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an *in vitro* study

Oriana Karolina Caldeira Ribera

Tese conducente ao **Grau de Mestre** em **Reabilitação Oral**

—

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Trabalho realizado sob a Orientação de
António Sérgio Silva e José Manuel Mendes.

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Article

Influence of popular beverages on the fracture resistance of implant-supported bis-acrylic resin provisional crowns: an *in vitro* study

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Abstract: Implant-supported provisional restorations are critical for improving the esthetics and shaping of the peri-implant tissue. The mechanical properties of these provisional materials can be influenced by saliva, food, beverages, and interactions between these materials in the oral environment. Therefore, integrity of provisional restorations should be preserved throughout the treatment period. This study aimed to evaluate the fracture strength of implant-supported polymethyl methacrylate (PMMA) provisional restorations made of computer-aided design and computer-aided manufacturing when immersed in different solutions at a controlled temperature of 37° C for 7 days. Each analog-pillar-crown set was submerged in different liquids (distilled water, tea, coffee, red wine, and Coca Cola®) for 1 week at a controlled oral temperature of 37° C. The samples were then subjected to fracture forces. The moment of fracture of the crown was recorded and compared with those of the other samples. Specimens immersed in distilled water (control group) had the highest fracture resistance (mean [M]=1331.00, standard deviation [SD]=296.74), while those immersed in tea had the lowest mean strength to fracture (M=967.00, SD=281.86). Nutritional deficiency and inappropriate eating habits influence the fracture strength of temporary crowns, rendering them more elastic or less resistant to fractures.

Keywords: fracture resistance; CAD/CAM; polymethyl methacrylate; provisional restorations; dental implant

1. Introduction

Provisional implant-supported restorations are critical for improving esthetics, contouring, and shaping of the peri-implant tissue architecture. Proussaefs et al. suggested the term "guided tissue healing" to describe the use of a provisional restoration for guiding soft-tissue architecture. This is a state-of-the-art approach in implantology [1,2], which also allows rehabilitation during the period of osseointegration, and restores function, phonetics, esthetics, and adaptation to the final shape of the restoration [3,4].

The fracture resistance of temporary materials is generally low; parafunctional habits, diet, and time are important factors that influence the fracture resistance. Fracture strength should be considered when selecting a temporary material for clinical use [3,5,6].

Strength tests are conducted to predict the fracture toughness of dental materials [7]. Since the strength of a material greatly influences its clinical performance [9], differences attributable to the effects of intraoral dietary solvents could be observed upon evaluating the strength of materials [5,10].

Fixed provisional restorations are fabricated using various resin-based materials [11]. Currently, there is no provisional material that meets the ideal requirements for all clinical situations. Dentists usually choose a product based on the ease of handling, esthetics, and cost [10,12]. Traditionally, polymethyl methacrylate (PMMA) is available as solute and solvent form and has a chemical polymerization process [2]. The advantages of this type of material are good marginal fit and transverse strength, thus providing a more durable restoration. PMMA has good polishability but low abrasion resistance [5, 11].

Computer-aided design and computer-aided manufacturing (CAD/CAM) technology in the fabrication of temporary crowns allows the shaping of materials with high precision, which cannot be easily achieved using a traditional method [13]. This process improves the physical properties of the materials over traditional methods [14,15]. CAD/CAM blocks are manufactured with an interface that facilitates cementation on a titanium base, allowing the fabrication of screw-retained provisional restorations on the implant [16].

Some solvents, particularly those with acidic components, can penetrate the organic polymer network, causing bulking and separation of the matrix filler phases, followed by softening of the polymers and chemical dissolution. In addition, the erosive effects of weak intraoral acids (citric and lactic acids) on inorganic fillers can contribute to a decrease in the hardness of the materials. Therefore, the chemical environment of the oral cavity may critically influence the degradation of restorations [5,7].

Fractures are a common cause for failure of temporary restorations; although they should be designed to avoid failure, they may still occur and cause discomfort to the patient. Thus, the mechanical strength of provisional crowns is important and should be considered to ensure clinical success while maintaining occlusal balance, preferably without the use of pontics [9,14].

This study aimed to evaluate the fracture strength of implant-supported PMMA provisional restorations made of computer-aided design and computer-aided manufacturing (CAD-CAM) when immersed in different solutions (popular beverages) at a controlled temperature of 37° C for 7 days. The specific objectives of this study were to evaluate the fracture resistance of temporary cemented crowns on implants, determine the influence of different solutions on the fracture resistance of temporary crowns, determine the solution that affects the fracture resistance of temporary crowns the most, and compare the qualitative results obtained in other studies. The null hypothesis was that the type of beverage does not influence the fracture resistance of PMMA provisional implant-supported crowns, and that oral temperature does not influence the fracture of crowns immersed in different substances.

2. Materials and Methods

2.1. Materials

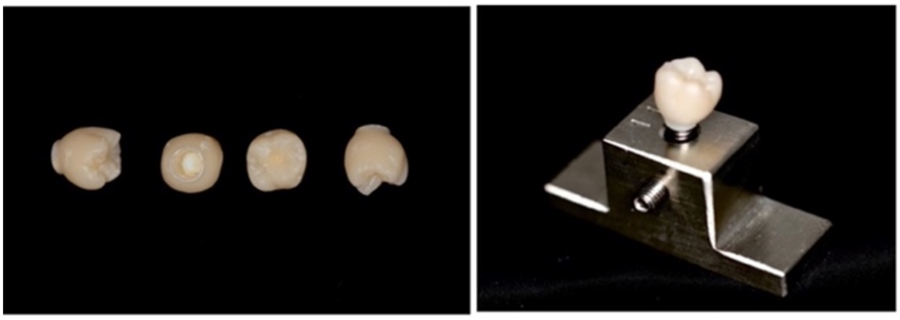
All the materials used in this study were selected based on their importance and utility in dentistry as well as their stability under normal use and storage conditions. All the materials and chemicals were used in accordance with the manufacturers' standards.

2.2. Methods

A standard laboratory protocol was established and employed to test all the selected samples at the Oral Pathology and Rehabilitation Research Unit, University Institute of Health Sciences (IUCS), CESPU, Gandra, Portugal.

2.2.1. Preparation of the sample

Sixty identical PMMA crowns milled with a CAD-CAM 5-TEC system (Zirkonzahn®, Gais, South Tyrol, Italy) were used in this study. These provisional crowns (Figure 1a) were divided into five groups of 10 crowns each. Each crown was cemented on a titanium abutment with Multilink resin cement® (Ivoclar®, Bremschlstraße, Bürs, Austria). All titanium abutments were screwed to an internal hexagon analog with 4.1 platform (IPD®, Mataró, Barcelona, Spain). The analogs were adapted to a previously prepared titanium base (Figure 1b), which served as a support table to fixate in the testing machine, Instron®, Electropuls E10000 Linear-Torsion (Norwood, MA, USA). The following aqueous solutions were used: distilled water, green tea, coffee, red wine, and Coca Cola®.



(a) (b)

Figure 1. a) PPMA crowns on CAD-CAM phases, and **b**) Implant with PMMA crown replica, adapted to the support table. PMMA, polymethyl methacrylate; CAD-CAM, computer-aided design and computer-aided manufacturing

The five groups with 10 provisional PMMA crowns, screwed on the replicas, were submerged in the different aqueous solutions separately. Each group was exposed separately for 7 days in a thermostatic oven at 37° C. Subsequently, all the crowns were subjected to force application at a constant rate until the occurrence of fracture.

2.2.2. Artificial aging

The five groups were separately subjected to artificial aging in different solutions for 7 days in a thermostatic oven at 37° C, similar to the environment of the oral cavity. A temperature-controlled Memmert Peltier-cooled incubator (Incubator IPP110 Plus) was used for artificial aging. Approximately 50–100 mL of different liquids were used on each sample

(Figure 2) to ensure that all the crowns were completely submerged in the liquids and placed inside the oven.

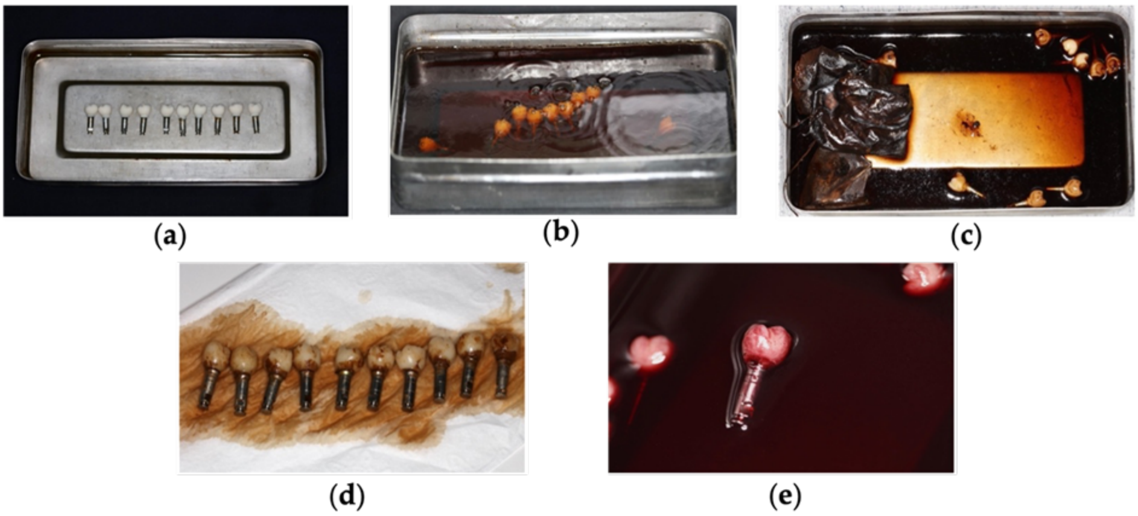


Figure 2. Artificial aging : **a**) distilled water; **b**) Coca Cola; **c**) tea; **d**) coffee; **e**) red wine

2.3. Compression test to measure the fracture strength

The fracture strength of temporary materials is subject to the geometry of the restoration and the aging processes that occur in clinical applications. Although the laboratory values of flexural strength under static load may not reflect intraoral behavior, these values are useful for comparing materials under controlled situations and can be a useful predictor of clinical performance (Yanikoğlu et al. 2014) (Delong and Douglas 1983).

The Instron Electropuls E10000 LT (Figure 3a) is a dynamic fatigue testing machine with a linear dynamic capacity of ±10 KN, linear static capacity of ±7 KN, linear stroke of 60 mm, torque capacity of ±100 Nm, torsional stroke of ±135°, and a diurnal aperture of 877 mm, which allows static and dynamic axial and torsional testing according to ISO 7500-1:2018. It has an accredited calibration force of up to 5 MN according to ISO 7500-1 and ASTM E4. A support table was attached to the machine for adaptation of the simulation structures to ensure that all the models were adjusted and produced equal compression.

The test structures (analogs, interphases, and crowns) were screwed onto the titanium base using a torque wrench in the INSTRON universal testing machine (Electropuls E10000LT) with a load cell having a capacity of 10,000 N. A traditional static load test per occlusal area of the crowns was applied in the central groove, which was progressively increased by 1 mm/min toward the structure until the occurrence of fracture (Figure 3b).

(a) (b) (c) (d)

Figure 3. (**a**) Instron® universal testing machine; (**b**) occlusal static load on a crown; (**c**) crown fracture (**d**) crowns after mechanical compressive strength test

The test results were transferred to WaveMatrix® version 2.0 Dynamic Test Software (Instron®, Norwood, MA, USA). This software allows users to define and run tests and acquire data for a wide variety of dynamic and quasistatic applications. Thereafter, all the values and data were transferred to Microsoft Office Excel®, version 16.0 (Redmond, WA, USA) where statistical analysis of the obtained data was performed.

2.4. Statistical Analysis

Data were analyzed using R (version 4.2.2) [18]. Description of the variables was performed with the presentation of means (M) and standard deviations (SD) as well as box and line diagrams with lateral dispersion of the points using the jitter function. The comparison of the mean strength to fracture (N) and time to fracture (s) according to type of substance was performed using one-way analysis of variance. A comparison of the mean strength-to-fracture (N) according to substance type, while controlling for time to fracture (s), was performed using analysis of covariance. The sequential sum-of-squares method was used when the samples were balanced, that is, with the same number of elements. The effect size was calculated with $\eta 2$ in the case of simple models and $\eta 2p$ in the case of multiple models, considering the cutoff points: $\eta 2 < 0.06$ (small effect), $\eta 2 < 0.14$ (moderate effect) and $\eta 2 \geq 0.14$ (large effect) and $\eta 2p < 0.13$ (small effect), $\eta 2p < 0.24$ (moderate effect), and $\eta 2p \geq 0.26$ (large effect). The significance level considered was 5% [8,18,26].

3. Results

In this study the fracture strength of PMMA provisional crowns submerged in five substances, namely, distilled water, coffee, tea, Coca Cola®, and red wine, at a controlled oral temperature of 37° C for 7 days were tested. Table 1 and Figure 4 present the results of the comparisons of the mean strength-to-fracture (N) and time-to-fracture (s) according to substance type. Tea had the lowest mean strength to fracture (M=967.00, SD=281.86), and distilled water had the highest fracture resistance (M=1331.00, SD=296.74). However, no significant differences were observed when comparing the fracture strength according to the various types of substances [$F(4,45)=1.89$ (p=0.128), $\eta 2=0.14$]. Moreover, the time to fracture was significantly associated with the substance analyzed [$F(4,45)=73.00$ (p<0.001), $\eta 2=0.87$], with a high effect size. Tukey's multiple comparison tests (Figure 5) revealed significant differences between distilled water and Coca Cola (p<0.001), distilled water and red wine (p<0.001), Coca Cola and coffee (p<0.001), red wine and coffee (p<0.001), Coca Cola and tea (*p*<0.001), and red wine and tea (*p*<0.001). Distilled water, coffee, and tea showed higher mean time until fracture compared with that of Coca Cola and red wine.

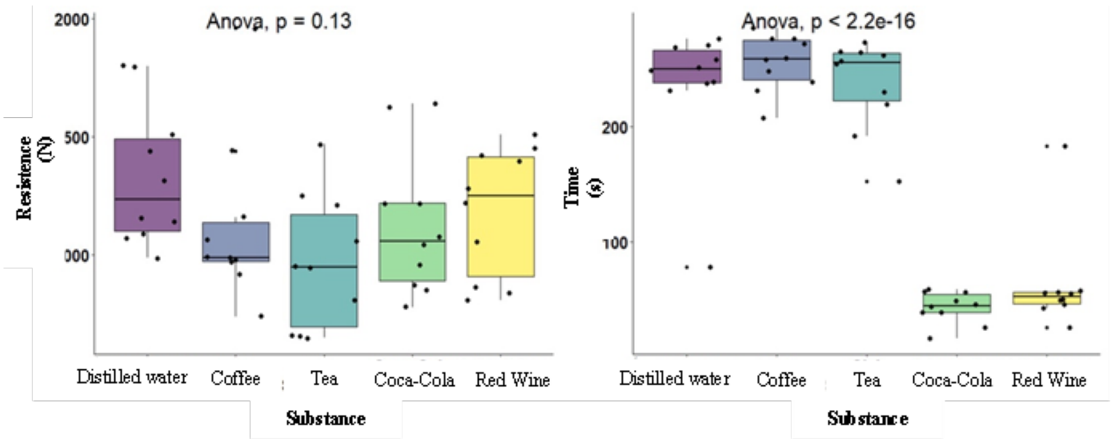


Figure 4. Box and line diagrams for the distribution of fracture toughness (N) and time to fracture (s) according to substance. ANOVA, analysis of variance

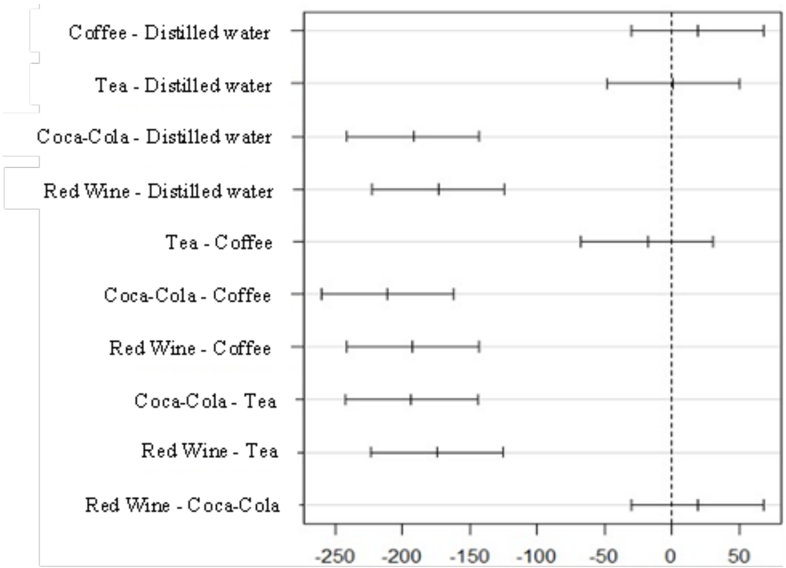


Figure 5. Tukey's multiple comparison test for the time to fracture (s)

Table 1. Univariate comparisons of fracture toughness (N) and time to fracture (s) according to the substance

	Fracture strength (N)		Time to Fracture (s)		
Substance	M	SD	M	SD	ANOVA
Distilled water	1331.00	296.74	235.66	57.24	Fracture Strength $F_{(4,45)}=1.89$ ($p=0.128$), $\eta^2=0.14$
Coffee	1122.00	345.18	254.81	24.09	
Tea	967.00	281.86	236.70	38.82	Time to Fracture $F_{(4,45)}=73.00$ ($p<0.001$), $\eta^2=0.87$
Coca Cola	1129.00	304.46	43.352	13.86	
Red wine	1185.00	272.53	62.432	43.52	

M, mean; SD, standard deviation; ANOVA, analysis of variance

Next, the interaction between the substance and time to fracture was evaluated based on the average force applied to the fracture. The results were significant [F (4, 40) = 2.43 (p = 0.0636), η2p = 0.20], with a high effect size. Observation of the heatmap (Figure 6) led to the conclusion that distilled water was conspicuous by consistently showing a higher strength and time to fracture in all the observations. Moreover, tea presented a high mean time to fracture but lower fracture toughness. Coca Cola and red wine had the lowest mean time to fracture, while coffee had the highest mean time to fracture.

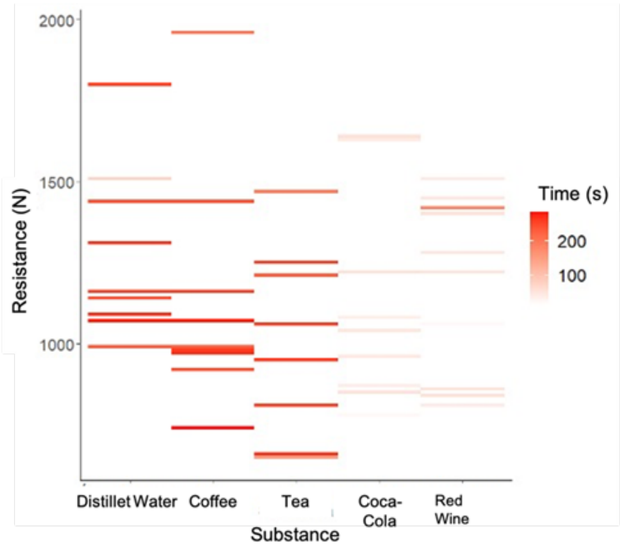


Figure 6. Heatmap for the association of strength to fracture (n), time to fracture (s) and substance

4. Discussion

Provisional implant-borne rehabilitation aims to provide protection, stability, and function between definitive treatments [15]. During treatment plan development, provisional restorations are used to determine esthetic and functional effectiveness. The prognosis of a fixed restoration depends on the quality of the provisional restoration [19,20,22].

For successful treatment, a temporary material should meet the biological, mechanical, and esthetic requirements. Resistance to functional loads and retention forces are the mechanical factors that should be considered when selecting temporary restorative materials for clinical use. Fracture of temporary restorations is one of the most common factors, which is uncomfortable and costly to both patients and clinicians [19,21].

In the oral cavity, saliva, food, beverages, and the interactions between these liquids can degrade and age dental restorations, causing changes in temporary restorations [21,22,23,25].

In this study, we tested the fracture resistance of implant-supported PMMA crowns submerged in different liquids (popular beverages) at a temperature of 37° C for 7 days, with the aim of evaluating the fracture resistance of the crowns.

According to Yanikog̃lu et al., provisional restorations soften upon exposure to organic acids and various liquid food constituents. Furthermore, when provisional restorations are soaked in saliva, disintegration occurs at the interface; therefore, the chemical environment in the oral cavity can critically influence the *in vivo* degradation of restorations. The authors also reported that the specimens were stored for 14 days in different solutions (coffee without sugar, cola, and burn energy) and distilled water (control group) to partially simulate the oral environment [5]. In our study, we obtained similar results, which corroborated those provisional restorations stored in coffee for 7 days demonstrated the lowest fracture resistance. Provisional crowns soften and become mostly elastic when the time to fracture decreases with exposure to various food and liquid constituents, such as tea and coffee (caffeine).

The normal pH of the oral cavity is mainly neutral (pH = 7). Any food or drink that can reduce the pH in the mouth from 5.2 to 5.5 can cause demineralization of any type of restoration or prosthesis [22,23] For example, the destructive effect of alcohol is attributed to the softening of the polymeric matrix. Unlike distilled water, alcohol has greater permeability in composites owing to its chemical characteristics. Alcohol molecules can easily diffuse into the resin matrix, causing an increase in volume. In addition, fluid infiltration through the material occurs, which increases dissolution. Alcohol can reduce the longevity of a temporary restoration by two mechanisms: either by creating stress cracks and thus decreasing the fracture resistance, or by the corrosive effect of alcohol on the surface of the temporary crown, accelerating fatigue fracture [23,25]. In our study, upon comparison with red wine, we found that alcohol not only directly influences the fracture resistance of temporary crowns but also lowers the mean times to fracture, making them much more susceptible to fracture and less elastic.

The surface hardness of a material is a complex mechanical property that is affected by several properties, including strength, proportional limit, ductility, malleability, and abrasion resistance. Diaz-Arnold et al. demonstrated that the hardness number linearly correlates with the transverse strength and modulus of elasticity. These authors demonstrated no difference in the fracture strength of provisional restorations after 48 h of storage in a moist or dry environment and stated that methacrylates are not cross-linked; without polymerization under pressure, air entrapment may occur, resulting in lower strength values [19]. This result does not coincide with that of our study but it is in agreement with the results of the study by Poonacha et al, where the authors documented that when exposed to aqueous environments, water absorption causes a subsequent mechanical deterioration of provisional restorations[24].

Although laboratory values of flexural strength under static load may not reflect intraoral behavior, these values are useful for comparing materials under controlled situations and can be useful predictors of clinical performance [10,21].

Akova et al. evaluated test specimens that were conditioned in food-simulating liquids for 1 week prior to testing. This period could be considered a long duration because temporary restorations come into contact with food and drinks only during eating and drinking, until the teeth are cleaned[5]. However, these chemical agents can become trapped in the margins, pores of poorly handled materials, and connectors of poorly fabricated provisional restorations [9]. This process can provide a constant supply of chemical agents and pathway for further diffusion into the restorative material, resulting in faster degradation [17,19], which was confirmed in our study. Although laboratory values of fracture strength under static load may not reflect intraoral behavior, the liquids studied directly influenced the fracture strength of the provisional crowns.

Lang et al. investigated the fracture resistance of temporary crown materials following 14 days of storage in distilled water and artificial aging. The authors observed low mechanical fracture behavior and total failure of the tested PMMA materials owing to deformation during the oral simulation. The authors also demonstrated that PMMA materials showed water absorption up to 32 μg/mm, mainly owing to the polar properties of the resin molecules, which can act as plasticizers, thereby reducing the fracture resistance of the materials. We obtained similar results concerning the plasticity of crowns that were submerged for 7 days in tea or coffee, where the provisional crowns became more elastic with a longer time to fracture; however the fracture resistance lowered because of caffeine [21].

Patients should be warned about the possible effects of alcohol on provisional restorations, especially if they need to be retained in the oral cavity for a long period [10,12,19].

5. Conclusions

Based on the results obtained and the methodology described in this study, we formulated the following conclusions:

- The PMMA crowns immersed in different liquids exhibited mechanical properties capable of withstanding masticatory forces after aging. Although the laboratory values of fracture strength under a static load may not reflect the intraoral behavior, the liquids used directly influence the fracture strength of temporary crowns.

- pH, and sugar, caffeine, and alcohol consumption are parameters that affect the structure, strength, and dissolution of temporary crowns, making them less resistant to fracture and more elastic in the case of caffeine.

- Crowns submerged in distilled water (control group) had the highest mean fracture strength and those in tea had the lowest mean strength to fracture, making provisional crowns more elastic. Similarly, the tests with Coca Cola® and coffee showed higher mean times to fracture of the provisional crowns.

- In our study we achieved statistically significant results on the strength and time to fracture of provisional crowns where they became soft and elastic with exposure to tea, coffee, and Coca Cola® (caffeine), which does not corroborate with the results of previous studies.

Author Contributions: Conceptualization, O.R and A.S.S.; Methodology, O.R and A.S.S.; Software. Validation, A.S.S and J.M.M.; Formal analysis, O.R, A.S.S and J.M.M.; Investigation, O.R, P.B and C.A.; Resources O.R.; Data curation, O.R, J.M and C.A.; Writing-original draft preparation, O.R, P.B.; writing-review and editing, A.S.S and J.M. Visualization, O.R and A.S.S.; Supervision A.S.S and J.M.M.: Project administration, O.R and A.S.S.; Funding acquisition, O.R, A.S.S and J.M.M.; All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

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