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Evaluation of flexural strength and degree of conversion of temporary crown materials at different aging periods in artificial saliva

Avaliação da resistência à flexão e do grau de conversão de materiais para coroas provisórias em diferentes períodos de envelhecimento em saliva artificial

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ABSTRACT

Objective: Evaluate the effects of different storage periods on flexural strength (FS) and degree of conversion (DC) of Bis-Acryl composite and Urethane dimethacrylate provisional restorative materials. **Material and Methods:** A total of 60 specimens were prepared from four temporary crown materials commercially available and assigned to four tested groups (n = 15 for each group): Prevision Temp, B&E CROWN, Primma Art, and Charm Temp groups. The specimens were stored in artificial saliva, and the FS was tested after 24 h, 7 d, and 14 d. A standard three-point bending test was conducted using a universal testing machine. Additionally, the DC was determined using a Fourier transform infrared spectroscopy (FTIR) device. The data were analyzed statistically using two-way ANOVA, Tukey`s HSD post-hoc test, and the Bonferroni test, all at a 5% significance level. For each group, a paired samples test was applied to compare the DC of the immediate and 24 h samples. **Results:** The highest FS value was found for the Prevision Temp material, while the Charm Temp material showed the lowest FS, with no statistically significant difference between the mean values of the groups at 24 h; while there were significant differences at 7d and 14 d of storage. However, within each group, the aging had no significant impact on the FS, except for an increase in the FS of the B&E CROWN group after 14 d. Prevision Temp also had the highest mean DC value. At each time interval, significant differences were recorded. Moreover, within each group of material, aging significantly increased the DC, except for the Primma Art. **Conclusion:** Bis-acryl composite resin materials exhibited higher flexural strength compared to traditional methyl methacrylate resin during the 14 d investigation period. Aging in artificial saliva did not significantly affect the mechanical performance of the tested materials. Materials with higher DC values showed greater flexural strength; where the Prevision Temp showed higher FS and DC values than the other tested materials.

KEYWORDS

Aging; Artificial saliva; Degree of conversion; Flexural strength; Temporary crown material.

RESUMO

Objetivo: Avaliar os efeitos de diferentes períodos de armazenamento na resistência à flexão (RF) e no grau de conversão (GC) de materiais provisórios à base de compósito de Bis-Acril e de Dimetacrilato de uretano. **Material e Métodos:** Um total de 60 corpos de prova foram preparados a partir de quatro materiais para coroas provisórias comercialmente disponíveis, divididos em quatro grupos testados (n = 15 por grupo): Prevision Temp, B&E CROWN, Primma Art e Charm Temp. Os corpos de prova foram armazenados em saliva artificial, e a RF foi avaliada após 24 horas, 7 dias e 14 dias. Um teste padrão de flexão em três pontos foi realizado usando uma máquina universal de ensaios. Adicionalmente, o GC foi determinado utilizando um espectrofotômetro de

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infravermelho com transformada de Fourier (FTIR). Os dados foram analisados estatisticamente utilizando ANOVA de dois fatores, teste post hoc de Tukey HSD e o teste de Bonferroni, todos com nível de significância de 5%. Para cada grupo, foi aplicado um teste pareado para comparar o GC entre as amostras imediatas e as de 24 horas. **Resultados:** O maior valor de RF foi encontrado para o material Prevision Temp, enquanto o material Charm Temp apresentou a menor RF, sem diferença estatisticamente significativa entre as médias dos grupos após 24 horas. Contudo, diferenças significativas foram observadas nos períodos de 7 e 14 dias de armazenamento. No entanto, dentro de cada grupo, o envelhecimento não teve impacto significativo na RF, exceto por um aumento na RF do grupo B&E CROWN após 14 dias. O Prevision Temp também apresentou o maior valor médio de GC. Em cada intervalo de tempo, foram registradas diferenças significativas. Além disso, dentro de cada grupo de materiais, o envelhecimento aumentou significativamente o GC, exceto para o Primma Art. **Conclusão:** Os materiais de resina composta à base de Bis-Acril exibiram maior resistência à flexão em comparação com as resinas tradicionais de metacrilato de metila durante o período de investigação de 14 dias. O envelhecimento em saliva artificial não afetou significativamente o desempenho mecânico dos materiais testados. Materiais com maiores valores de GC apresentaram maior resistência à flexão, sendo o Prevision Temp o material com maiores valores de RF e GC em comparação aos demais testados.

PALAVRAS-CHAVE

Envelhecimento; Saliva artificial; Grau de conversão; Resistência à flexão; Material para coroas provisórias.

INTRODUCTION

Permanent fillings represent one of the most rapidly advancing fields in dentistry. The use of permanent prosthetics is considered the most beneficial and convenient solution for patients [1]. However, prosthetic rehabilitation with permanent restorations involves multiple clinical and laboratory procedures at various stages. During these intervals, which can range from a few days to up to 20 days, patients need to maintain normal family and social activities. Therefore, modern prosthodontics relies on temporary crowns and bridges to provide patients with functional solutions while awaiting the final restorations [2-5].

Provisional restorations play a crucial role in fixed prosthodontics treatment, bridging the gap between tooth preparation and the placement of permanent prosthetics, such as veneers, inlays, onlays, crowns, bridges, and implants [1,3].

The strength of a prosthesis refers to the stress required to induce fracture or a certain degree of plastic deformation. One way to assess a prosthesis's ability to endure functional loads is by measuring the material's flexural strength (FS), also referred to as transverse strength. This indicates the material's resistance to a static load and combines aspects of compressive and tensile strength tests, including proportional and elastic properties limits [4,6].

The mechanical and physical properties of dental acrylic and resin-based materials (including dimethacrylate and composites) are influenced by the degree of polymerization. High levels of residual monomer can negatively impact properties, leading to reduced hardness, strength, wear resistance, and color stability. Furthermore, the oral mucosa and adjacent tissues, including the pulp, may get irritated by the residual monomer [7].

However, it was necessary to examine the mechanical properties of provisional materials immediately after mixing and curing, respectively, because they are fitted and luted directly after fabrication. Another key factor for ensuring long-term durability is the conversion of most monomers into polymers during the material's polymerization process, which results in an adequate degree of conversion (DC). A low DC leads to poorer mechanical properties and quicker degradation of dental restorations. Consequently, the DC of the double bonds within the resin matrix is considered crucial for both the mechanical performance and the longevity of the restoration [8,9].

The goal of the study was to evaluate the strength of materials used for provisional prosthetic fillings. The research sought to compare the physical and mechanical properties of four commercially available restorative materials. The null-hypothesis tested was two-fold: first; that there is no significant difference in the FS between the tested materials at different aging periods, and second that there would be no difference in DC among the provisional crown and bridge materials at different aging periods.

MATERIAL & METHODS

Four commercially available chemically polymerized provisional crowns and fixed dental prosthesis resins were utilized in the present study. Details of the materials used are provided in Table I. Based on a pilot study, the sample size was calculated at an 80% power and 95% confidence level with 10 MPa as a minimum expected difference between the means of the comparison groups and 9.5 standard deviation. The results indicated that each group should be composed of 14.17 specimens. Thus, 15 specimens were considered for each group and a total of 60 samples were chosen..

Sample preparation

Sixty bar-shaped specimens (25×2×2 mm), with 15 specimens for each provisional material, were prepared using a specially designed custom-made split Teflon mold (Figure 1a), according to ISO 4049 [10].

A layer of petroleum jelly was applied to the Teflon mold to facilitate the easy removal of the specimen after complete polymerization. Prior to sample preparation, a small quantity of the material was placed on a mixing pad without the auto-mixing tip to ensure both orifices were open. Each provisional material was then dispensed using the manufacturer's mixing tip and syringed directly into the mold, slightly overfilling it while it was positioned on a glass plate. To standardize the procedure, the time from the start of mixing to the end of dispensing into the mold was kept consistent at 1 min for all materials. After placing the material, a second glass plate was set on top of each unset material. The material was left to set in the mold for 15 min to ensure complete polymerization. Once fully set, the mold was carefully opened, and the specimens were carefully examined to eliminate samples containing visible defects such as cracks or bubbles. The excess was removed by gently abrading with 600-grit silicon carbide paper [11]. The specimens were checked by a vernier caliper for accurate dimensions (Figure 1b).

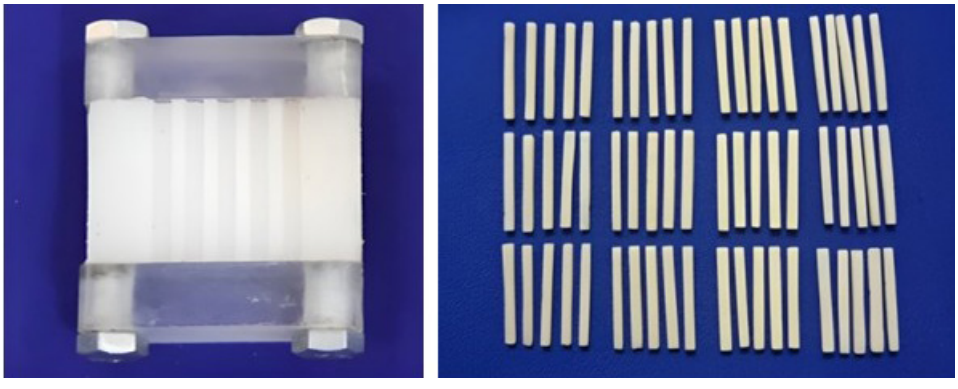
The specimens were allowed to dry at room temperature for 30 min. Subsequently, specimens of each material were randomly divided into four groups of 15 specimens each and assigned to three different storage periods.

Preparation of the artificial saliva and aging process

To prepare a neutral solution (pH 7.0) of artificial saliva, the following composition was used: 100 mL Na_2HPO_4 (2.4 mM), 100 mL of KH_2PO_4 (2.5 mM), 100 mL of NaCl (1.0 mM), 100 mL of $KHCO_3$ (1.50 mM), 100 mL of $CaCl_2$ (1.5 mM), 100 mL of $MgCl_2$ (0.15 mM), and 6 mL of citric acid (0.002 mM) [12].

Table I - Resin materials used in the present study for prosthetic filling

Materials	Manufacturers	Composition	Shade	Polymerization
Prevision Temp	Kulzer GmbH Germany	Multifunctional methacrylic ester. Bis-Acryl composite	A2	Self-cure
B&E CROWN	B&E South Korea	Bis-Acryl composite	A2	Self-cure
Primma art	FGM – Brazil	Bis-Acryl composite	A2	Self-cure
Charm temp	Dent kist -Korea	Barium Glass, Urethane dimethacrylate (UDMA)	A2	Self-cure



(a) (b)

Figure 1 - (a) The mold used in fabricating specimens and (b) Prepared specimens of provisional restorative materials.

Specimens from each material were stored for 24 h, 7 d, and 14 d at 37˚C in artificial saliva in labeled plastic jars. During the storage periods, the solutions were not changed. Figure 2 shows specimens from each material stored in artificial saliva in labeled plastic jars.

Flexural strength test

After each storage period, the specimens were taken out of the saliva bath. Residual artificial saliva was wiped off the surface with tissue paper, and the specimens were allowed to air-dry for 5 min.

The specimens were tested for FS using a universal testing machine with a three-point bending test (see Figure 3). The specimens were placed on supports spaced 20 mm apart, and the crosshead speed of the machine was set to 1 mm/min [13]. Each specimen was subjected to incremental loading until it flexed and fractured. The load required to break the specimen was recorded in kN and then converted to N. The F was calculated using the following Equation 1.

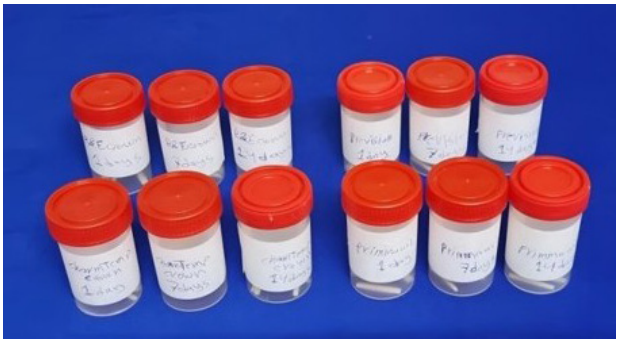


Figure 2 - Specimens stored in artificial saliva.

$$FS = 3FL / 2bd^2 \quad (1)$$

Here, F represents the force or load needed to break the samples; L is the distance between the supports which is 20 mm; b is the width of the specimen which is 2 mm and d is the thickness of the specimen, also 2 mm. The resulting value for FS is expressed in MPa where 1 MPa equals 1 N/m^2.

Fourier Transform Infra -Red Spectroscopy (FTIR)

The DC was measured using a Spectrum™ 100 FTIR device (Bruker, Germany) equipped with a universal diamond ATR unit (spectral range: 4000–500 cm^{-1}; spectral resolution: <0.5 cm^{-1}). For the analysis, 10 specimens from each temporary material were prepared using the same sample preparation technique previously outlined. For each material, five specimens were tested immediately after mixing and five after 24 h. To determine the DC, the FTIR spectra of the mixed materials were collected immediately after mixing (4 scans per specimen) and also after 24 h.

In the present study, the DC (%) was calculated by comparing the proportion of residual carbon double bonds in the sample at 24 h to the amount present immediately after mixing using the internal standard method. The quantity of remaining carbon double bonds was assessed from the absorbance spectrum, specifically between the aliphatic double bond peak at 1637 cm^{-1} and the aromatic double bond peak at 1608 cm^{-1}, before and after polymerization using the baseline method. The absorbance peak at 1637 cm^{-1} is attributed to aromatic double bonds.

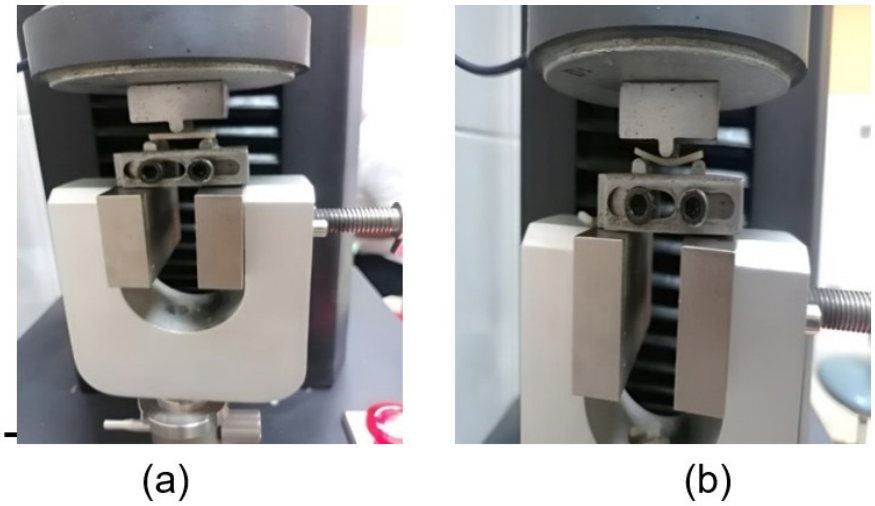


Figure 3 - Specimens in the universal testing machine (a) unloaded and (b) loaded conditions.

The degree of conversion for each material was determined using the following Formula 2

$$DC\% = 1 - \left\{ \frac{(1637/1608)\ \text{peaks height after polymerization}}{(1637/1608)\ \text{peaks heights before polymerization}} \right\} \times 100\% \quad (2)$$

Statistical analysis

Flexural strength data were assessed using a two-way ANOVA test ($P<0.05$) to detect significant differences between materials and aging conditions. This was followed by a Tukey´s HSD multiple comparison test ($p<0.05$) to pinpoint the specific factors affecting the FS values. Statistical analysis for the DC data of the groups of tested materials was performed using one way analysis of variance (ANOVA) and the Bonferroni test at a significance level of 5%. Paired samples test was applied to compare the DC of the immediate and 24 h periods in each group of the tested materials.

RESULTS

Flexural strength

The mean, standard deviation, and *P* values of the FS among groups and different storage times are presented in Table II. The highest FS value was found for the Prevision Temp material, while the Charm Temp material showed the lowest FS value.

Two-way ANOVA of the FS results showed no statistically significant difference between the mean values ($p > 0.05$) of the groups at 24 h, while there were significant differences at 7 and 14 d of storage times within each group. Aging had no significant impact on the FS, except for an increase in FS in the B&E CROWN group after 14 d.

Degree of conversion (DC) analysis

FTIR analysis Immediately

The DC was determined by analyzing the FTIR results from each sample and calculating the percentage for each sample group. Significant differences in DC values for the temporary materials were found in the present study ($p < 0.05$). The mean values and their standard deviations (SD) along with the *P* values are presented in Table III and illustrated in Figure 4. Prevision Temp had the highest mean DC value, with significant differences among the tested material groups at each time interval. ($p < 0.05$). In relation to aging within each material, increases in DC values were recorded, which were significant, except for the Primma

Table II - Descriptive statistics, two-way ANOVA test, and Tukey´s HSD test for comparison of significance of FS among the different groups at different storage times

Groups	24 h	7 d	14 d	F	*p* value
	Mean (±SD)	Mean (±SD)	Mean (±SD)		
Prevision Temp.	94.20 (8.93)^{Aa}	102.80 (3.12)^{Aa}	98.80 (5.45)^{Aa}	1.011	.393
B&E CROWNs	85.00 (6.32)^{Aa}	85.40 (6.63)^{Ba}	98.00 (7.48)^{Bb}	4.690	.031
Primma Art	91.20 (4.47)^{A}	94.40 (4.83)^{AB}	91.00 (5.05)^{AB}	.958	.411
Charm Temp.	78.80 (9.49)^{A}	79.40 (7.14)^{B}	79.80 (7.30)^{B}	.015	.985
F	2.852	14.164	9.828		
p value	.070	.000*	.001*		

Uppercase letters demonstrate column differences, while lowercase letters demonstrate raw differences ($p > 0.05$).

Table III - Descriptive statistics, one-way ANOVA test, Bonferroni test, and paired t test for comparison of significance of DC values among the different groups at different storage times.

Groups	Immediate	24 h	Paired t test	*p* value
	Mean (SD)	Mean (SD)		
Prevision Temp.	46.610 (4.430)^{Aa}	52.108 (2.661)^{Ab}	3.863	0.018
B&E CROWNs	33.976 (1.581)^{Ba}	40.570 (2.795)^{Bb}	3.647	0.022
Primma Art	42.250 (2.828)^{Aa}	46.342 (2.682)^{Ca}	1.878	0.134
Charm Temp.	34.120 (2.709)^{Ba}	40.062(2.848)^{BDb}	4.870	0.008
F	20.875	21.218		
p value	0.000	0.000		

Uppercase letters demonstrate column differences, while lowercase letters demonstrate raw differences ($p > 0.05$).

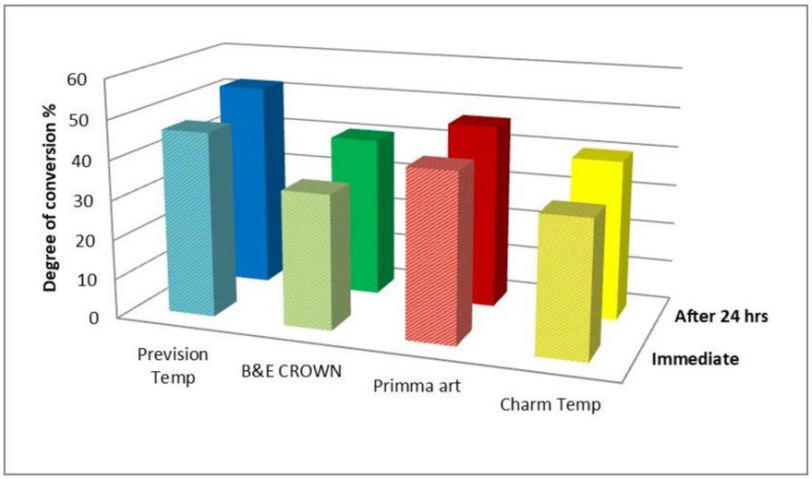


Figure 4 - Mean and standard deviation for DC (%) of the tested temporary prosthetic filling materials.

Art. At the immediate time of testing, significant differences between each pair of materials were observed, except between the Prevision Temp and Primma Art groups, and the B&E CROWN and Charm Temp groups.

FTIR analysis after 24 hours

The DC (DC%) mean values obtained from different temporary materials after 24h showed that the Prevision Temp group had the highest mean DC value, and significant differences between each pair of materials were observed, except between the B&E CROWN and Charm Temp groups.

The majorityof the groups demonstrated no statistically significant differences between the immediate and 24 h ($P < 0.005$) time periods, and the DC values after 24 h showed higher mean values than the immediate measurement. However, Prima Art showed no significant difference between the two time intervals.

DISCUSSION

Provisional fixed dental prosthesis are fundamental elements of fixed prosthodontic treatment success. However, it must meet biological, esthetic, and mechanical criteria. These criteria involve the ability to withstand functional loads, resist removal forces, maintain proper alignment of the abutments, protect the pulpal tissues, prevent bacterial contamination and preserve the periodontal tissues [14,15].

Flexural strength refers to a material's ability to resist bending without fracturing, which is essential for dental restorations to endure the forces encountered during chewing [16]. It is a key property for provisional restorative materials used in long-term provisionalization since it plays a crucial role in the success of fixed prosthodontic treatments. Additionally, the DC of the material can reflect both its mechanical properties and the durability of the restoration [8]. It can be anticipated that interactions between saliva, food particles, and beverages in the oral environment might damage and degrade dental restorations [15]. Therefore, the present study was carried out to investigate the effects of different storage periods on the FS and DC of four bis-acryl resin provisional restorative materials. According to the result of the present study, there are significant differences in the FS and DC values among the tested materials with significant effect for the aging periods since the FS enhanced with time. Therefore, the null-hypothesis was rejected.

Within each group of materials, aging had a non significant effect on the FS, however, the FS increased in the B&E CROWN group after 14 d. Firstly, this may be attributed to the continuous exposure to moisture which could induce further cross-linking, improving the internal structure. Secondly, the storage in artificial saliva allows stress relaxation, reducing internal tensions, leading to higher FS over time [17]. Bis-acryl composites with specific groups demonstrated better FS compared to those containing urethane dimethacrylate (Charm Temp). However, the incorporation of multifunctional methacrylic ester into the bis-acryl composite improved its FS, similar to the performance observed with the Prevision Temp group. All provisional resin materials evaluated in the present study exhibited FS exceeding the ISO 4049 limit of 50 MPa,

measured 24 h after mixing [18]. The FS of all bis-acryl resins notably improved after 24 h of storage and continued to maintain these elevated levels after 7 days of storage. It is important to highlight that, in comparison with other studies, there is limited information in the literature regarding the tested materials. Direct comparison among various studies cannot be done since this property is material specific and was continuously developed to improve the material properties.

Based on their chemical composition, provisional materials can be categorized into two primary groups. The first group consists of acrylic resin-based materials, which includes polymethylmethacrylate (PMMA) and polyethylene or butyl methacrylate (PEMA). The second group encompasses composite resins such as urethane dimethacrylate (UDMA) and bisphenol A-glycidyl dimethacrylate (Bis-GMA) [19,20]. In relation to the effect of storage time, the current results agree with the studies by Balkenhol et al. [21] They observed that all bis-acryl resin materials which are auto-polymerized exhibited low FS 10 min after mixing. However, this strength increased after 1 to 72 h of storage in water at 37°C and also after thermo-cycling. This early low strength could be attributed to insufficient cross-linking between oligomers during the initial setting phase. As cross-linking progresses over time, the materials exhibit greater fracture resistance. Additionally, stress buildup within the polymer network during polymerization may make the materials more prone to fracture during the initial setting phase [22].

The mean FS of the Prevision Temp group specimens, which contains polymethyl methacrylate (PMMA), is substantially higher than the average flexural strength of the Charm Temp specimens, which contains urethane dimethacrylate (UDMA) after 7 and 14 d. The reason for the difference in FS can be partially attributed to differences in chemical composition. The polymerization process is vital in determining the FS of various materials since it involves the chemical reaction where monomers, the basic units of polymers, link to form a more complex structure. Partial polymerization can lead to structural weaknesses, decreased bond strength between polymer chains, and decreased mechanical characteristics. When used in various provisional materials, the monomers exhibit differences in characteristics such as the exothermic heat generated during polymerization and resistance to shrinkage. However, during polymerization, resin shrinkage tends to occur towards the center of the mass, which can cause variations in FS. The lightly polymerized urethane dimethacrylate (UDMA) resin showed the lowest FS, highlighting a considerable strength disparity between materials. For the UDMA specimens, excess material was removed during the initial polymerization phase and then placed back into the mold for complete curing. This process might have caused specimen distortion and alterations in FS [23,24].

The current result is in agreement with Poonacha et al. [23] since they compared the FS for three provisional materials, and they found that the FS of methacrylate resin decreased significantly, whereas bis-acrylic composite resins exhibited a notable increase in FS after being stored in artificial saliva for 24 h. Further support was gained from Mehrpour *et al.* [25], when they compared the FS of five interim restorative materials. They stated that Bis-acryl resins were statistically superior to traditional methacrylate and light-cured resins. Therefore, they recommended that application of bis-acryl resins should be deliberated in patients with heavy occlusion and in cases that need long-term use of interim restorations.

The current results of the DC support and justified the FS results since greater FS values combined with greater DC values . Several techniques have been described for assessing the DC in resins; one of them being Fourier transform infrared spectroscopy. The use of FTIR in the present study offers several benefits, including specificity, sensitivity, high reliability and cost-effectiveness [21,26,27].

In the present study, the tested materials showed decreased DC values ranging between 33.9% to 46.6% when measured immediately, and 40% to 52% after 24 h.

This was in agreement with previous studies since they stated that the DC of acrylic resin based temporary crowns and FPD materials were lower than those of restorative composite resins [21,26,27]. This is because provisional crown materials have a greater proportion of di-methacrylate monomers compared to restorative composite resins. As the amount of di-methacrylates in these composites increases, the DC generally decreases [27].

FTIR analysis confirmed that the DC after 24 h showed higher mean values than the immediate measurement with no significant differences. This result is in agreement with Altarazi et al. [28] who found that no significant difference ($P > 0.05$) in DC was observed when the post-curing time was extended from 20 to 50 minutes. Balkenhol *et al.* found a positive relationship between the duration of storage and mechanical properties [21]. Koumjian and Nimmo observed similar findings and additionally found that dry storage yielded higher transverse strength values for all materials compared to wet storage. Moreover, several earlier studies have demonstrated significant improvements in the mechanical properties of specific bis-acryl and PMMA interim resin materials when comparing storage times of 1 h to 24 h [14,29].

Prevision Temp and Primma Art both have a relatively higher DC than the B&E CROWN and Charm Temp. This result may be attributed to the correlation between the DC and rate of polymerization. Consequently, a quicker setting time typically results in a lower DC. After polymerization, any remaining unpolymerized monomer can impact the mechanical and physical properties, as well as biocompatibility, potentially decreasing dimensional stability and strength. Therefore, the higher DC mean of the Prevision Temp and Primma Art can improve the FS [27].

The study found that variations in the mechanical properties of provisional materials are linked to the type of monomer system employed [4], and the chemical composition of the materials [30]. A contemporary category of materials used for provisional crowns and FPD are di-methacrylate based composites, developed to address the issues associated with mono-methacrylates. During polymerization, these di-methacrylate monomers form cross-links which restrict the movement of the monomers due to the early solidification of the polymer network. Additionally, methacrylate groups on polymer chains that have not reacted cannot move through the matrix because they are already bonded to the polymer [27,31].

One of the limitations of the current study is that it was an *in vitro* study, which differs from what occurs in the clinical conditions inside the oral cavity where additional considerations for temperature, moisture, and pH are required. Moreover, the present study only evaluated the FS and DC, which justified the mechanical behavior. Therefore, additional studies could be conducted on other properties such as fatigue strength, tensile strength, repairability, color stability along with solubility, biocompatibility and permeability. All that could be conducted in the future as *in vitro and in vivo* studies.

From a clinical perspective, all tested interim crown materials demonstrated FS values exceeding the ISO 10477 minimum standard of 50 MPa, making them suitable for interim restorations [32]. The FS of the materials remained unaffected after aging, which is a positive feature for interim crowns to withstand stress and occlusal load [33]. Bis-acryl composite resin provisional materials are preferred over methacrylate resins due to their superior mechanical properties. For cases requiring high mechanical strength after fabrication, bis-acryl composite resins, particularly the Prevision Temp, are recommended as the best option.

A lower DC is associated with a lower polymerization rate and a greater amount of unpolymerized monomer which can negatively impact the material's mechanical properties as well as its biocompatibility. This can lead to reduced dimensional stability, strength, wear resistance, and softening of the resin [34]. Furthermore, unpolymerized monomers can leach into the oral environment, potentially causing cytotoxic effects on the pulp and oral mucosa, inhibiting protein synthesis in oral epithelial cells [35]. Therefore, a higher DC improves the biocompatibility of the polymer-based provisional crowns and fixed partial dentures.

CONCLUSION

Within the study's limitations, it can be concluded that all bis-acryl composite resin materials exhibited higher FS compared to traditional methyl methacrylate resin over the 14 d investigation period, with the Prevision Temp outperforming the B&E CROWN and Primma Art. Aging in artificial saliva did not significantly affect the mechanical performance of the tested materials. Additionally, materials with higher DC values showed greater FS. Clinically, bis-acryl composite resin materials are recommended when high mechanical strength is crucial.

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Author's Contributions

HAA: Conceived, designed the analysis, and writing draft. ZAAI: Collected the data. MAM: Performed the data analysis. SAN: Formal analysis, Validation, Supervision, Reviewing and Editing.

Conflict of Interest

We declare no conflicts of interest related to the present article. The views expressed are entirely those of the authors and have not been affected by any financial or personal relationships.

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Regulatory Statement

The present article did not include the use of hazardous materials, living organisms, or any procedures that could potentially harm the environment. There was no requirement to adhere to specific regulations related to occupational health and safety or environmental protection. All appropriate steps were taken to ensure adherence to ethical research standards and laboratory safety protocols.

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