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THE BIAXIAL FLEXURAL STRENGTH AND WEIBULL ANALYSIS OF POLISHED AND GLAZED CAD/CAM POLYMETHYLYMETHACRYLATE PROVISIONAL MATERIAL

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ABSTRACT

Aim: To assess the influence of polishing and glazing treatments on the flexural strength of Polymethylmethacrylate (PMMA) provisional material.

Methods: Twenty-four PMMA discs (10 mm diameter x 2 mm thickness) were sliced from Yamahachi blank (Aichi, Japan). Then discs were divided according to the surface finish treatment into (n=8 in each); Group A: As milled with no surface finish, Group P: Polished, and Group G: Glazed. Polishing and glazing were performed following the manufacturer's instructions. All discs experienced 5000 cycles of thermocycling between 5 ± 2°C and 55 ± 2°C. Biaxial flexural strength test was carried out using a universal testing machine and the mode of failure was recorded by the same observer. Data was analyzed using one-way ANOVA followed by Tukey's post hoc test. Weibull distribution parameters were estimated using the maximum likelihood method.

Results: Flexure strength results showed that there was no significant difference between different groups. The highest strength value was found in Group A (139.89±33.07) (MPa) and the lowest value was found in Group G (115.24±21.39) (MPa). Group G had the highest Weibull modulus.

Conclusions: Neither polishing nor glazing had an influence on the flexural strength of CAD/CAM milled PMMA provisional material.

KEYWORDS: Provisional restoration, CAD/CAM, Polymethylmethacrylate, Strength.

INTRODUCTION

Advanced dental care has greatly improved with the use of computer-aided design and computer-aided manufacturing (CAD/CAM) technology, one of the many remarkable developments in the rapidly developing area of dentistry. [1] When compared to traditional techniques, digital technology aids in treatment delivery that is more efficient in terms of time, effort, and cost. [2], [3]

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Provisional restorations are used to preserve or stabilise prepared teeth between dental appointments. In order to achieve success, it is imperative that these restorations meet the biological, mechanical, and aesthetic criteria. [4] The construction of long-span bridges and the restoration of patients with parafunctional habits present significant challenges and requirements, especially in the context of interim restorations. These materials will not be able to bear the load of occlusal forces unless they possess a high degree of strength. [5] Yannikakis [6] claims that a duration of 30 days is regarded as a stage of long-term provisionalization. Long-term provisional restorations play a crucial role in certain clinical circumstances, such as oral implantation treatment or comprehensive occlusal therapy, that are exposed to significant functional stresses. [7], [8] Therefore, it is essential for the long-term provisional restorative material to possess favorable flexural strength, enhanced wear resistance, dimensional stability, low creation of marginal gaps, as well as higher resistance to staining and discoloration. [9]

Commonly used conventional provisional resin materials have varying chemical and polymerization characteristics, as well as physical and mechanical properties. These include hand-mixed polymethyl methacrylate (PMMA), polyethyl or polybutyl methacrylate (PEMA), and automixed dimethacrylates or bisacrylate composite resins. [10], [11], [12], [13] PMMA-based CAD-CAM polymers have been developed recently as an alternative to traditional temporary materials. The chemical structure of CAD-CAM PMMA-based polymers exhibits resemblance to that of traditional PMMA materials. Nevertheless, polymethyl methacrylate (PMMA) polymers used in computer-aided design and computer-aided manufacturing (CAD-CAM) systems have enhanced mechanical characteristics, significant cross-linking, enhanced uniformity, and minimal water absorption and solubility. These polymers have been stated to exhibit fewer production faults due to their polymerization process being conducted at elevated temperature and pressure, without any water interference. [14], [15], [16] The determination of the mechanical strength, stiffness, and rigidity of a material is significantly influenced by its flexural strength. A material exhibiting a higher flexural strength is generally more resistant to failure. [9]

The characteristics of the particles and the surface topology influence the surface roughness and mechanical properties of restorative materials. Localised stress accumulation areas can emerge in porous regions when materials with porosity are subjected to load. Thus, reduced porosity may have favourable mechanical effects. [17] Mechanical or chemical polishing is a commonly employed technique for reducing the occurrence of scratches and porosity. [18] Instead of applying the process of polishing, the use of surface sealants (such as glazes) has been implemented to diminish the presence of scratches and porosity. According to the findings of Emmanouil et al., [19] the use of various surface sealants on acrylic resin denture base materials resulted in an enhancement of both surface microhardness and wear resistance. Nevertheless, there is a dearth of research examining the impact of surface sealants and polishing methods on the flexural strength of CAD-CAM PMMA-based polymers.

The objective of this in vitro investigation was to assess the impact of polishing and glazing treatments on the flexural strength of CAD-CAM milled provisional material composed of polymethyl methacrylate (PMMA). The null hypothesis posited that the flexure strength of CAD-CAM milled PMMA-based provisional material would not be influenced by either polishing or glazing.

MATERIALS AND METHODS

Sample size calculation

To provide adequate statistical power and facilitate the testing of the null hypothesis, a power analysis was conducted. The minimum required sample number (n) was found to be 24 samples, with 8 samples allocated per group. The sample size was determined using G Power version 3.1.9.7, [20] which is a software tool commonly employed for calculating statistical power based on the examination of prior investigation findings. [21]

Samples preparation

A virtual cylindrical shape with a diameter of 10 mm was produced using computer-aided design (CAD) software (3Shape, Cambridge). Subsequently, the design was transferred to the milling unit (the CAM 5-S1 impression milling machine, Vhf in Baden-Württemberg, Germany) for the production of milled cylindrical blocks from Yamahachi PMMA blank (Aichi, Japan). The cylinder was sliced using an Isomet saw (Buehler, Lake Bluff, IL, USA) to obtain 24 discs measuring 2 mm in thickness and 10 mm in diameter. Subsequently, the dimensions of the samples were confirmed using a digital caliper. Then discs were divided into three groups according to the surface finish procedures (n=8 in each).

Group A : As milled.

Group P: Polished.

Group G: Glazed.

Polishing procedures:

Polishing procedures were performed using Enhance finishing and polishing kit (Dentsply, USA) by the same operator and following the manufacturer's instructions. Aluminium oxide discs mounted on a low-speed handpiece for 30 seconds in a circular motion were used to finish the samples. Next, a polishing cup (one cup for each specimen) and Prisma Gloss 1μm polishing paste followed by Prisma Gloss 0.3μm Extra Fine particles were used for 15 seconds of polishing.

Glazing procedures

The discs were finished using aluminium oxide discs, as previously mentioned, followed by the application of two subsequent clear glaze coats (Optiglaze, GC tricorporate, Tokyo, Japan). The application of each glaze layer was performed unidirectionally using a brush, followed by a 90-second light-polymerization process in an ultraviolet box.

Thermocycling

For each disc, thermocycling was done using a Robota thermocycler (Alexandria, Egypt). With a dwell time of 30 seconds in each bath and 20 seconds between baths at room temperature, the samples experienced 5000 cycles of thermocycling between 5 ± 2°C and 55 ± 2°C.

Biaxial flexural strength test:

A biaxial flexure test (uniform pressure on disc) with a ball on ring fixture was chosen for this study. Testing was done at a cross-head speed of 1 mm/min with a computer controlled materials testing machine (Model 3345; Instron Industrial Products, Norwood, MA, USA) with a loadcell of 5kN and data were recorded using computer software (Instron® Bluehill Lite Software). The test was conducted at room conditions (30 ± 1°C, and 70% ± 5% relative humidity). As shown in figure (1), each disc was placed on a 8-mm diameter circular knife-edge support and loaded centrally with a spherical indenter of 3.8-mm diameter. The polished surface of the disc was the tension side while the unpolished surface was the loaded one. A tin foil was placed between each sample and load applicator tip to facilitate a uniform distribution of the load. The bi-axial flexure strength was calculated according to the following Equation:

$$\sigma = P/h^2 \{(1+v)[0.485x \ In\ (a/h) + 0.52] + 0.48\}$$

where σ; the biaxial flexure strength (MPa), P; the measured load at fracture (N), a; the radius of the circular knife-edge support (mm), h; the specimen thickness and *v* the Poisson's ratio for the material. The load-deflection curves were recorded with computer software (Instron® Bluehill Lite Software). The mode of failure was visually inspected and percentages were calculated according to the number of fractured fragments.

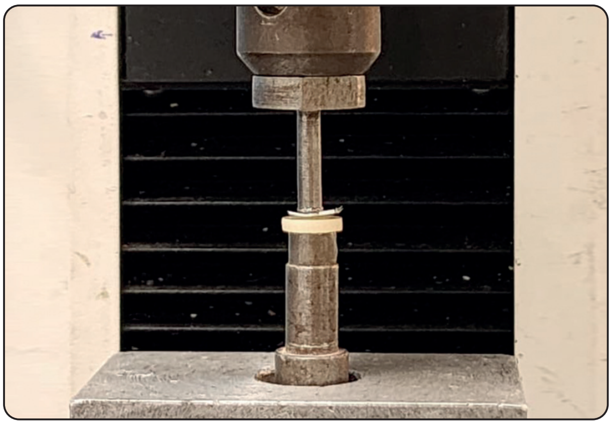

Fig. (1): Biaxial flexural strength test.

RESULTS

The numerical data was expressed in terms of mean and standard deviation (SD) values. The Shapiro-Wilk test was chosen to assess the assumption of normality. Levene's test was employed to assess the homogeneity of variances. The data exhibited a parametric distribution and homogeneity of variance and were subjected to analysis using a one-way ANOVA followed by Tukey's post hoc test. The parameters of the Weibull distribution were determined using the maximum likelihood method. For each test, the significance level was set at $p<0.05$. The statistical examination was conducted using R statistical analysis software version 4.3.1 for the Windows operating system. [22]

Biaxial Flexural strength results showed that there was no significant difference between different groups ($p=0.240$). The highest strength value was found in Group A (139.89±33.07) (MPa) followed by Group P (138.06±26.28) (MPa), while the lowest value was found in Group G (115.24±21.39) (MPa) (Fig. 2). Parameters of Weibull distribution based on the flexural strength data are presented in table (1) and the probability of failure plot is presented in figure (3). The highest modulus was found in Group G, followed by Group P, while the lowest modulus was found in Group A. While for characteristic strength, the highest value was found in Group A, followed by Group P while the lowest value was found in Group G. Observations of failure revealed that 75% of Group A had been fractured into three pieces, 75% of Group P had been fractured into four pieces and 100% of Group G had been fractured into three pieces. Figure (4) shows examples of different modes of failure.

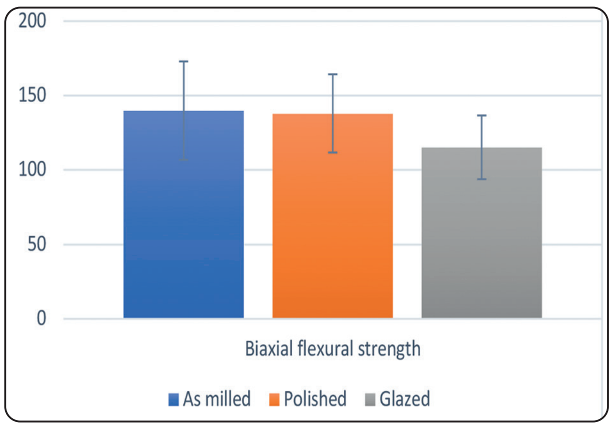

Fig. (2): Bar chart showing mean and standard deviation values (error bars) of biaxial flexural strength for different groups.

TABLE (1) Weibull distribution parameters.

Groups	Weibull modulus	Characteristic strength
As milled (Group A)	4.76	151.89
Polished (Group P)	5.95	148.06
Glazed (Group G)	7.35	122.70

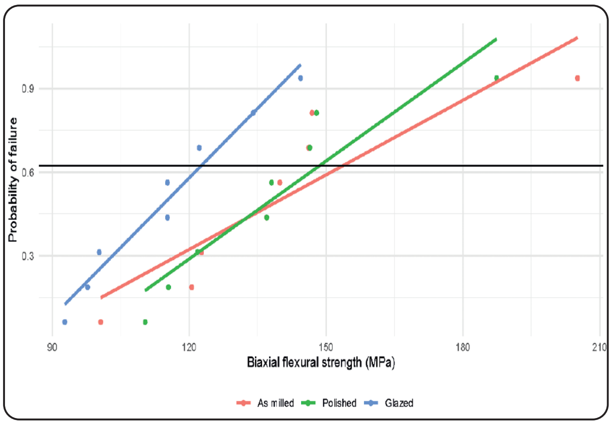

Fig. (3) Probability of failure plot of biaxial flexural strength data.

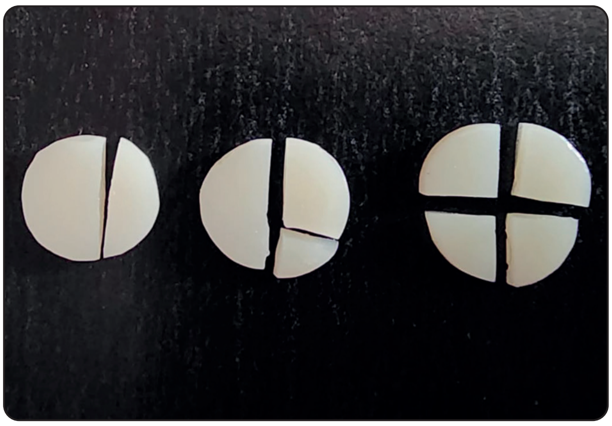

Fig. (4) Different modes of failure according to number of fractured fragments.

DISCUSSION

The durability of any restoration is significantly influenced by flexural strength, which is considered a crucial element. Provisional restorations have the potential to fracture when possessing extremely low flexural strengths. Several investigations have indicated that fractures represent a significant factor contributing to the clinical failure of provisional restorations. [(23)] The biaxial flexure strength test is a widely used approach for assessing fracture strength and estimating the mechanical forces that a material can endure. Although there are two popular procedures for measuring flexural strength, the three-point and the biaxial test, many researchers prefer the biaxial test because it does not lead to edge fracture complications. [(24)] In accordance with the findings of Padunglappisit et al. [(25)] and Sadek et al. [(26)], the diameter of the specimens utilized in this investigation was detected to be 10 mm. A thickness of 2 mm was established in order to replicate the occlusal clearance observed in crown preparation. Lupercio et al. [(27)] suggested that the utilization of the ball-on-ring flexural strength test was reliable. The findings of their study revealed that the highest magnitude of main stress was observed in the region of the disk that experiences tensile forces, namely within the area contained by the loading ball. Moreover, the rate of stress was found to be greatest at the center of the disk and gradually decreased as the radius of the disk increased.

Aging affects the mechanical behavior of provisional materials. [(28)] The variation in the number of cycles has been observed across different research studies. Morresi et al. [(29)] reported that 10,000 thermocycles are equivalent to one year of clinical use. Hence, in the current investigation, a total of 5,000 cycles were chosen to simulate the process of physiological aging over a period of 6 months, as documented in the research conducted by Yao et al. [(30)]

Flexure strength results of the present study showed that there was no significant difference between different groups. The highest strength value was found in Group A (139.89±33.07) (MPa) followed by Group P (138.06±26.28) (MPa), while the lowest value was found in Group G (115.24±21.39) (MPa). The findings of this work align with the research conducted by Çakmak et al., [(31)] which demonstrated that the flexural strength of CAD-CAM PMMA-based polymers was not impacted using traditional polishing techniques and surface sealants.

While it has been documented that surface glaze can enhance the smoothness [(32), (33)] and mechanical qualities of a surface by filling in microfissures and microdefects as a surface sealant, [34], [35] it is important to note that glaze tends to have limited resistance to abrasion and may not adhere effectively. [31] The aforementioned issues have been linked to the elevated viscosity of the substance, leading to inadequate distribution. Furthermore, it has been documented that the presence of an inadequately polymerized sealant film layer leads to the formation of microcracks. [33] Moreover, Dede et al. [32] have revealed that the process of thermocycling has the potential to generate contraction and expansion of the sealant layer. This phenomenon can lead to the formation of microcracks and the detachment of nonadherent surface particles due to temperature variations experienced during thermocycling. A total of 3000 thermocycles were administered. [32] In the present investigation, a total of 5,000 thermocycles were employed, potentially amplifying the impact of thermocycling on sealants. While the evaluation of surface sealant adherence was not conducted in the current investigation, the absence of a statistically significant distinction between the polished and glazed groups of provisional materials could perhaps be attributed to the potential loss of sealants during and following the thermocycling process. [31]

On the contrary, Thompson et al. [17] conducted an evaluation to assess the impact of various storage media, storage temperature, storage duration, thermocycling, post-polymerization thermal treatment, and application of a surface sealer on the microhardness and flexural strength of a PMMA (Jet Acrylic) and two bis acrylate composite resin (Protemp 3, Garant and Integrity) provisional materials. According to their findings, the application of Sealants resulted in a notable enhancement in both the microhardness and flexural strength of provisional materials. The different results could be referred to the utilization of various PMMA materials or glazes across various brands.

One reliable method of analyzing the statistical fracture of ceramics is the Weibull distribution of the probability of failure. The larger the Weibull modulus the less variation in fracture stress and the higher the degree of homogeneity between samples. [27] The greater Weibull modulus with less strength scatter is preferable for clinical use. [36] Possibly due to its uniform structure and consistent crack distribution, glazed discs had the greatest Weibull moduli in this investigation. Regardless of its biaxial flexural strength values, this reveals the consistency of the material's behavior and durability in clinical applications. [26] The highly regulated production conditions of CAD–CAM dental polymer blocks increase monomer conversion and minimize residual monomer due to longer polymer chains. A homogenous, strongly cross-linked material structure is also produced. [37], [38]

This study had some limitations such as not addressing potential influences like saliva, food, acidic beverages, dental hygiene procedures, and dentifrices on biaxial flexural strength. Unlike the homogeneous thickness utilized in this investigation, changing specimen thicknesses may affect biaxial flexural strength. In this study, flexural strength was considered since it indirectly reflects tensile, compressive, and elastic modulus. However, future investigations should assess additional provisional restoration physical features. Future studies should examine microhardness, fracture, and impact strength. The flexural strength of PMMA may vary with surface sealants. Future studies should examine surface sealant adherence on provisional materials and thermocycling length.

CONCLUSIONS

Neither polishing nor glazing had an influence on the flexural strength of CAD/CAM milled PMMA provisional material.

Clinical recommendations:

Glazing of CAD/CAM milled PMMA is recommended for clinical durability according to Weibull distribution for probability of failure due to uniform structure and consistent crack distribution.

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