©Operative Dentistry, 2022, **47-1**, 97-106

Mechanical Properties of Bisacryl-, Composite-, and Ceramic-resin Restorative Materials

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Clinical Relevance

Understanding mechanical properties and wear resistance of resin-based materials aids in material selection and enhances clinical performance. Certain bisacryl resin materials may have favorable mechanical properties and resistance to wear to suggest a longer term of use than commonly intended.

SUMMARY

Objective: Resin-based materials used in restorative dentistry are introduced at a fast pace with limited knowledge about their properties. Comparing properties of these materials from different restorative categories is lacking but can help the clinician in material selection. This study aimed to compare mechanical properties and wear resistance of bis-acryl-, composite-, and ceramic-resin restorative materials.

Methods and Materials: Bisacryl-resin (Bis-R, LuxaCrown, DMG), composite-resin (Com-R, Filtek Supreme Ultra, 3M Oral Care), and ceramic-resin (Cer-R, Enamic, VITA Zahnfabrik) specimens were prepared for mechanical tests: fracture toughness (FT) with and without initial thermomechanical loading using a mastication simulator, flexural strength (FS), and flexural modulus (FM), compressive strength (CS), and volumetric wear loss measurement. The datasets for FT and wear resistance were each analyzed using two-way ANOVA followed by pairwise comparisons or Tukey testing as appropriate. The datasets for FS, FM, and CS were analyzed using one-way ANOVA followed by the Tukey test.

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http://doi.org/10.2341/20-191-L

Results: Analysis of FS, FM, and CS showed significant differences between materials, with all pairwise comparisons between materials showing significance. Analysis of FT resulted in a significant interaction between the material and treatment, with analysis of wear loss showing a significant interaction between the material and the number of cycles.

Conclusions: Cer-R demonstrated superior FT, CS, and wear resistance compared to Bis-R and Comp-R materials. Fracture toughness of Bis-R increased after thermomechanical loading.

INTRODUCTION

Resin-based materials have a wide range of use in modern dentistry and have become a popular alternative to traditional ceramic and metal restorations.[1,2] Nowadays, resin-based materials encompass a wide variety of dental materials including provisional materials, conventional composite-resin, and CAD/CAM blocks. However, there are still issues surrounding resin-based restorations such as relatively poor mechanical properties and wear resistance when compared to ceramic material.[3,4]

Provisional materials are used to protect and maintain remaining tooth structure and function during the fabrication of a permanent prosthesis. It is important that the provisional material has acceptable biological, mechanical, and physical properties to ensure the protection of hard and soft tissues throughout treatment.[5] Although provisional materials are meant to be replaced by permanent prostheses, they may need to survive for periods greater than six months depending on the treatment plan.[3] Since its emergence in the late 1990's, bisacryl has become a popular choice for provisional restorations. Bisacryl resin-based materials offer superior mechanical properties and wear resistance compared to earlier counterparts.[6] A variety of polymerization methods also make bisacryl a popular choice for clinicians. However, it has been reported that dual-polymerizing materials may show inferior flexural strength if they are only allowed to polymerize chemically.[5]

Composite-resin is a popular choice for direct restorations due to its ease of handling, natural esthetics, and relatively strong mechanical properties. Although composite-resins lack the strength of ceramics, their hardness and flexural properties are similar to natural teeth, which help limit opposing wear.[7,8] The composition of the material is a primary factor in determining the mechanical properties. For example, Bis-GMA has hydrophilic properties, which may affect the mechanical strength of the material through increased water sorption and surface degradation.[3] The quantity and size of the inorganic filler can also influence the overall mechanical strength and wear pattern of the material.[9]

CAD/CAM technology was first developed with CEREC in 1985, giving the ability to produce in-office restorations through milling.[10] This technological breakthrough provided the ability to reproduce consistent esthetic restorations in a time-efficient manner that often require minor additional processing.[4] The two main CAD/CAM groups consisted of ceramic and composite, each having issues with longevity due to the brittleness of ceramic and the wear resistance and poor mechanical strength of composite. The introduction of a polymer-infused ceramic CAD/CAM material attempted to address this issue by combining the positive properties of both ceramic and composite.[4] The polymer network provides increased flexural strength and minimized opposing wear, while the ceramic matrix provides improved wear resistance and strength.[11] As suggested by He and Swain, this combination provides similar characteristics to natural teeth, thus making it an ideal restorative material.[8]

A review of the literature indicates that a comparison between bisacryl-, composite-, and ceramic-resin materials focusing on material selection for clinicians has not been performed. As a result, comprehensive analysis of mechanical properties and wear resistance of these materials is lacking. Therefore, the aim of this study was to provide a detailed comparison of mechanical properties and wear resistance of resin-based materials. The two null hypotheses were: 1) There is no difference in fracture toughness values between the different types of resin-based materials, and 2) thermomechanical loading has no effect on the fracture toughness values of the investigated materials. There is no difference in flexural strength, flexural modulus, and compressive strength properties of the resin-based materials. There is no difference in the wear resistance of the resin-based materials investigated.

METHODS AND MATERIALS

Bisacryl-resin (Bis-R, LuxaCrown [LC], DMG Chemisch-Pharmazeutische, Hamburg, Germany), composite-resin (Com-R, Filtek Supreme Ultra, 3M Oral Care, St. Paul, MN, USA), and ceramic-resin (Cer-R, Enamic, VITA Zahnfabrik, Bad Säckingen, Germany) CAD/CAM blocks (Table 1) were prepared for the following mechanical tests:

- Fracture toughness (FT); with and without initial thermomechanical loading using a mastication simulator.

Table 1: *Resin-based Materials Studied*

Material	Manufacturer	Shade/Lot Number(s)	Code
LuxaCrown	DMG	A2/789645	Bis-R
Filtek Supreme Ultra	3M Oral Care	A2B/N967677	Com-R
Enamic	VITA	2M2/78140	Cer-R

- Flexural strength, and flexural modulus (FS, FM).
- Compressive strength (CS).
- Volumetric wear loss measurement.

Fracture Toughness

The FT of the studied materials were measured using the single edge V-notched beam under a three- point bending test. The preparation and testing parameters followed ASTMD5045-14; ISO/NP 13586.[12,13]

A custom mold was created (21.0 ± 0.1 mm in length, 4.0 ± 0.1 mm in depth, and 3.0 ± 0.1 mm in thickness) from polyvinylsiloxane (PVS) impression material for specimen preparation. Materials were carefully injected into the mold and covered by a transparent ethylene film and glass slide. Slight pressure (5-10 N) was applied to the center of the glass slide to evenly distribute the material and extrude excess. Bis-R specimens were allowed to self-polymerize according to the manufacturer's recommended time. Com-R specimens were carefully photo-polymerized according to the manufacturer's recommended time of exposure using a visible photo-polymerizing unit (Elipar DeepCure-S, 3M Oral Care) with mean irradiance of 1200 mW/cm^2. The irradiance of the photo-polymerizing unit was tested every 24 hours using the MARC Light Collector (BlueLight Analytics, Halifax, NS, Canada) to ensure the consistency of polymerizing conditions. Each specimen was polymerized in three + overlapping irradiations to ensure efficient polymerization of the specimen. Each specimen was inspected for defects prior to polishing. If defects were significant, they were discarded. Remaining specimens were polished under water using 600-grit silicon-carbide abrasive paper (MicroCut, Buehler, Lake Bluff, IL, USA) to remove excess material. A digital micrometer with an accuracy of 0.01 mm, (QuantuMike Micrometer, Mitutoyo Corporation, Sakado, Japan) was used to monitor the dimensions during polishing. The final width (b) and thickness (w) of each specimen was recorded before storing in deionized water at 37°C for 24 hours prior to testing.

Cer-R blocks were sectioned into smaller workable blocks to be further sectioned using an IsoMet-1000 sectioning saw. A 15 HC diamond coated blade (Buehler) was wafered under water at 150 rpm according to manufacturer's recommendations. The Cer-R block was fixed to a flat vice and secured by melted wax during sectioning. To achieve the final specimen dimension, three consecutive cuts were made (21.0 ± 0.1 mm in length, 4.0 ± 0.1 mm in depth, and 3.0 ± 0.1 mm in thickness). Due to the accuracy of the sectioning machine, no further processing on Cer-R was necessary prior to testing. Specimens were stored in a dry, air-tight container until testing.

Specimens were remounted in the IsoMet 1000 to create a 0.50-mm deep notch at the center using a 150-μm thick diamond coated blade. The notch was then coated with diamond polishing paste (3.5 μm, Kent Supplies, Quebec, Canada) and a razor blade was used to form the notch into a V-shape with a final depth of 0.80 mm to 1.20 mm. A consistent horizontal motion and force (5 N-10 N) with the razor blade ensured a uniform notch formation. Each side of the notch was measured using a light microscope with a >50× magnification and averaged for a final notch depth.

A Universal Instron machine (Model 4411, Instron, Norwood, MA, USA) with an attached 3-point bending fixture was used to determine the FT of the specimens. Specimens were placed evenly on the fixture and loaded until failure with a crosshead speed of 0.5 mm/min. The peak fracture load was recorded to three significant figures and the FT was determined in units of MPa$\cdot$m$^{1/2}$ according to the formula:

$$K_{IC} = (P / bw^{1/2}) * (L / w) * ((3\,\alpha^{1/2}) / ((2\,(1-\alpha))^{3/2})) * Y,$$

where $Y = 1.9887 - (1.326*\alpha) - (3.49-0.68*\alpha) + (1.35\alpha^2)(\alpha)(1-\alpha)/(1+\alpha^2)$, α = average V-notch depth of the group, P = fracture load, b = width of the specimen, w = thickness of the specimen, and L = distance between support beams.

Thermomechanical Loading

Specimens for FT were separately prepared for thermomechanical loading. Each group was mounted in a custom fabricated stainless-steel holder with acrylic resin. The acrylic resin was then allowed to fully set following the manufacturer's recommended time prior

to loading. Stainless steel holders were then mounted in the masticating simulator (CS-4.8, SD Mechatronik, Feldkirchen-Westerham, Germany). The force was calibrated using a force meter (KM-3, SD Mechatronik) with a weight of 4 kg mounted to an antagonist bar (1 kg). The machine was set to 100 cycles to obtain an average z-axis force. The testing parameters were set for 1,200,000 mechanical cycles (1.2 Hz) at 50 N with simultaneous thermocycling in deionized water (5° and 55°C) for a 30-second dwell time.[14] A break detection system (PM-3, SD Mechatronik) was installed in each chamber and monitored any premature fractures. Surviving specimens were tested for FT.

Flexural Strength and Modulus (FS and FM)

The FS (MPa) and FM (GPa) was determined using a three-point bending test. The testing parameters and preparation followed ISO Standard 4049.[15]

A custom mold (21.0 ± 0.1 mm in length, 2.0 ± 0.1 mm in depth and 2.0 ± 0.1 mm in thickness) was fabricated from PVS for specimen preparation. Bis-R and Com-R were polymerized, finished, and stored for testing as previously described.

Cer-R CAD/CAM blocks were sectioned into smaller workable blocks as previously described. To achieve the final specimen dimension, three consecutive cuts were made (21.0 ± 0.1 mm in length, 2.0 ± 0.1 mm in depth, and 2.0 ± 0.1 mm in thickness). Specimens were stored as previously described.

A Universal Instron machine with an attached three-point bending fixture was used to determine the FS and FM of the specimens. Prior to loading, specimen dimensions were imputed to determine modulus. Specimens were placed evenly on the fixture and loaded until failure with a crosshead speed of 0.5 mm/min. The peak fracture load and modulus were recorded to three significant figures and the FS was determined according to the formula:

$$\alpha = 3\,FL/2wt,$$

where F = maximum force applied, L = distance between support beams, w = width of specimen, and t = thickness of specimen.

Compressive Strength

The CS of the studied materials was determined and analyzed according to ISO Standard 9917-1. A custom mold (6.0 ± 0.1 mm in length and 4 ± 0.1 mm in diameter) was fabricated from PVS for specimen preparation. Bis-R and Com-R were polymerized as previously described.

Bis-R and Com-R were polished under water using 600-grit silicon-carbide abrasive paper (MicroCut) to achieve the desired specimen height. A digital micrometer was used to confirm the length and diameter of each specimen. The diameter was measured twice, each at 90° from the previous and averaged. Specimens were stored for testing as previously described.

Cer-R CAD/CAM blocks were used to create cylindrical specimens using a milling machine. Blocks were mounted in the machine and computer-generated models of the specimens were created. After milling, the dimensions were confirmed and the specimens stored according to the methodologies previously described.

A Universal Instron machine was used to calculate the peak of each specimen. Calibration of the Instron was done prior to testing according to manufacturer's instructions. Cylindrical-shaped specimens were placed flat at the center of the compression plate and loaded until fracture with a crosshead speed of 0.5 mm/min. The peak load was recorded, and the CS was determined according to the formula:

$$\text{Compressive strength} = F/\varpi r^2,$$

where F = maximum force applied and r = radius of the specimen.

Volumetric Wear Loss

The volumetric wear loss of the studied materials was determined using the masticating simulator and the wear measurement system. Eight specimens were prepared for each group (N=24) using custom-made (inner Ø 10 mm, depth 2 mm) stainless steel holders. Bis-R and Com-R were injected into the holders and polymerized as previously described.

Cer-R specimens (n=8) were prepared from CAD/CAM blocks using an IsoMet 1000 (Buehler) sectioning machine. Blocks were mounted to the vise arm and sectioned in 2-mm discs with a diamond-coated blade. Cer-R discs were then mounted in custom made (inner Ø 18 mm, depth 3 mm) stainless steel holders using acrylic resin.

All specimens were polished in a graded series to establish a fine finished surface. Excess material was removed using 600-grit silicon carbide abrasive paper and then finished with 1200-grit silicon carbide paper under running water at 400 rpm for 1 minute per side. Specimens were then stored as previously described.

Each group was mounted in the masticating simulator and the wear measurement system was calibrated to establish a zero-point for each chamber. Steatite balls (Ø-6 mm) were used as antagonists to simulate enamel hardness.

Specimens were submitted to a wear test, measuring the progression of wear after 5k, 10k, 20k, 40k, 60k, 80k, 100k, and 120k cycles.

The following parameters were set in the masticating simulator for thermomechanical loading: Load - 50 N; Upstroke - 2 mm; Downstroke - 1 mm; Horizontal movement - 0.7 mm; Upward speed - 60 mm/second; Downward speed - 60 mm/second; Horizontal speed - 40 mm/second; Frequency - 1 Hz; Thermocycling - 5-55°C 30-second holding time, transfer time 15 seconds, total cycle 90 seconds; Direction - Back and forth.

After each cycle interval was complete, light-body (Honigum Pro Light, DMG America, Ridgefield Park, NJ, USA) and putty (Virtual Putty Fast Set, Ivoclar Vivadent, Amherst, NY, USA) PVS impression materials were used to record the wear. Putty was hand mixed with a 1:1 ratio (base:catalyst) and quickly placed inside of a cylindrical tray before setting. Light-body impression material was then inserted into the wear mark and the tray was placed over the specimen. The light-body impression material was allowed to fully set before removing the tray for inspection. If any defects were present, the impression was retaken. Impressions were scanned using a 3D laser scanner (LAS-20, SD Mechatronik) with a 0.2 mm resolution. The digital scan was then uploaded to Geomagic Control X (3D Systems, Rock Hill, SC, USA) to calculate the volumetric wear loss. Using the digital points uploaded from the scan, a 3D model of the wear mark was created. The volume of the wear was calculated at each measurement interval to create a trend for each material.

Data Analyses

The FT data was summarized by means and 95% confidence intervals for each material and condition. The Akaike information criteria[16] (AIC) and the Bayesian information criteria[17] (BIC) that produced an optimized fit[18,19] of this dataset was determined. Then these data were analyzed by a two-way ANOVA with the interaction term included in the model, using maximum likelihood estimates and a lognormal error distribution (PROC GLMMIX, SAS Proprietary Software 9.4, SAS Institute Inc., Cary, NC, USA). For any effect found statistically significant, the overall effect was analyzed by Bonferroni-corrected (SAS PROC MULTTEST) pairwise comparisons that were *a priori* determined to reflect clinical interest. For each of the FS, FM, and CS properties, the data were summarized by means and 95% confidence intervals for each material. The AIC and BIC that produced an optimized fit of each dataset was determined. Then each of these three data sets were analyzed by a one-way ANOVA, using maximum likelihood estimates and a lognormal error distribution, with any found significant effect resolved further by Tukey testing. The wear data were summarized by means and 95% confidence intervals for each material and number of cycles. The AIC and BIC that produced an optimized fit of this dataset were determined. Then this dataset was analyzed by a two-way repeated-measures ANOVA with the interaction term included in the model, using maximum likelihood estimates, a normal error distribution, the Satterthwaite degrees of freedom method, and a covariance structure of compound symmetry (PROC MIXED, SAS Proprietary Software 9.4). For any effect found statistically significant, the overall effect was analyzed by Bonferroni-corrected pairwise comparisons that were *a priori* determined to reflect clinical interest. Each ANOVA and associated subsequent pairwise comparisons used an overall $\alpha = 0.05$ within each property.

RESULTS

The means and 95% confidence limits of the fracture toughness data are provided in Figure 1. Analysis of the FT data resulted in a significant interaction [$F(2:54)=36.12$, $p<0.0001$)], so pairwise comparisons were made between the two conditions for each material and between all possible pairs of materials for each condition. There were significant differences between the two conditions for each material, with Bis-R and Cer-R each getting tougher on thermomechanical loading ($p\leq0.0013$), and Com-R getting less tough ($p<0.0001$). As formed, Bis-R had lower toughness than either of the other materials ($p<0.0001$) and post-

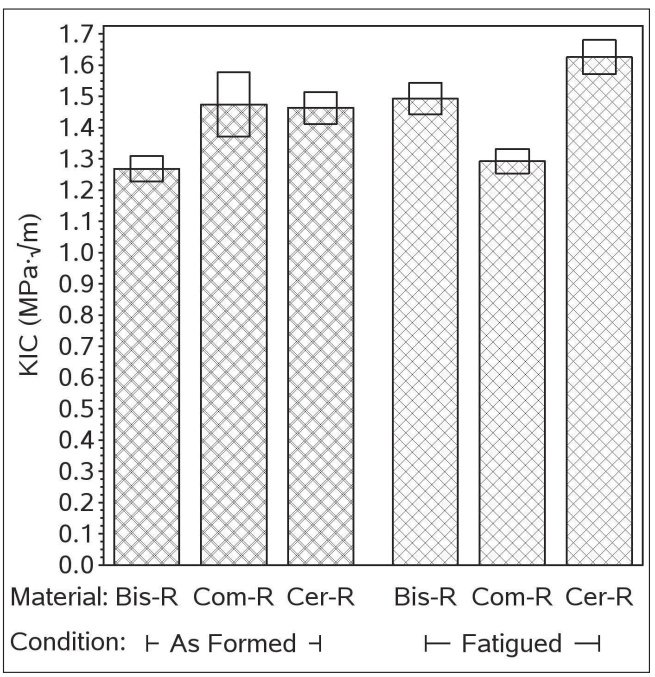

Figure 1. *Means and 95% confidence intervals of fracture toughness for materials and conditions studied.*

thermomechanical loading, and significant differences were found between every pair of materials ($p \leq 0.0144$).

The means and 95% confidence intervals for the FS and FM data are shown in Figure 2. Analysis of the FS data showed a significant difference between materials [$F(2:27)=95.02$, $p<0.0001$] and all pairwise comparisons between materials showed significance ($p \leq 0.0005$). Analysis of the FM data showed a significant difference between materials [$F(2:27)=4587$, $p<0.0001$] and all pairwise comparisons between materials showed significance ($p<0.0001$).

The means and 95% confidence intervals for the CS data are shown in Figure 3. Analysis of the strength data showed a significant difference between materials [$F(2:27)=164.6$, $p<0.0001$], with all pairwise comparisons significant ($p \leq 0.0373$).

The means and 95% confidence intervals for the wear data are shown in Figure 4 for the materials and number of wear cycles studied. Analysis of the wear data showed a significant interaction between materials and the number of cycles [$F(16:168)=11.10$, $p<0.0001$]. Therefore, pairwise comparisons were only evaluated between all possible pairs of materials at each number of cycles and between all possible pairs of number of cycles for each material. For material pair comparisons, the wear of Bis-R was greater than that of Com-R ($p=0.0415$) at 5 k cycles. The wear of Cer-R was greater than that of Com-R at 20 k cycles ($p<0.0001$) and at 40 k cycles ($p=0.0089$). Then at 120 k cycles, the wear of Cer-R was less than that of Com-R ($p<0.0001$) and that of Bis-R ($p=0.0017$). Table 2 indicates statistically significant differences found between numbers of cycles for each material.

DISCUSSION

Resin-based materials are increasingly used in restorative dentistry due to their acceptable strength, wear, elasticity, and affordability when compared to ceramic materials. Therefore, it is important to consider the mechanical characteristics of resin-based materials used in different clinical situations to facilitate their accurate selection favoring clinical longevity. This present laboratory study was performed under controlled conditions to provide a side-by-side comparison of commonly used resin-based restorative materials from different categories known to clinicians as being temporary-, mid-, and long-term restorative material options.

FT is the ability of the material to resist crack propagation and presents a positive correlation with clinical failure; flexural strength presents a positive correlation with wear.[20] FT has also been considered an acceptable method of assessing the mechanical strength and long-term clinical success of a material.[21] Lucsanszky and Ruse found that FT is significantly affected by aging in resin-based materials.[22] In this laboratory study, FT was evaluated pre- and post- thermomechanical loading. Fatiguing may mimic the vertical and lateral occlusal forces in addition to thermal stressing of the material, providing an environment similar, to some extent, to

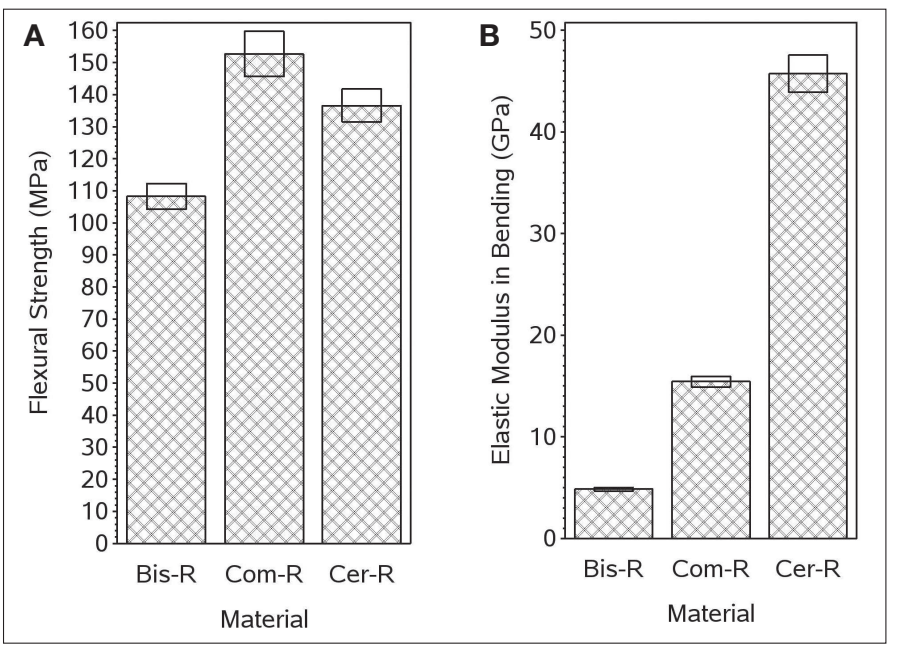

Figure 2. *Means and 95% confidence intervals of flexural strength (a) and of flexural modulus (b) for materials studied.*

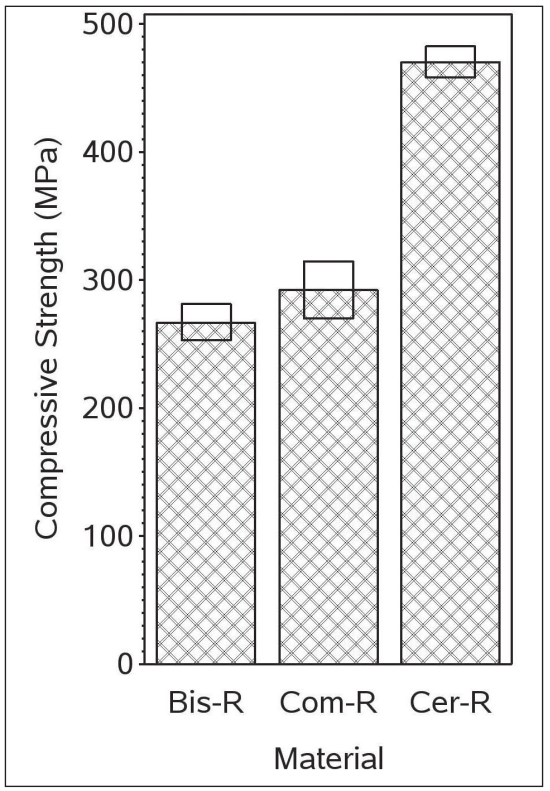

Figure 3. *Means and 95% confidence intervals of compressive strength for materials studied.*

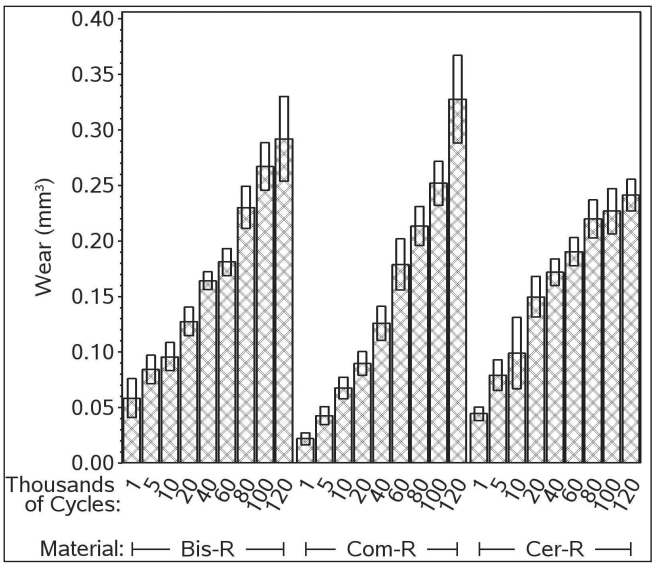

Figure 4. *Means and 95% confidence intervals of wear volume for materials and number of cycles studied.*

the oral environment. In resin-based materials, the matrix and filler play a major role in the mechanical property of the material. The FT of Com-R and Cer-R were greater prefatiguing than Bis-R. The presence of urethane dimethacrylate in Com-R and Cer-R may help contribute to the toughness of the material due to the increased degree of polymerization and flexibility of the urethane linkages.[23] However, Bis-R and Cer-R showed a significant increase in FT after fatiguing while a decrease in the FT of Com-R was observed. The increase in the FT of Bis-R and Cer-R may be attributed to the absorption of water during fatiguing, causing an increase in flexibility, lowering internal stress caused by polymerization shrinkage and increasing the plastic zone. However, the uptake of water in Com-R may have caused swelling and degradation of the matrix and hydrolytic breakdown of the filler-matrix interface, which led to a decrease in mechanical properties.[24] Similar studies reported an increase in the FT of Cer-R after aging, which may be attributed to the increase in flexural modulus.[22,25] Since Cer-R is composed primarily of a ceramic core, it may not have been affected by the absorption of water to the extent of Com-R. The Bis-R material performed favorably after fatiguing, which may be related to the nature of its methacrylate/glass filler composition. Based on these outcomes, the first null hypothesis was rejected. There were differences in FT values of the resin-based materials as formed, and the thermomechanical loading had a significant effect on the FT values of the materials.

Statistical analysis of the results showed Com-R to have the greatest flexural strength of the materials tested, followed by Cer-R and Bis-R. Cer-R lacks the flexibility of Com-R due to the ceramic core, and therefore it is unable to withstand the tension and compressive forces of the three-point bending. Bis-R had a lower FS than the other resin materials and this was supported by its low FM, which was significantly lower as well. Therefore, with the differences in FS and FM of the different materials, the second null hypothesis was rejected.

CS is another acceptable method of evaluating the overall strength of a material. One of the main causes of failure in posterior restorations is caused by compressive forces, therefore it is important for a restorative material to have a CS capable of resisting the forces produced in the mouth.[26]

Cer-R withstood the greatest compressive force of the materials tested, followed by Com- R and Bis-R. High CS of Cer-R may be expected due to the strength of the ceramic core and added flexibility provided by the infiltrated resin.[27] Bis-R and Com-R lack the strength of a ceramic, and therefore are unable to withstand high compressive force. However, it is commonly known that bisacryl-resins are lower in strength than composite resins and hence their temporary restorative

Table 2: *Significant Difference in Wear Between Number of Cycles for Each Material Studied*

Material	Number of Cycles		*p*-value[b]
	Lower	Least of Upper[a]	
Cer-R	1000	10,000	<.0001
Com-R	1000	10,000	0.0007
Bis-R	1000	10,000	0.0223
Cer-R	5000	20,000	<0.0001
Com-R	5000	20,000	0.0004
Bis-R	5000	20,000	0.0021
Cer-R	10,000	20,000	0.0001
Com-R	10,000	40,000	<0.0001
Bis-R	10,000	40,000	<0.0001
Cer-R	20,000	60,000	0.0062
Com-R	20,000	40,000	0.0338
Bis-R	20,000	40,000	0.0289
Cer-R	40,000	80,000	0.0003
Com-R	40000	60,000	<0.0001
Bis-R	40,000	80,000	<0.0001
Cer-R	60000	100000	0.0293
Com-R	60,000	100,000	<0.0001
Bis-R	60,000	80,000	0.0001
Com-R	80,000	100,000	0.0146
Bis-R	80,000	100,000	0.0272
Com-R	100,000	120,000	<0.0001

Abbreviations: Bis-R, bisacryl-resin; Cer-R, ceramic-resin; Com-R, composite-resin.
[a]*All higher number of cycles were different than the lower number of cycles for each row.*
[b]*Bonferroni-corrected* p-*values.*

nature is used in transitioning to a more definite restoration.[28] Bis-R displayed mechanical properties similar to Com-R, which is encouraging considering its indication of use beyond the limited time period of a couple of weeks for a conventional temporary restoration. Moreover, providing an option to use a self-polymerizing, long-term temporary can become a valuable option for temporization during a long-term treatment plan, or simply to be used as a definitive restoration in patients who cannot afford the cost of a more expensive restorative treatment plan. Significant difference in the CS of Cer-R material led to rejecting the null hypothesis.

Wear evaluation using a mastication simulator with a steatite antagonist is a well-documented method.[15] It may provide insight to properties of a relatively new material available for clinical use but lacking proper independent clinical evidence of performance. The wear loss from Bis-R and Com-R exceeded the wear of Cer-R, which was expected due to the composition of the tested materials. As previously mentioned, FS has been reported to show positive correlation with wear.[20] Although Com-R had the greatest flexural strength of the tested materials, it also had the greatest wear loss. The limited wear loss of Cer-R was expected due to the primarily ceramic matrix. The greater the volumetric wear, the smaller the modulus, suggesting that increased elasticity leads to greater wear. However, opposing wear is less severe when the elastic modulus of the material is similar to tooth structure. Therefore, both the wear of the material and the wear of the opposing must be considered thoroughly when choosing an appropriate restorative material. Wear of enamel has been reported to be 0.22 mm^3 in a study testing the wear of enamel with a methodology similar to the one used in this study.[29]

Considering this a standard rate of wear, the Cer-R wear rate is closest to enamel, followed by Bis-R and

Com-R. With these differences in wear resistance amongst the resin-based materials, the null hypothesis was rejected. Noteworthy, Cer-R restorations are usually glazed with a varnish (methyl methacrylate and acrylic resin) layer to enhance color stability and are claimed by the manufacturer to be abrasion-resistant. This layer may delay wear of the Cer-R material and prolong its wear-resistance, as it may take longer to wear through the glaze.

These laboratory tests should be interpreted with care, and making any clinical relevance of such findings can only be confirmed with proper clinical investigation. Unfortunately, clinical trials investigating such properties are scarce. New materials are introduced at a fast rate with very limited to no clinical evidence of their support. Therefore, laboratory testing can provide useful information about a relatively new material with proper testing, given that the results are interpreted with care and consideration of the limitations. Although artificial aging is known to affect the mechanical properties of a resin-based material, time limitations only allowed for fracture toughness and volumetric wear of each material to be determined before and after thermomechanical loading.

CONCLUSIONS

Considering the limitations of this laboratory study, the following conclusions may be drawn:

1. Fracture toughness of Bis-R is lower than Cer-R and Com-R materials. Thermomechanical loading increased the FT of Bis-R to levels comparable to Cer-R while decreasing the FT of Com-R.
2. Flexural strength of Comp-R was higher than other materials, while the FM of Bis-C was significantly lower. Contrarily, the CS of Cer-R was significantly higher than Bis-R and Comp-R, which were comparable.
3. Cer-R was more resistant to wear than the other materials; however, Bis-R and Com-R wore at a rate similar to enamel, with Bis-R slightly more resistant to wear.

Conflict of Interest

The authors of this article certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

(Accepted 18 March 2021)

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