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A COMPARISON BETWEEN THE FLEXURAL STRENGTH OF MILLED, CONVENTIONAL, AND CARBON FIBER PMMA FOR INTERIM IMPLANT SUPPORTED FIXED COMPLETE DENTURES: AN *IN VITRO* STUDY

Jenny Abou Nader[1] | Paul Boulos[2] | Jihad Fakhouri[3] | Nancy Chemaly[1] | Carole Yared[4]

Objectives: to investigate the flexural strength of three materials commonly used for interim implant-supported fixed complete dentures (ISFCDs): conventional heat cure PMMA, CAD/CAM milled PMMA, and carbon fiber-reinforced PMMA.

Methods: Sixty specimens (n=60) divided equally into three groups (heat cure, milled, carbon fiber) were prepared. Samples were inspected to ensure absence of voids or irregularities and when required, minor adjustments were made to adjust the dimensions. The samples underwent thermocycling (5-55°C for 2500 cycles) and were then tested using a three-point bend test.

Results: There was a statistically significant difference between heat cure PMMA and carbon fiber PMMA ($p<0.001$), between CAD-CAM resin and carbon fiber resin ($p<0.001$). There was no significant difference between CAD-CAM and conventional PMMA resin ($p>0.05$).

Conclusions: as clinical implications, using carbon fiber is a viable treatment option for interim ISFCDs. Veneering the material with pink and white resin would improve the overall esthetics.

Keywords: CAD/CAM technology, carbon fiber reinforcement, flexural strength, implant-supported fixed complete dentures, PMMA.

Corresponding author:
Jenny Abou Nader; e-mail: jenny_abounader_24@hotmail.com

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The authors declare no conflicts of interest.

1. DDS, MSc, Department of Removable Prosthodontics, Faculty of Dental Medicine, Saint Joseph University of Beirut, Beirut, Lebanon.
2. DDS, PhD, Professor, Former Head of Department, Department of Removable Prosthodontics, Faculty of Dental Medicine, Saint Joseph University of Beirut, Beirut, Lebanon.
3. DDS, PhD, Associate Professor, Director of Post Graduate Program, Department of Removable Prosthodontics, Faculty of Dental Medicine, Saint Joseph University of Beirut, Beirut, Lebanon.
4. DDS, PhD, Associate Professor, Head of Department, Department of Removable Prosthodontics, Faculty of Dental Medicine, Saint Joseph University of Beirut, Beirut, Lebanon.

UNE COMPARAISON ENTRE LA RÉSISTANCE À LA FLEXION DU PMMA FRAISÉ, CONVENTIONNEL ET EN FIBRE DE CARBONE, POUR LES PROTHÈSES COMPLÈTES FIXES PROVISOIRES SUR IMPLANTS: UNE ÉTUDE IN VITRO

Objectifs: étudier la résistance à la flexion de trois matériaux couramment utilisés pour les prothèses dentaires complètes fixes temporaires soutenues par des implants (ISFCD) : l'acryl conventionnel polymérisé à chaud, disques d'acryl pré-polymérisé pour CFAO, et l'acryl renforcé par des fibres de carbone.

Méthodes: Soixante échantillons (n=60) répartis également en trois groupes (cuisson à chaud, fraisés, fibre de carbone) ont été préparés. Les échantillons ont été inspectés pour garantir l'absence de vides ou d'irrégularités et, si nécessaire, des modifications mineures ont été effectués pour adapter les dimensions. Les échantillons ont subi un thermocyclage (5-55°C pendant 2500 cycles) puis ont été testés à l'aide d'un test de flexion en trois points.

Résultats: Il existe une différence statistiquement significative entre l'acryl à chaud et l'acryl renforcé par des fibres de carbone ($p < 0,001$), entre l'acryl CAD-CAM et l'acryl renforcé par des fibres de carbone ($p < 0,001$). Pas de différence significative entre la résine CAD-CAM et la résine PMMA conventionnelle ($p > 0,05$)

Conclusions: pour les implications cliniques, l'utilisation de fibres de carbone est une option de traitement viable pour les ISFCD temporaires. L'application de résine rose et blanche sur le matériau améliorerait l'esthétique globale.

Mots-clés: CFAO, fibres de carbone, polymethyl metacrylate, prothèse totale implanto-porté, résistance à la flexion.

Introduction

Dentistry has witnessed a paradigm shift with the evolution of implant-supported fixed complete dentures (ISFCDs), providing edentulous patients with both aesthetic restoration and masticatory function [1]. Notably, these dentures excel in offering superior support to facial soft tissues compared to conventional fixed prostheses, and address challenges such as component fracture, screw loosening, and bone resorption [1]. In clinical scenarios with significant issues like severe bone resorption and soft tissue loss, implant-supported or retained overdentures with bar attachments prove to be a satisfactory solution [2].

In the context of ISFCD protocols, immediate interim prostheses play a crucial role during the healing and osseointegration phase, requiring excellent mechanical properties to sustain extended occlusal loading for 4 to 6 months. Hence, the choice of high flexural strength materials is vital for denture longevity and durability amid the dynamic alveolar ridge resorption process [3, 4]. Traditionally, interim ISFCDs were fabricated on the spot, by drilling screw holes through a conventional heat processed PMMA complete denture, with implant temporary abutments joined using self-curing PMMA [4]. However, the low flexural strength of PMMA made these temporary dentures highly susceptible to fracture [5]. This challenge led to the exploration of innovative materials and manufacturing techniques. For example, a study found that implant fixed interim structures milled from high-density PMMA blanks had 35% higher flexural strength than heat-processed denture base PMMA [5]. Another study investigated the flexural strength of complete removable dentures made of zirconia-impregnated PMMA nanocomposites, showing a slight increase in equivalent flexural strength with fatigue cyclic loading [6]. Additionally, fiber reinforcement emerged as a promising venue to improve the flexural strength of denture acrylic resins [7-9].

Despite the widespread acceptance of ISFCDs, there is a noticeable gap in the dental literature, with no comprehensive comparison of the flexural strength among CAD/CAM-processed ISFCDs, heat-cured PMMA, and carbon-reinforced PMMA. Hence, this study aims to fill the gap by providing valuable insights into the in vitro flexural performance of these materials, aiding clinicians in material selection for ISFCDs.

Hypotheses:

Null Hypothesis: No statistically significant difference exists in the flexural strengths of milled, conventional, and carbon fiber-reinforced PMMA.

Alternative Hypothesis: There is a statistically significant difference in the flexural strengths among milled, conventional, and carbon fiber-reinforced PMMA.

Materials and Methods

This study received approval from the research committee of the Saint Joseph University of Beirut, Lebanon (USJ-2020-94).

Rectangular plates measuring 64mm x 10mm x 3.3mm were obtained. Subsequently, three groups of twenty PMMA acrylic denture base resins were processed into rectangular plates, each measuring 64mm x 10mm x 3.3mm. The processing adhered to ISO 20795-1 standards, resulting in a total sample size of sixty plates. The three groups differed in their method of processing and resin composition: conventional heat cure PMMA, carbon reinforced PMMA (Ruthinium Disc, Ruthiunium Group, Italy), and pre-polymerized CAD/CAM milled resins (IvoBase, Ivoclar, Switzerland). After processing, the plates underwent finishing and polishing, and then, ageing was done by thermocycling for 2500 cycles at 5°C - 55°C, with a dwelling time of 30 seconds. The 2500 cycles are thought to approximate the thermal stresses of dental materials for a prolonged period in the oral environment [10]. Flexural strength was subsequently assessed using a Universal Testing Machine (YLE Universal Testing Machine, YLE Gmbh, Finland) through a three-point bend test at 1mm/min cross head speed.

Conventional Processing

Wax plates were flasked and invested in ISO type 3 dental plaster according to manufacturer instructions. The flask underwent heating in a boil-out solution, followed by a cooling process. ALCOTE separator (Dentsply IH GmbH, Bensheim, Germany) was applied, and Lucitone 199 Resin (Dentsply IH GmbH, Bensheim, Germany was mixed and packed into the mold. The flask (Figure 1) was subjected to a curing process and cooled before deflasking.

Figure 1. Heat cured PMMA dis

Carbon Fiber Fabrication

Rectangular blocks were cut to the dimensions 64mm x 10mm x 3.3mm from carbon discs (Ruthinium Disc, Ruthiunium Group, Italy) (Figure 2) using a laser beam (Gold Laser Machine, China).

Pre-polymerized CAD/CAM PMMA

Pre-polymerized CAD/CAM PMMA (IvoBase, Ivoclar, Switzerland) blocks (Figure 3) were cut to the same dimensions using the same laser beam.

Figure 2. Carbon Fiber Disk.

Figure 3. CAD-CAM PMMA disks.

Figure 4. PMMA rectangular blocks after inspection.

Preparation of Samples for Flexural Strength Test

After cutting, samples were inspected to ensure absence of voids or irregularities (Figure 4). Manual adjustments were performed to ensure the rectangles met the specific dimensions, using a carbide bur on a handpiece. They were then finished with silicon carbide paper and measured with digital calipers. Prior to the flexural strength test, all samples were conditioned by storing them in distilled room-temperature water for one week and then subjected to thermocycling (5-55°C for 2500 cycles) [10].

Three-Point Bend Test and Measurement of Flexural Strength

Samples underwent a three-point bend test as per ISO 20795-1 guidelines for denture base polymers. Each sample was positioned on circular support beams with a 50mm span, and a load was applied until fracture using a Universal Testing Machine (YLE Universal Testing Machine, YLE Gmbh, Finland). The head was round with a diameter of 4.5mm. The moment of fracture was noted when the applied load dropped to zero. Data was recorded using Bluehill Software (Instron, United States).

Calculations and Statistical Analysis

The maximum load applied was recorded in Newtons (N), and flexural strength (Fs) was calculated. Given that the samples were all rectangular and the force was applied at the center, the following formula was used:

Where:

σ is the flexural strength (in Pascals,

$$\sigma = \frac{3FL}{(2bh^2)}$$

Pa).

F is the maximum load applied (in Newtons, N).

L is the span length between the supports (in centimeters, cm).

b is the width of the specimen (in centimeters, cm).

h is the thickness of the specimen (in centimeters, cm).

A descriptive analysis was first performed: the quantitative variables are described by their minimum, maximum, mean and standard deviation (SD), and the qualitative variables are presented in the form of frequencies and percentages. The Kolmogorov-Smirnov test has proven the non-normality of the distribution. To assess potential differences in flexural strength of different resin types, the Kruskal-Wallis H test as well as a pairwise post-hoc test (significance values were adjusted by the Bonferroni correction for multiple tests) have been used. A p-value of less than 0.05 was considered statistically significant.

IBM SPSS Statistics 25 software (IBM, Chicago IL) was used for data analysis.

Results

Sixty (n=60) samples were included in the study, and they were equally distributed between the different types of resin: 20 samples of PMMA conventional resin (33.3%), 20 samples of milled resin (33.3%) and 20 samples of carbon fiber resin (33.3%). The values and the distribution of flexural strength for the different types of resin are presented respectively in table 1 and figure 5.

At the level of bivariate statistics, a statistically significant difference was found between the mean flexural strengths of the three resin types with a p-value lower than 0.001[1]. The pairwise post-hoc tests showed statistically significant differences between:

- PMMA Conventional resin and carbon fiber resin

1. Kruskal- Wallis H test

Table 1. Flexural strength of the different types of resin (n=60).

Type of resin	Statistics			
	Minimum	Maximum	Mean	SD
PMMA Conventional	40.74	111.11	66.20	19.95
CAD-CAM	36.26	111.11	63.19	18.35
Carbon Fiber	425.93	680.56	542.36	72.99

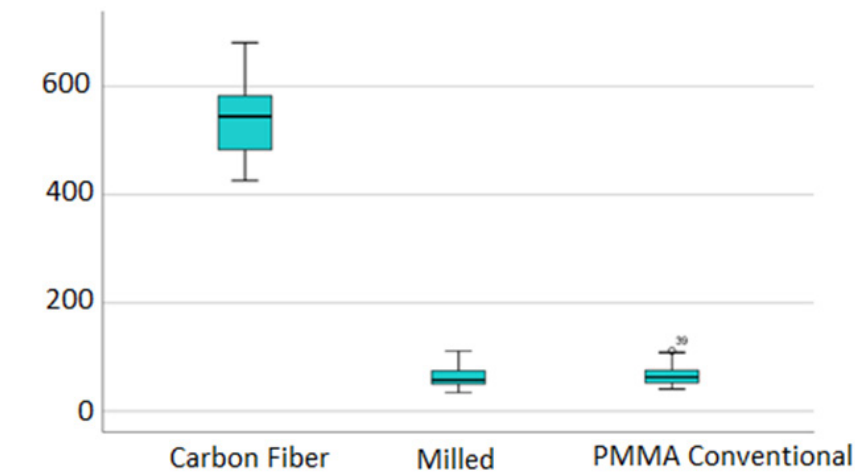

Figure 5. The distribution of the different flexural strength values for the different types of resin (n=60)

(p<0.001), with carbon resin having higher mean flexural strength (542.36±72.99) compared to conventional resin (66.20±19.95).

– CAD-CAM resin and carbon fiber resin (p<0.001), with carbon resin having a higher mean flexural strength (542.36±72.99) compared to CAD-CAM resin (63.19±18.35).

No statistically significant difference was found between the mean values of flexural strengths of CAD-CAM and conventional PMMA resin (p-value>0.05)

Discussion

The aim of this in vitro study was to evaluate the flexural strength of three materials used for interim implant-supported fixed complete dentures.

The null hypothesis that no difference between the flexural strengths of milled, conventional and carbon fiber reinforced PMMA was partially rejected. Conventional heat cure and CAD-CAM PMMA presented similar flexural strength values which were lower than that of carbon fiber resin.

The similarity of flexural strength between conventional and PMMA was contradicted in the literature [11-13] 9 were processed for data extraction and only 7 underwent meta-analysis. Two, six, and one study showed high, moderate, and low risk of bias, respectively. Random-effects model was used for analysis and resulted in the average FS of 120.61 MPa [95% confidence interval (CI. Angelara et. *al* demonstrated that PMMA disks were up to 35% stronger due to a more controlled fabrication procedure [5] . A study demonstrated that milled interim prosthesis exhibited the greater strength only one day after production. But when subjected to 30 days of humidity their strength diminished while heat cured prosthesis almost maintained their initial values [14].

The effect of carbon fiber on improving flexural strength was documented in the literature [9, 15, 16] various reinforcement strategies such as using nanoparticles, wires, fibers, and meshes have been investigated and reported. In this study, it was aimed to conduct a comparative investigation of the effect of fiber additives with different characteristics on the flexural properties of heat-cured PMMA denture base resins. Glass fibers (GFs) . It consists of a composite material in which carbon fibers bestow essential strength and stiffness, while a polymer matrix assumes the dual role of safeguarding the fibers and binding them to ensure structural integrity. The resulting material exhibits a lower weight profile in comparison to zirconium or Chromium-Cobalt (Cr-Co) while maintaining mechanical properties akin to zirconia and chromium-cobalt [2, 9] various reinforcement strategies such as using nanoparticles, wires, fibers, and meshes have been investigated and reported. In this study, it was aimed to conduct a comparative investigation of the effect of fiber additives with different characteristics on the flexural properties of heat-cured PMMA denture base resins. Glass fibers (GFs) . These composite materials are highly versatile, as their artificial composition allows for tailored properties and performance adjustments, including variations in strength, length, directionality, fiber quantity, and the selection of an appropriate polymer matrix [18]. A comparative study assessing various reinforcement strategies for denture bases, specifically Glass fibers (GFs), polypropylene fibers (PPFs), and carbon fibers (CFs), revealed that the (CF)-reinforced groups displayed the most favorable flexural properties within the test groups. Nonetheless, it is noteworthy that the practical utilization of CFs for reinforcement is constrained by their propensity to induce a dark gray discoloration of the denture base resin [9] various reinforcement strategies such as using nanoparticles, wires, fibers, and meshes have been investigated and reported. In this study, it was aimed to conduct a comparative investigation of the effect of fiber additives with different characteristics on the flexural properties of heat-cured PMMA denture base resins. Glass fibers (GFs) . But regardless of the mechanical benefits of carbon fiber, their unesthetic greyish appearance could be an obstacle for the patience acceptance [17]various reinforcement strategies such as using nanoparticles, wires, fibers, and meshes have been investigated and reported. In this study, it was aimed to conduct a comparative investigation of the effect of fiber additives with different characteristics on the flexural properties of heat-cured PMMA denture base resins. Glass fibers (GFs) . One way to improve this acceptance can be by placing the fibers only holes which constitute the tension side at the site of initiation of crack propagation [18] or veneering the material with pink and white resin.

Another polymer that has gained recent popularity recently is PEEK (polyether-ether-ketone) is well renowned for its elasticity that simulates the bone or the dentine. It can be manufactured conventionally through injection molding, however unlike PMMA it requires a particular vacuum pressing system It can also be manufactured digitally by milling which ensures more homogeneity and better properties. PEEK is highly esthetic and can be veneered to improve its optical properties. It is also possible to reinforce it carbon fiber or ceramic particles to increase its mechanical performance. In the context of ISFCDs, it has been studied as a material for frameworks but there are no studies assessing its use for interim prosthesis [17] . In addition, PEEK is an appropriate material for all-on-four framework reconstruction in certain circumstances, with greater success achieved by minimizing the distal cantilever length to 10mm [11] .

It is essential to note that the results are based on an in vitro study that does not simulate accurately the conditions of the oral cavity. In fact, a study demonstrated that even humidity could reduce the substantial effect of carbon fibers on flexural strength as water sorption could reduce the adhesion of the fibers to the matrix [19, 20] . Other factors could affect the flexural strength of a material in vivo include [4]:

- The prosthesis design: in this study, the specimens prepared are rectangular in shape and do not represent the complex denture design.
- The occlusal scheme which affects the distribution of forces on the prosthesis [21, 22] .
- The masticatory force, which is affected by variables such as age, gender, TMJ health, state of the opposing dentition: whether it is a natural dentition, a complete denture, or fixed prosthesis [23].
- The presence of parafunctions: in fact, bruxers presented a higher prevalence of mechanical complications than non-bruxers [24, 25]based on the most recent listed sign and symptoms of bruxism according to the International Classification of Sleep Disorders. A diagnostic grading system of \"possible,\" \"probable,\" and \"definite\" sleep or awake bruxism was used, according to a recent published international consensus. A case-control matching model was used to match the bruxers with a group of non-bruxers, based on five variables. Implant-, prosthetic-, and patient-related data were collected, as well as 14 mechanical complications, and compared between groups.\nRESULTS: Ninety-eight of 2670 patients were identified as bruxers. The odds ratio of implant failure in bruxers in relation to non-bruxers was 2.71 (95% CI 1.25, 5.88 .
- The absence of cantilever structure as the force was applied in the central part of the specimen which may occult the behavior of the material in cantilever structures much advocated in All-on-4 concepts [26].

Additionally, the methodology does not examine the morphology and microstructure of fractured acrylic specimens by Scanning Electron Microscopic (SEM) analysis and although this study provides information about flexural strength measurements, SEM analysis can be performed as a follow up study to allow for descriptive analysis of porosities, craze lines, orientation of fibers, etc... Furthermore, the slight variation in dimensions noted in the study underscores the importance of meticulous specimen preparation in research settings. However, in a standardization scope, efforts were made to maintain consistency and any difference in dimension greater than 0.2 mm with respect to length, width, or thickness, resulted in a discarded specimen.

Finally, temporary restorative materials treatment should meet specific requirements for strength, marginal adaptation, and durability which is why in further studies, it would be essential to assess the ageing of fiber reinforced resins and their behavior after being used for several month in the oral cavity.

Conclusion

Carbon fiber reinforcement emerges as a promising avenue for enhancing mechanical properties, of interim prosthetic rehabilitation. Clinicians should weigh the mechanical advantages of carbon fiber-reinforced PMMA against esthetic considerations when selecting materials for interim ISFCDs.

Future research should explore the microstructure of fractured acrylic specimens, assess the aging process of fiber-reinforced resins in the oral cavity, and consider patient acceptance factors, particularly esthetic concerns associated with carbon fibers. Additionally, investigations into the long-term clinical performance of interim ISFCDs fabricated using carbon fiber-reinforced PMMA are warranted to validate the laboratory findings and provide evidence for informed clini-

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