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Mechanical properties of interim restorative materials: conventional vs. CAD/CAM

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BOSTON UNIVERSITY
HENRY M. GOLDMAN SCHOOL OF DENTAL MEDICINE

THESIS

**MECHANICAL PROPERTIES OF INTERIM RESTORATIVE MATERIALS:
CONVENTIONAL vs. CAD/CAM**

by

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DEDICATION

To my grandfather, **Dr. Agustín Barrios Correa**

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I want to thank my brother Agustin Bortone for his support and advice during all my training and prior to that. I want to thank my mother Maria Elena Barrios for encouraging me to always achieve more and do better.

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**MECHANICAL PROPERTIES OF INTERIM RESTORATIVE MATERIALS:
CONVENTIONAL vs. CAD/CAM**

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Boston University, Henry M. Goldman School of Dental Medicine, 2017

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ABSTRACT

To determine the effects of thermal accelerated aging on flexural strength and flexural modulus of conventional and CAD/CAM provisional crown and bridge restorative materials.

Six provisional crown and bridge materials were selected for this study. Three conventional resins: Jet Set 4 (Lang), Luxatemp (DMG), and Protemp Plus (3M ESPE); and three CAD/CAM materials: ArtBloc Temp (Merz), Telio CAD-Temp (Ivoclar Vivadent), and Vita CAD-Temp (Vita). Specimens of conventional materials were fabricated using a custom-made aluminum mold 25 x 2 x 2 mm. CAD/CAM blocks were sectioned to the same dimensions. A total of 180 bar-shaped specimens were obtained (30 of each material) and were divided into three groups per treatment. Groups 1 and 2 were immersed in 37°C water for 24 hours, and 6 days, respectively. Group 3 was subjected to

5,000 thermal cycles between 5°C and 55°C in water with 35 seconds dwelling time. All specimens were tested for flexural properties using three-point bending protocol on an Instron 5566A at a crosshead speed of 0.5mm/min.

The results were analyzed by one-way ANOVA and post hoc Tukey test with material type and aging conditions as the main variables. Significance level was set at ($p < 0.05$).

Overall CAD/CAM materials demonstrated significantly higher flexural strength and flexural modulus over conventional resins. No significant difference in flexural strength and flexural modulus was found among three treatments except for: Luxatemp, which showed significant increased flexural strength and flexural modulus after thermal cycling, and Protemp Plus which showed increased flexural strength after 6 days of water storage.

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1. INTRODUCTION

Interim fixed partial dentures (FPD's) are used as transitional restorative materials while final restorations are being fabricated in the dental laboratory. Interim FPD's protect the dental structures from biological, mechanical, and physical effects. The ideal properties of interim restorative restorations are biocompatibility and dimensional stability. They should be fracture resistant, functional and occlusal load resistant, and have a minimal exothermic setting reaction. They should be able easy to polish and be tissue friendly, as well as being esthetically satisfying (McDonald; Strassler, 2013).

The chemical compositions of interim restorations are classified into two main categories: methacrylate resins and composite resins. They include auto-polymerizing and dual curing resins, such as poly methyl methacrylate (PMMA), poly ethyl methacrylate (PEMA), polyvinyl ethyl methacrylate (PVEMA), bis-GMA resins, bis-acryl resin composites, and visible light cured (VLC) urethane dimethacrylate resins (Christensen, 1996; McDonald).

The fabrication of provisional restorations is accomplished using two techniques: custom fabrication and fabrication with pre-formed materials. Both of these procedures are accomplished with direct clinical, indirect laboratory, or a combination of these techniques; and all of them can be used for single unit or multiple unit interim restorations (Regish et al., 2011).

The use of polymer-based materials as provisional restorations has been used extensively in dentistry. The oldest group of polymeric materials PMMA was developed in 1932 by Imperial Chemical Industries as clear and more durable form of safety glass in

cast sheet form. By 1946, it was estimated that 95 % of the dentures base market was using PMMA (Rueggeberg, 2002).

During the late 1950s and early 1960s polymer-based restorative materials became remarkably improved. Dr. Rafael Bowen pioneered this era of improvement using high molecular weight epoxy and methacrylate derivatives that added inorganic filler loading. In 1969 the introduction of a high molecular weight, bifunctional monomer (known as bis-GMA or Bowen's Resin) helped the commercial development of materials containing inorganic fillers or composites. Bis-acrylic resins are hydrophobic materials similar to bis-GMA (Rueggeberg, 2002).

PMMA is both economical and easy to manipulate. However, some disadvantages have been reported such as: polymerization shrinkage, water sorption, marginal misfit, degradation of the resin matrix, and pulpal damage associated with exothermic polymerization reaction (Karaokutan et al., 2015).

Heat processed acrylic resin requires more labor but has shown to be a better option if the interim prostheses are intended to be worn for a long period of time for because of its increased strength compared to autopolymerizing acrylic resins (Patras et al., 2012). Bis-GMA composite based provisionals present higher flexural strength and flexural modulus, compared to PMMA. This can be attributed to the large size of the bis-GMA monomer. Bis-GMA composite based interim restorations are popular among clinicians due to their low exothermic reaction, minimal shrinkage, and convenient cartridge dispensing system that allows proper mixing of the material. Modification to the bis-GMA structure can improve its properties. Its strength can be increased by adding inorganic fillers and altering the monomer chemistry (Kamble et al., 2012; Patras et al., 2012).

This behavior can also be observed on bis-GMA Computer-aided design (CAD) and computer-aided manufacturing (CAM) interim restorative materials. (Başaran et al., 2013) CAD/CAM has increased in popularity in the dental field over the past 30 years as this technology can be used in both the dental laboratory and in the dental office. It can be applied for the fabrication of inlays, onlays, veneers, crowns, fixed partial dentures, implant abutments, and provisional restorations among others.(Jedynakiewicz and Jedynakiewicz, 200106) (Davidowitz and Kotick, 2011)

CAD/CAM interim restoration materials are fabricated from industrially polymerized blocks. The blocks are manufactured with consistency, which produces a denser high quality material for the fabrication of interim restorations with the indirect technique, preventing shrinkage and heat of polymerization. These materials are costly, they require special equipment, they require individuals to learn a new software, and are technique sensitive (Rayyan et al., 2015).

1.1 Flexural Strength

Strength is the stress necessary to produce a fracture or a specific amount of plastic deformation. Provisional restorations are subjected to masticatory forces, in many situations for long periods of time. Particularly, in patients with parafunctional habits, multi-unit complex interim prosthesis with short pontic height and connectors width. (McDonald; Strassler, 2013)

The use of flexural strength, also known as transverse strength or modulus of rupture, is considered a parameter by which to estimate the performance of the material. The three-point bending test has been commonly used as a test for measuring flexural strength of interim restorative materials. This test determines the strength of the material

and the amount of distortion by applying static load on the specimen until it fractures. This test uses a combination of compressive and tensile strength (Osman and Owen, 1993; 2012).

1.2 Flexural Modulus

Flexural modulus describes the rigidity of the materials. It is calculated using the results of a bending test, giving the slope of the stress deflection-curve. It has been documented a correlation between the flexural modulus and the percentage of filler, by increasing volume (vol%) or, by increasing weight (wt%) content (Osman and Owen, 1993)(Poonacha et al., 2013). Evaluation of the modulus of elasticity of several resin-based composites that are currently commercially available have shown significantly different moduli, even for materials of the same category, which indicates that compositional differences between composites from different manufacturers such as: type of monomer, inorganic filler shapes and sizes, can improve the mechanical performance of these materials (Burns et al., 2003; Gratton and Aquilino, 2004).

1.3 Statement of the problem

Failures and other deficiencies of provisional restorations are encountered by clinicians on a daily basis. Mechanical properties of interim restorations are considered key factors when selecting a material, especially if they are intended for long term applications or patients with parafunctional habits. Limited information is available concerning the properties of CAD/CAM interim materials.

1.4 Null Hypothesis

- There is no significant difference in the flexural strength of conventional and CAD/CAM interim restorative materials.
- There is no significant difference in the flexural modulus of conventional and CAD/CAM interim restorative materials.
- There is no significant difference in flexural strength and the flexural modulus between the groups stored under water and those subjected to the effects of thermal accelerated aging.

1.5 Objectives

The aims of this study are as follows:

1. To evaluate the flexural strength of conventional and CAD/CAM interim restorative materials.
2. To evaluate the flexural modulus of conventional and CAD/CAM interim restorative materials.
3. To determine the effects of storage under water and of thermal accelerated aging of the flexural strength and flexural modulus of conventional and CAD/CAM interim restorative materials.

2. MATERIALS AND METHODS

2.1 Materials:

The following interim conventional materials were tested in this study:

- Jet Set-4 (Lang Dental Mfg. Co., Inc. Illinois, USA. Lot 3803-13AV).
- Luxatemp (DMG. Hamburg, Germany. Lot #70054).
- Protemp Plus (3M-ESPE. Minnesota, USA. Lot #B506571).

The following interim CAD/CAM materials were tested in this study:

- ArtBloc Temp (Merz Dental GmbH. Lütjemburg, Germany. Lot #24512).
- Telio CAD (Ivoclar Vivadent AG. Schann, Liechtenstein. Lot #S38569).
- Vita CAD-temp (VITA Zahnfabrik. Bad Säckingen, Germany. Lot #33000).

2.1.1 Jet Set-4 (Lang Dental Manufacturing, Co)

Jet Set-4 is a two-component product composed of powder and liquid chemically activated material. Powder methyl methacrylate with a polymer content of < 99% diethyl phthalate <20%, and monomer methyl methacrylate content of > 95% N-dimethyl (Figure 1).



Figure 1. Jet Set-4

2.1.2 Luxatemp (DMG)

Luxatemp is a bis-acryl which is a chemically activated material with a glass filler in a matrix of methacrylates; catalyst, stabilizers and additives. It contains a total filler of 44% weight and 24% volume with 0.02 to 2.5 μm filler size (Figure 2).



Figure 2. Luxatemp

2.1.3 Protemp Plus (3M-ESPE)

Protemp Plus is a bis-acryl composite chemically activated that contains a base paste of: dimethacrylate (50–60%), silane treated amorphous silica (20-30%), polyurethane methacrylate (10–20%), silane treated silica (5-10%); and a catalyst paste of: ethanol (70-80%), diacetate benzyl-phenyl-barbituric acid, and silane treated silica (Figure 3).



Figure 3. Protemp Plus

2.1.4 ArtBloc Temp (Merz Dental GmbH)

ArtBloc Temp is a polymethyl methacrylate highly cross-linked block with an organic modified polymer network without fillers (Figure 4).



Figure 4. artBlocTemp Blocks

2.1.5 Telio CAD (Ivoclar Vivadent AG)

Telio CAD is a cross linked PMMA block with a weight composition of PMMA 99.5% PMMA and pigments <1.0% (Figure 5).



Figure 5. Telio CAD Blocks

2.1.6 Vita CAD-Temp (VITA Zahnfabrik)

Vita CAD-Temp is made of a non-fibrous, homogenous, high-molecular acrylate polymer network with an inorganic microfiller contains of 14% weight. Blocks are polymerized into a homogenous network using a repressing technique (Figure 6).



Figure 6. Vita CAD-Temp Blocks

2.2 Methods

2.2.1 Flexural Strength and Flexural Modulus test

Sample Geometry:

Thirty rectangular bar shaped specimens of each conventional interim material were fabricated using custom made aluminum molds with the following dimensions: 25 x 2 x 2 mm (American Dental Association Specification No. 27) (Figure 7).

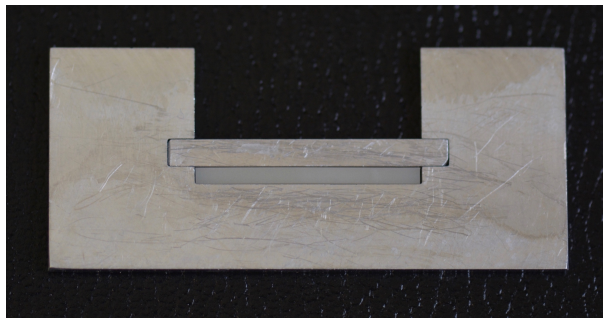


Figure 7. Custom Aluminum Mold

CAD/CAM blocks were sectioned into 30 rectangular bars by material with the following dimensions: 25 x 2 x 2 mm. The sectioning was performed using a Precision Sectioning Blade IsoMet Series 15 HC Diamond, no. 11-4276 with 0.5mm thickness mounted on an Isomet® 2000 Precision Saw (Buehler, Lake Bluff, Illinois) (Figure. 8). The cuts were made at 800 rpm with 300 grams of load. The cutting area was constantly cooled by a dual-nozzle water irrigation system.



Figure 8. Isomet® 2000 Precision Saw

Sample Preparation:

For specimen preparation, methacrylate resin and ethyl methacrylate (Jet Set-4) were measured by volume. Following the manufacturer recommendations, the ratio powder/liquid used was (3:1). Materials were hand mixed with stroke movements in a resin bowl using a stainless steel spatula. The mixed material was poured into the custom molds and pressed in between glass slides. Samples were left at room temperature for autopolymerization for 5 minutes before removing them from the molds. Before the specimen preparation of the bis-acrylics (Luxatemp DMG, and Protemp Plus 3M-ESPE), a small amount of material was dispensed onto a mixing pad without the automixing tip in place. Subsequently, the automixing tip was placed and the material dispensed using a cartridge system into the molds, pressure was exerted by hand to display excess material. A glass slide was placed under and over the molds, and pressure was exerted manually for 3 minutes.

2.2.2 Mechanical Testing

Three Point Bending Test

This test was used to evaluate the flexural stress and flexural modulus. A total of 180 bar-shaped specimens were polished with 600-grit SiC abrasive paper by the same operator for one minute to remove any flash. Specimen dimensions were measured 3 times using a micrometer (Model no. 293-715; Mitutoyo Corporation, Kanagawa, Japan). All groups had 10 specimens by material. Group 1 was stored in distilled water at 37°C for 24 hours, group 2 was stored in distilled water at 37°C for 6 days, and group 3 was subjected to 5,000 thermal cycles between 5°C and 55°C in water with 35 seconds dwelling time.

Subsequently the test was carried out on the specimens using an Instron 5566A Universal Testing Frame (Instron. Norwood, Massachusetts) at a crosshead speed of 0.5mm/min with 1 kN load cell. Once the fixture contacted the specimen, both compressive and tensile forces were exerted. Once the specimen fractured, the failure load was recorded by the software.

The flexural strength (S) was calculated using the following formula:

$$\sigma = 3Fl / 2db^2$$

Where:

σ Flexural strength (MPa)

F Load at break or yield (N)

l Distance between supports (25mm)

b Width of the bar (mm)

d Thickness of the bar (mm)

The flexural modulus was calculated using the following formula:

$$E = L^3m / 4bd^3$$

Where:

E Flexural modulus (MPa)

L Distance between supports (25 mm)

m Deflection at linear region of load deflection curve

b Width of the bar (mm)

d Thickness of the bar (mm)

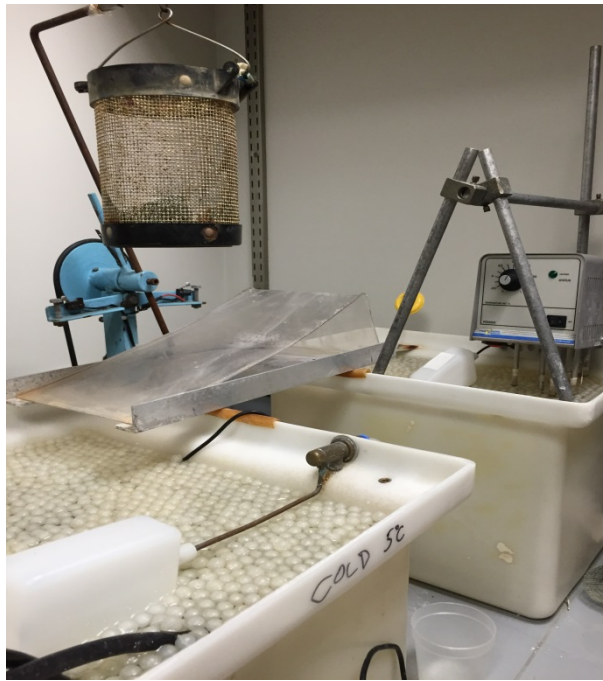


Figure 9. Thermocycling Machine



Figure 10. Instron 5566A Universal Testing Frame

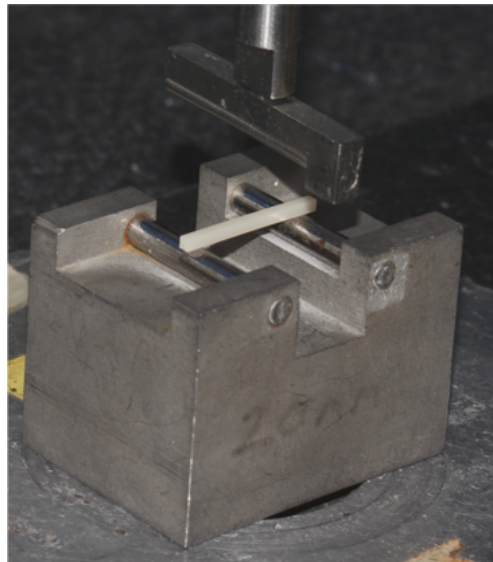


Figure 11. Three Point Bending Test Fixture

3. RESULTS

A summary of the mean values obtained in testing each material and group of samples can be seen in Tables 1 and 2. The values were analyzed by one-way ANOVA and post hoc Tukey test with material type and aging conditions as the main variables. The significance level was set at ($p < 0.05$).

3.1 Flexural Strength

Mean flexural strength values are compared in Table 1.

After 24 hours immersed in water at 37°C Telio CAD specimens exhibited the highest value in flexural strength (130.7 ± 9.9 MPa), followed by artBloc Temp (118.6 ± 6.2 MPa), Protemp Plus (99.7 ± 8.9 MPa), Luxatemp (98.2 ± 8.1 MPa), VITA CAD-Temp (73.6 ± 6.5 MPa) and Jet Set-4 (58.4 ± 6.6 MPa). From the groups immersed for 6 days in water at 37°C, Telio CAD showed the highest value in flexural strength (134.5 ± 6.8 MPa), followed by Protemp Plus (121.6 ± 11.5 MPa), artBloc-Temp (112.9 ± 8.2 MPa), Luxatemp (108 ± 4.3 MPa), VITA CAD-Temp (77.7 ± 4.9 MPa), and Jet Set-4 (63.3 ± 5.1 MPa). From the group subjected to 5,000 thermal cycles between 5°C and 55°C in water with 35 seconds dwelling time, Luxatemp (133.5 ± 8.6 MPa) demonstrated the highest value in flexural strength, followed by Telio CAD (123.3 ± 9.2 MPa), artBloc Temp (123 ± 6.8 MPa), Protemp Plus (109.1 ± 9.1 MPa), VITA CAD-Temp (73.7 ± 5.5 MPa) and Jet Set-4 (55.8 ± 8.1 MPa).

A one-way ANOVA indicated the effects of different levels among different aging treatments and material. There were statistically significant differences between materials and different aging treatments ($p < 0.05$), for Luxatemp, and Protemp Plus.

A pairwise multiple comparison (post hoc) using the Tukey-test method showed that there was a significant increase in flexural strength of Protemp Plus after 6 days immersed in water at 37°C and in Luxatemp after the thermal cycling treatment.

PMMA blocks (Telio CAD and artBloc Temp) demonstrated the highest flexural strength of all the materials tested. Microfiller reinforced polyacrylate block (VITA CAD-Temp) demonstrated the least flexural strength among the CAD/CAM materials.

Conventional bis-acryl composite material (Protemp Plus) increased its flexural strength after 6 days of water storage at 37°C while another conventional bis-acryl (Luxatemp) increased its flexural strength after 5,000 thermal cycles between 5°C and 55°C in water with 35 seconds dwelling time. Conventional PMMA (Jet Set-4) demonstrated the lowest flexural strength among all the materials tested.

Table 1. Flexural Strength (MPa) of Provisional C&B Materials in Three Different Treatments, Mean ± SD

Material	Treatments (MPa)		
	Water/24 hours	Water/6 days	5,000 Thermal Cycles
JET SET 4	58.4 ± 6.6 I	63.3 ± 5.1 HI	55.8 ± 8.1 I
LUXATEMP	98.2 ± 8.1 F	108.0 ± 4.3 EF	133. ± 8.6 AB
PROTEMP PLUS	99.7 ± 8.9 F	121.6 ± 11.5 BCD	109.1 ± 9.1 EF
ARTBLOC	118.6 ± 6.2 CDE	112.9 ± 8.2 DE	123.0 ± 6.8 ABCD
TELIO CAD	130.7 ± 9.9 ABC	134.5 ± 6.8 A	123.3 ± 9.2 ABCD
VITA CAD	73.6 ± 6.5 GH	77.7 ± 4.9 G	73.7 ± 5.5 GH

Levels not connected by same letter are significantly different. (p < 0.05)

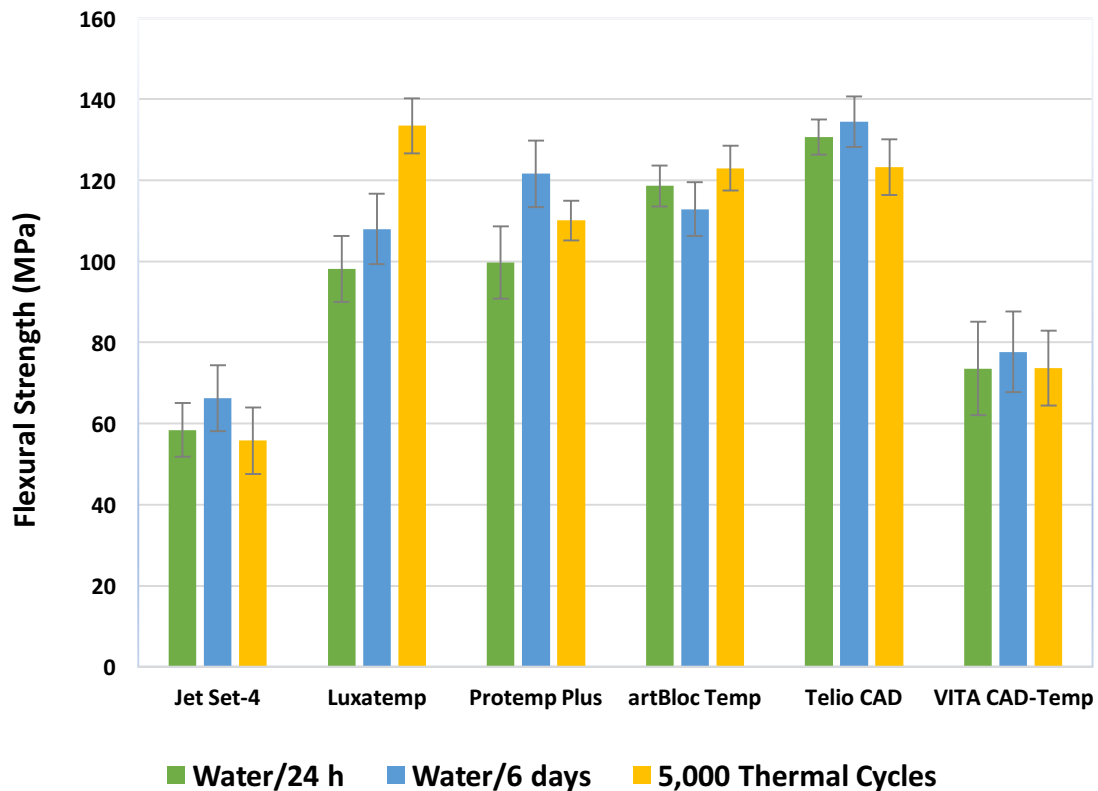


Figure 12. Flexural Strength (MPa) of Provisional C&B Materials in Three Different Treatments

3.2 Flexural Modulus

The mean flexural modulus values are compared in Table 2.

After 24 hours immersed in water at 37°C VITA CAD-Temp (4.08 ± 0.72 GPa) presented the highest value in flexural modulus, followed by artBloc Temp (3.19 ± 0.72 GPa), Telio CAD (2.99 ± 0.72 GPa), Protemp Plus (2.48 ± 0.77 GPa), Luxatemp (2.44 ± 0.65 GPa) and Jet Set-4 (1.75 ± 0.6 GPa). From the groups stored for 6 days immersed in water at 37°C, VITA CAD-Temp exhibited the highest value in flexural modulus (3.70 ± 0.59 GPa), followed by Telio CAD (3.50 ± 0.73 GPa), Protemp Plus (3.25 ± 0.59 GPa), Luxatemp (2.90 ± 0.49 GPa), artBloc Temp (2.89 ± 0.43 GPa), and Jet Set-4 (1.92 ± 0.4

GPa). From the group subjected to 5,000 thermal cycles between 5°C and 55°C in water with 35 seconds dwelling time, Luxatemp exhibited the highest value in flexural modulus (4.55 ± 0.55 GPa), followed by VITA CAD-Temp (3.75 ± 0.84 GPa), Telio CAD (3.48 ± 0.88 GPa) Protemp Plus (3.35 ± 0.49 GPa), artBloc Temp (3.10 ± 0.35 GPa), and Jet Set-4 (1.61 ± 0.68 GPa).

A one-way ANOVA indicated the effects of different levels among different aging treatments and materials. There were statistically significant differences between materials and different aging treatments ($p < 0.05$), post hoc Tukey-test method shows that there was a significant increase of flexural modulus of Luxatemp after thermal cycling treatment.

Microfiller reinforced polyacrylic block (VITA CAD-Temp) demonstrated the highest flexural modulus among all the materials tested. Overall CAD/CAM interim restorative materials exhibited higher flexural modulus.

Conventional provisional resin bis-acryl (Luxatemp) increased its flexural modulus significantly after 5,000 thermal cycles between 5°C and 55°C in water with 35 seconds dwelling time. Conventional PMMA (Jet Set-4) showed the lowest flexural modulus of all the materials tested.

Table 2. Flexural Modulus (GPa) of Provisional C&B Materials in Three Different Treatments, Mean \pm SD

Material	Treatment (GPa)		
	24 hours	6 days	5,000 Thermal Cycles
JET SET 4	1.756 \pm 0.60G	1.923 \pm 0.40 FG	1.619 \pm 0.68 G
LUXATEMP	2.449 \pm 0.65 EFG	2.907 \pm 0.49 CDEF	4.559 \pm 0.55 A
PROTEMP PLUS	2.485 \pm 0.77 DEFG	3.250 \pm 0.59 BCDE	3.352 \pm 0.49 BCDE
ARTBLOC	3.199 \pm 0.72 BCDE	2.893 \pm 0.43 CDE	3.101 \pm 0.35 BCDE
TELIO CAD	2.996 \pm 0.72 CDE	3.503 \pm 0.73 ABCD	3.481 \pm 0.88 ABCD
VITA CAD	4.087 \pm 0.72 AB	3.708 \pm 0.59 ABC	3.754 \pm 0.84 ABC

Levels not connected by same letter are significantly different. ($p < 0.05$)

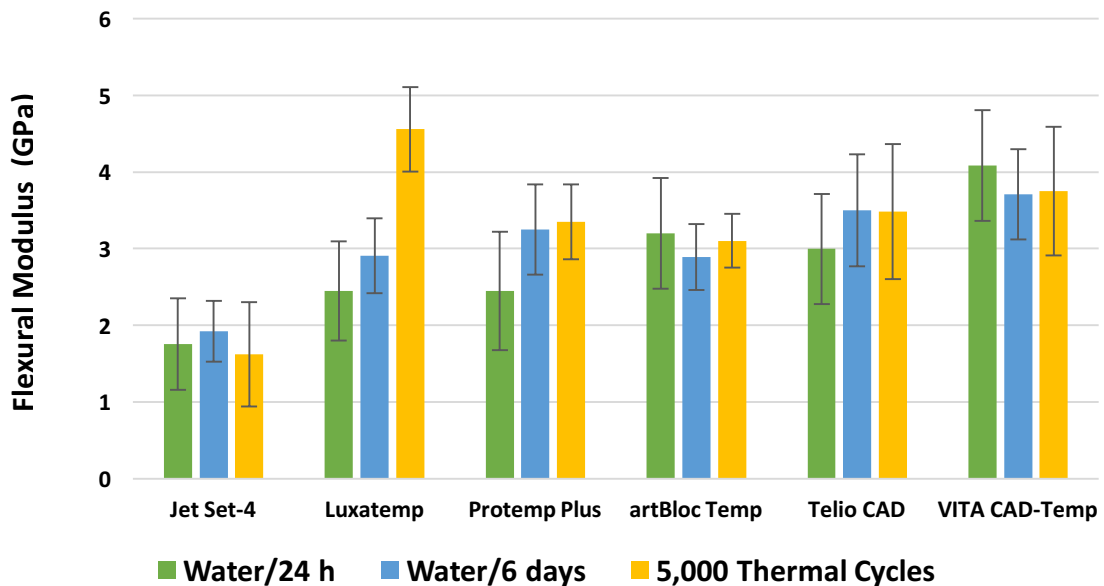


Figure 13. Flexural Modulus (GPa) of Provisional C&B Materials in Three Different Treatments

4. DISCUSSION

The results of flexural strength and flexural modulus under static load in a controlled environment might not reproduce intraoral conditions. However, these results are acceptable predictors of the clinical performance of the materials (Lang et al., 2003).

The purpose of this study was to investigate the difference in performance of interim restorations fabricated by a traditional direct technique with conventional materials and those fabricated with the more modern approach by indirect technique with CAD/CAM materials.

The null hypothesis that there is was no significant difference in the flexural strength of conventional and CAD/CAM interim restorative materials was rejected. CAD/CAM interim restorative materials PMMA blocks (Telio CAD and artBloc Temp) demonstrated superior flexural strength among all tested materials. Microfiller reinforced polyacrylic block (Vita CAD-Temp) showed inferior flexural strength when compared to PMMA CAD/CAM blocks, and bis-acryl conventional resins (Protemp Plus, Luxatemp). This is in agreement with studies by (Abdullah et al., 2016; Yao et al., 2014). (Peñate et al., 2015) reported non-significant differences between the fracture strength of CAD/CAM interim restorative materials and conventional materials, but only after the latest were reinforced with glass fiber.

The null hypothesis that there was no significant difference in the flexural modulus of conventional and CAD/CAM interim restorative materials was rejected. CAD/CAM interim restorative materials blocks demonstrated superior flexural modulus. This can be attributed to the mode of CAD/CAM blocks fabrication which utilizes an industrial

polymerization process, featuring a high homogeneity material. The blocks are milled extra-orally avoiding polymerization shrinkage and exothermic reaction.

The null hypothesis that there was no significant difference in flexural strength or the flexural modulus between the groups stored under water and those subjected to the effects of thermal accelerated aging was partially rejected. Conventional bis-acryl composite material (Protemp Plus) increased its flexural strength after 6 days at water storage at 37° while another conventional bis-acryl (Luxatemp) increased its flexural strength and flexural modulus after 5,000 thermal cycles between 5°C and 55°C in water with 35 seconds dwelling time. The increase of flexural strength after 6 days at water storage of Protemp Plus and the increase of flexural strength and flexural modulus after thermal cycling treatment in Luxatemp can be attributed to continuous cross linking of the materials (Kerby et al., 2013; Poonacha et al., 2013).

Further research can be done in order to compare the quality of these materials. Future studies could evaluate marginal fit, repaired bond strength, color stability, surface roughness and wear resistance.

CONCLUSION

- Overall CAD/CAM materials demonstrated significantly higher flexural strength and flexural modulus over conventional resins.
- No significant difference in flexural strength and flexural modulus was found among the three treatments except for Protemp Plus and Luxatemp.
- Luxatemp showed significant increased flexural strength and flexural modulus after thermal cycling.
- Protemp Plus showed increased flexural strength after 6 days in water storage at 37°.

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CURRICULUM VITAE

