 |
| TIME | 0.005070 | 2 | 0.002535 | 2.779 | 0.065 |
| TIME*SOLUTION | 0.005673 | 6 | 0.000946 | 1.037 | 0.404 |
| TIME*GROUP | 0.005081 | 2 | 0.002540 | 2.785 | 0.065 |
| TIME*SOLUTION*GROUP | 0.006743 | 6 | 0.001124 | 1.232 | 0.293 |

**Table 10.** Repeated measure ANOVA results for the Roughness values. SS (Sum Squares), Df (Degree of freedom), MS (Mean Squares), F, and *p* (p value).

# 3 Discussion

# 3 DISCUSSION

According to the present results, CAD/CAM PMMA resin showed a higher microhardness values and flexural properties than Conventional PMMA. Therefore, the first null hypothesis was partially accepted.

Surface properties.

Roughness is a property related to adequate polishing, and its stability depends on the characteristics of the polymeric structure. [10] Also, it has been described that low surface roughness prevent staining and microbial adherence. [15,17] Microhardness is a property based on the resistance to wear and density of the polymer; according to the ADA specification, a base denture resin should have, at least, 15 KHN. [18] According to literature, research showed that two CAD/CAM PMMA resin had higher microhardness values (Avadent and Tizian-Schütz) and lower roughness values than conventional PMMA with significant difference (p<0,00). [19] Comparing to the present results, Article 1 and Article 2, showed that CAD/CAM PMMA resins had microhardness values were closed to 20 KHN, while the conventional PMMA values were closed to 18KHN, with a significant difference (p<0,05).

In terms of surface roughness, the tested resins did not have statistical difference (p>0,05) and both resins were under the 0,2 µm threshold. This fact could be explained by the CAD/CAM´s polymerization protocol (higher temperature and controlled pressure), which results in a homogenous polymer with a higher degree of conversion and low monomer release, and an adequate polishing protocol. [10,20] However, Perea-Lowery et al., have reported that, after water storage, some

CAD/CAM PMMA would have a reduction on its microhardness values (p<0,05) and the roughness values were similar among the groups (p=0,126). [2]

Flexural properties

In vitro tests help to understand the behavior of the material under certain conditions. In this research, flexural properties might simulate high functional loads during mastication and parafunction. [16,20] According to literature, CAD/CAM PMMA resin had higher flexural strength and flexural modulus than conventional resin (p<0,05), [20] which means that thinner bases might be indicated and would be resistant to deformation. [20] However, Perea-Lowery et al., (2020) reported a variation among CAD/CAM PMMA brands, and conventional PMMA showed higher flexural strength values. [2] Our results showed higher FS values in the tested CAD/CAM PMMA resin (122,4 MPa) than conventional PMMA (97,7 MPa) with significant difference (p<0,05). However, at baseline, all resins were above the ISO 20795-1 for denture base polymers (65 MPa). [16]

Continuous chemical disinfection did affect the PMMA in different ways with distinctive characteristics and variations among the experiments, superficial and flexural properties. Based on these results, the second null hypothesis was partially accepted.

Surface properties

Chemical disinfection would affect the PMMA resin as an initiator, or it could penetrate the resin and alter the polymeric network and compromise its physical and mechanical properties. [10,21] However, there is still no consensus on the best chemical disinfectant and its prolonged effect on the base denture. [10,22] The present thesis is the first study describing the effect of continuous chemical disinfection on the mechanical properties on CAD/CAM PMMA base denture resin. Literature have described that short-term immersion exposure to the disinfectant solution might not alter the superficial properties of conventional PMMA resin. [23,24] These results are similar to the present experiment (article 1), where roughness and microhardness values did not affect the CAD/CAM PMMA resin though the continuous exposure (total time: 140 minutes).

According to literature, as the exposure time increased, a reduction on the microhardness values could be observed. [22,25] It was reported that high condensed polymers could not be affected by continuous exposure, but the pH of the solutions could be relevant to the adverse effect of the resin surface. [26] In the present work, solutions with pH close to neutral (0,5% sodium hypochlorite and 2% chlorhexidine gluconate) did not affect the microhardness and slightly reduced the surface roughness at T2 (Article 2).

Flexural properties

In conventional PMMA resin, short-term chemical exposure had no significant effect on the FS values, [27] but long-term exposure would affect the FS values with significant difference. [28] More recently, thermal aging on CAD/CAM PMMA resins showed a significant difference when comparing commercially available brands. [20,29] Since it is the first research evaluating the effect of continuous chemical disinfection on CAD/CAM PMMA resin, chemical immersions did not affect the FS through time ($p=0,600$) and were significant different to conventional PMMA resin ($p<0,001$). FM also suffered an increase in the mean values at the end of the experiment (T2) with significant difference. however both resins were above clinical recommendation (65 MPa): CAD/CAM PMMA (FS=124,4±10,5 MPa; FM=3048,2±475,6 MPa) and Conventional PMMA (FS=102,83±11,7 MPa; FM= 2717,3±408,2 MPa).

# 4 Conclussions and final considerations

# 4 CONCLUSIONS OR FINAL CONSIDERATIONS

CAD/CAM PMMA resin showed higher mechanical values in terms of microhardness and flexural properties at baseline when compared to conventional PMMA. However, CAD/CAM PMMA resins could be safety disinfected with the tested chemical solutions and would be above the minimal recommendations for clinical acceptance.

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# Annexes

# Annex 1

## Manuscript Details

| | |
|---|---|
| **Manuscript number** | SDENTJ_2020_418 |
| **Title** | Does chemical disinfection affect the superficial properties of CAD CAM resin blocks? |
| **Short title** | Disinfection on CAD CAM base denture |
| **Article type** | Full Length Article |

**Abstract**

Complete dentures are being fabricated by computer-aided design and computer-aided manufacturing (CAD CAM) showing high mechanical and superficial properties. The purpose of this study was to evaluate the effect of chemical disinfection on the superficial roughness (Ra) and Knoop hardness (KHN) of a CAD CAM resin block after 14 and 30 immersion cycles. Quadrangular specimens (12x3mm) were divided into 2 groups: Control Group (n=10)(heat and pressure-controlled polymerization, Vipi Cril Plus, VIPI®) and a CAD CAM group (n=10)(pre-polymerized resin pucks, Vipi GUM, VIPI®). The immersion solutions were Control Group (deionized water), H1 (Sodium hypochlorite 1%) and C2 (chlorhexidine gluconate 2%). The immersion cycles were evaluated according to Baseline (0 cycles), T1 (14 cycles) and T2 (30 cycles). Measurements were applied on a contact profilometer (Roughness, Ra) and a hardness tester (Knoop microhardness, KHN). The results were analyzed using a 3-way ANOVA and a Tukey HSD pos hoc test ($p=0.05$). Roughness: At Baseline, the CAD CAM (0,17±0,02μm) showed no difference to conventional (0,18±0,01μm) resin. At T2, CAD CAM resins exposed to CG and H1 showed a reduction in Ra values, with significant difference among the solutions ($p<0,00$), groups ($p<0,00$), and their interaction with time ($p<0,01$). Microhardness: CAD CAM resin showed a higher value (20,3±0,5 KHN) than the conventional resin (18,6±0,5 KHN). CG and H1 did not affect KHN values ($p>0,05$) for both resins, but there was a significant difference between groups ($p<0,00$), time ($p<0,00$) and time*solution ($p<0,00$). However, the C2 reduced the KHN values for both resins at T1, and it was restored at T2. Disinfection solutions (H1 or C2) did not affect adversely roughness or hardness of the CAD CAM resin. Both tested materials demonstrated values above minimal clinical requirements.

| | |
|---|---|
| **Keywords** | Computer-aided design; Computer-aided manufacturing; base denture; disinfection; microhardness; roughness |

| | |
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# Annex 2

## The Journal of Prosthetic Dentistry

### Does continuous chemical disinfection affect mechanical properties of CAD/CAM PMMA

--Manuscript Draft--

| | |
|---|---|
| Manuscript Number: | |
| Article Type: | Research and Education |
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| Abstract: | State of the problem : Complete dentures fabricated by computer-aided design and computer-aided manufacturing (CAD/CAM) have shown higher mechanical properties when compared to conventional base denture resins, but there is no evidence of its performance after repeated disinfection immersions.<br>Purpose : The purpose of this paper was to analyze the effect of consecutive disinfection immersions on physical properties of CAD/CAM base denture blocks.<br>Materials and Methods : Two groups of base denture resins were tested: Heat-polymerized (VipiCryl, VIPI®) and milled blocks (VipiGum, VIPI®). The specimens were designed into quadrangular (12x3mm) (n=40) and rectangular (64x10x3,3mm) (n=240) specimens. Specimens were stored in water for 48 hours. Therefore, they were immersed in the disinfection chemical solutions: CG (control group, deionized water), H1 (sodium hypochlorite 1%), H05 (sodium hypochlorite 0,5%) and C2 (Chlorhexidine 2%). Each disinfection cycle represented a weekly disinfection process (10 min immersion). The immersion periods represented: baseline (0 cycles), 2.5 years (130 cycles) and 5 years (260 cycles). The analysis was based on the Roughness (Ra), Microhardness alterations (KHN), Flexural strength (FS) and Flexural Modulus (FM). The applied statistical tests were a 3-way ANOVA and Tukey HSD Pos Hoc Test were applied for all experiments, significance level of 5%.<br>Results: CAD/CAM PMMA showed higher flexural properties: flexural strength ($p=0,001$) and flexural modulus ($p<0,000$), than conventional PMMA. Microhardness KHN ($p<0,000$) was superior than conventional PMMA, but the chemical solution affected all resin in the surface roughness ($p=0,007$), values were under the 0,20 µm threshold for microbial adherence.<br>Conclusions : Within the limitations of this study, the CAD/CAM PMMA blocks can be safely disinfected without a negative effect on flexural and superficial properties. |