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Laboratory Research

Mechanical Properties and Simulated Wear of Provisional Resin Materials

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Clinical Relevance

Erosive wear behavior as a function of time is an important parameter for the selection of a provisional restoration.

SUMMARY

The purpose of this study was to determine flexural properties and erosive wear behavior of provisional resin materials. Three bis-acryl base provisional resins—1) Protemp Plus (PP), 2) Integrity (IG), 3) Luxatemp Automix Plus (LX)—and a conventional poly(methylmethacrylate) (PMMA) resin, UniFast III (UF), were evaluated. A resin composite, Z100 Restorative (Z1), was included as a benchmark material.

Six specimens for each of the four materials were used to determine flexural strength and elastic modulus according to ISO Standard 4049. Twelve specimens for each material were used to examine wear using a generalized wear simulation model. The test materials were each subjected to wear challenges of 25,000, 50,000, 100,000, and 200,000 cycles in a Leinfelder-Suzuki (Alabama) wear simulator. The materials were placed in custom cylinder-shaped stainless-steel fixtures, and wear was generated using a cylindrical-shaped flat-ended stainless-steel antagonist in a slurry of non-plasticized PMMA beads. Wear (mean facet depth [μm] and volume loss [mm^3]) was determined using a noncontact profilometer (Proscan 2100) with Proscan and AnSur 3D software. The laboratory data were evaluated using two-way analysis of variance (ANOVA; factors: 1) material and 2) cycles) followed by Tukey HSD post hoc test (α=0.05).

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The flexural strength ranged from 68.2 to 150.6 MPa, and the elastic modulus ranged from 2.0 to 15.9 GPa. All of the bis-acryl provisional resins (PP, IG, and LX) demonstrated significantly higher values than the PMMA resin (UF) in flexural strength and elastic modulus ($p<0.05$). However, there was no significant difference ($p>0.05$) in flexural properties among three bis-acryl base provisional resins (PP, IG, and LX). Z1 demonstrated significantly ($p<0.05$) higher flexural strength and elastic modulus than the other materials tested. The results for mean facet wear depth (μm) and standard deviations (SD) for 200,000 cycles were as follows: PP, 22.4 (5.0); IG, 51.0 (6.5); LX, 63.7 (4.5); UF, 70.5 (8.0); and Z1, 7.6 (1.2). Volume loss (mm^3) and SDs for 200,000 cycles were as follows: PP, 0.311 (0.049); IG, 0.737 (0.074); LX, 0.919 (0.053); UF, 1.046 (0.127); and Z1, 0.111 (0.017). The two-way ANOVA showed a significant difference among materials ($p<0.001$) and number of cycles for both facet depth and volume loss. The post hoc test revealed differences ($p<0.05$) in wear values among the tested materials examined in this study. The findings provide valuable information regarding the flexural properties and the relative wear behavior of the provisional resins examined in this study.

INTRODUCTION

Provisional restorations are used to prevent damage from occurring during the interim period between tooth preparation and fitting a definitive restoration. Besides the immediate protective, functional, and stabilizing value, interim restorations are useful for diagnostic purposes in which the functional occlusal and esthetic parameters are developed to identify an optimum treatment outcome before the completion of definitive procedures.[1-4] Occasionally, however, interim treatment has to function for extended intervals and provide long-term tooth protection and stability while adjunctive treatment is accomplished. Therefore, maintaining long-term stability of provisional restorations in the oral environment is required for complex treatment, including dental implant therapy.[5-8]

In the past decade, bis-acryl base resins containing inorganic fillers have been made available to provide long-term stability due to their enhanced mechanical properties in the oral environment. These newly developed provisional restorative materials have a different curing mechanism when compared with conventional poly(methylmethacrylate) (PMMA) provisional resins.[6] Also, this type of provisional restoration purportedly reduces the exothermic setting reaction and is easier to manipulate than conventional PMMA resins.[9] Although there are several published research reports regarding their mechanical properties,[10-15] little is known about their erosive wear behavior. To select the optimum provisional materials, evaluating the performance of wear characteristics is an important parameter. In addition, dental clinicians need more information about the clinical relevance of the improved mechanical properties of newer provisional restorative materials and the relationship of these properties to wear resistance. However, trying to relate clinical and laboratory wear data is a significant challenge because adequate clinical data are not available.

Recently, Barkmeier and others[16-18] recommended that a benchmark resin composite material (Z100 Restorative, 3M ESPE Dental Products, St Paul, MN, USA), which has exhibited good clinical and simulated wear performance, be used as a standard for laboratory wear comparison of other restorative materials. The recommendation is further strengthened by the good agreement of clinical and laboratory wear rates of the Z100 Restorative material.[17,18] The purpose of this study was to determine flexural properties and erosive wear behavior of bis-acryl base resins containing inorganic fillers. During the course of this research, the flexural properties and the wear behavior of bis-acryl provisional resins were compared with a PMMA conventional resin and a benchmark resin composite (Z100 Restorative). The hypothesis proposed was that bis-acryl–based resins will demonstrate significantly higher flexural properties and wear resistance than a PMMA conventional resin.

METHODS AND MATERIALS

Study Materials

Flexural properties and wear resistance of three bis-acryl base provisional resins—1) Protemp Plus (PP; 3M ESPE Dental Products), 2) Integrity (IG; DENTSPLY Caulk, Milford, DE, USA), and 3) Luxatemp Automix Plus (LX; DMG Chemisch-Pharmazeutishe Fabrik GmbH, Hamburg, Germany)—and a conventional PMMA resin, 4) UniFast III (UF; GC Corp. Tokyo, Japan), were examined. A resin composite, Z100 Restorative (Z1; 3M ESPE Dental Products), was also included as a control material.

Table 1: *Study Materials*

Provisional Materials	Shade	Manufacturer	Main Components[a]	Code
Protemp Plus (Lot No. B 498865, Lot No. C 495535)	A2	3M ESPE Dental Products (St Paul, MN, USA)	Base: dimethacrylate (BISEMA 6), silane-treated amorphous silica, reaction products of 1,6-diisocyanatohexane with 2-[(2- methacryloxy) ethyl]6-hydroxyhexanoate, 2-hydroxyethyl methacrylate (DESMA), silane-treated silica Catalyst: ethanol, 2,2′-[(1-methylethylidene) bis(4,1-phenyleneoxy)]bisethyl diacetate, silane-treated silica, benzyl-phenyl-barbituric acid, tert-butyl peroxy-3,5,5-trimethylhexanoate	PP
Integrity (Lot No. 100630)	A2	DENTSPLY Caulk (Milford, DE, USA)	Barium boron alumino silicate glass, hydrophobic amorphous fumed silica, polymerizable dimethacrylate resins	IG
Luxatemp Automix Plus (Lot No. 451192)	A2	DMG Chem-Pharm Fabrik GmbH (Hamburg, Germany)	Acrylic resin, glass powder, silica, urethane dimethacrylate, aromatic dimethacrylate, glycol methacrylate	LX
Unifast III (Lot No. Powder 1209253, Lot No. Liquid 1209121)	A2	GC Corporation (Tokyo, Japan)	Powder: ethyl-methyl methacrylate polymer, polymethylmethacrylate, barbituric acid derivative, organic copper compound, pigments Liquid: methyl methacrylate, *N,N*-dimethyl-*p*-toluidine trimethylolpropane, ethylene glycol dimethacrylate	UF
Resin composite				
Z100 Restorative (Lot No. N416713)	A2	3M ESPE Dental Products (St Paul, MN, USA)	Bisphenol A glycidyl dimethacrylate, triethylene glycol dimethacrylate, zirconia/silica	Z1

Abbreviations: IG, Integrity; LX, Luxatemp Automix Plus; PP, Protemp Plus; UF, UniFast III; ZI, Z100 Restorative.
[a] *Manufacturer's information.*

The test materials and their components are listed in Table 1.

Flexural Strength and Elastic Modulus Measurement

Flexural properties of the provisional resins were tested according to procedures specified in ISO International Standard 4049. The provisional resins (PP, IG, LX, UF) were mixed according to the manufacturers' instructions and placed into stainless-steel molds (25 mm × 2 mm × 2 mm) with a condenser. The resin composite paste (Z1) was placed into the mold in three increments. Each increment was light cured for 30 seconds with a Spectrum 800 Curing Light (DENTSPLY Caulk) set at 600 mW/cm^2. After the removal of the cured hardened specimens from the mold, all six sides were wet ground with No. 1200 SiC papers (Struers Inc, Cleveland, OH, USA). The specimens were then stored for 24 hours in distilled water at 37°C before the mechanical tests. The specimens were kept moist during testing to avoid desiccation. After the storage time, six specimens per test group were subjected to the three-point bending flexural strength test using an MTS Insight machine (MTS Systems Corporation, Eden Prairie, MN, USA) at a cross-head speed of 0.75 mm/min until the specimen fractured. The specimens were positioned on a three-point bending apparatus with a span length of 20.0 mm. The peak breaking stress and the modulus of elasticity were determined from the stress-strain curve using TestWorks 4 software (MTS Systems Corporation).

Generalized Wear Simulation

Twelve specimens of each provisional restorative material (PP, IG, LX, UF) and Z1 resin composite were prepared for simulated generalized wear (contact-free area (CFA) wear) using custom stainless-steel fixtures with a cavity in the center of the surface 4.5 mm in diameter and 4 mm in depth. The provisional resins were mixed and placed into the stainless-steel fixtures according to the manufacturers' instructions. For the resin composite material (Z1), two increments (approximately 2 mm in thickness) were each placed and cured for 40 seconds with the Spectrum 800 Curing Light. After 24 hours, all of the specimens were polished flat to 4000 grit using a sequence of silicon carbide papers (Struers Inc).

A Leinfelder-Suzuki wear simulation device (Alabama machine) was used for wear simulation in this study. The simulator has a plastic water bath, and the custom wear fixtures were mounted inside the four-station bath. A brass cylinder was then placed

around each fixture in the bath to serve as a reservoir for the abrasive media (water slurry of unplasticized PMMA with an average particle size of 44 μm). The media were placed inside the brass cylinders to cover the surface of the testing materials in the custom fixtures. The water slurry of PMMA inside the brass cylinders was approximately 6 mm in height over the surface of the test materials.

The antagonist for the generalized wear simulation (CFA) was a stainless-steel cylinder (diameter 6.5 mm) with a flat tip. The antagonist tips were mounted on spring-loaded pistons to deliver the wear challenges. During the application of the load, the antagonists rotated approximately 30° as the maximum force was reached (maximum load of 78.5 N at a rate of 2 Hz) and then counterrotated back to the original starting position as the load was relaxed to complete the cycle. Each specimen was subjected to wear challenges of 25,000, 50,000, 100,000, and 200,000 cycles in the wear simulator.

Wear Measurements

Prior to wear simulation, the surface of each test specimen was profiled using a Proscan 2100 noncontact optical profilometer (Scantron Industrial Products, Ltd, Taunton, England) with Proscan software. These profiles provided the pretest digitized contours (12 test specimens each for the four provisional resins and one resin composite material).

Following the wear challenge cycles, the specimens were ultrasonically cleaned (L&R Solid State Ultrasonic T-14B, South Orange, NJ, USA) in distilled water for three minutes and then profiled again using the Proscan 2100 unit. The X, Y, and Z coordinates of the before and after scans from the Proscan software were exported to another computer for analysis with AnSur 3D software (Minnesota Dental Research Center for Biomaterials and Biomechanics, University of Minnesota, Minneapolis, MN, USA). The X, Y, and Z coordinates generated with the Proscan software were saved as PRN files and then imported into the AnSur 3D program.

Scanning Electron Microscopy Observations

Specimens were prepared for argon-ion etching and scanning electron microscopy (SEM) examinations. The surfaces of the cured test materials were ground with abrasive discs (Fuji Star Type DDC, Sankyo Rikagaku Co Ltd, Saitama, Japan) followed by a series of diamond pastes down to 0.25-μm particle size (DP-Paste, Struers, Ballerup, Denmark) to bring the surfaces to a high gloss. The prepared surfaces were then subjected to argon-ion beam etching (IIS-200ER, Elionix, Tokyo, Japan) for 45 seconds with the ion beam directed at the polished surface (accelerating voltage of 1.0 kV, ion current density 0.4 mA/cm^2). The surfaces were then coated in a vacuum evaporator with a thin film of Au. Observations were done with an SEM (FE-8000, Elionix) at an operating voltage of 10 kV.

SEM examinations were also completed on the wear facets of the five test materials. Following the wear analysis, representative samples of each material were sputter coated with Au and Pd (Emitech SC7620 Mini Sputter Coater, Quorum Technologies, Ashford, UK). The coated specimens were then examined with a TM3000 Tabletop Microscope (Hitachi-High Technologies Corporation, Tokyo, Japan) using an accelerating voltage of 15 kV.

Statistical Analysis

A one-way analysis of variance (ANOVA) and Tukey post hoc test were used for analysis of flexural strength and elastic modulus. The wear simulation data (mean facet depth and volume loss) were analyzed using a two-way ANOVA and Tukey post hoc test. Factors for the ANOVA tests were 1) test materials and 2) number of cycles. Linear regression analysis of mean depth and volume loss data was used to examine the relationship of the two variables in the wear simulation tests: 1) test materials and 2) number of cycles. The association strength between the variables, R^2 (square of the correlation coefficient), was determined for each test material at the four cycling periods (25,000, 50,000, 100,000, and 200,000). A regression line was also developed to predict wear rates and volume loss rates for the test materials.

RESULTS

Flexural Strength and Elastic Modulus Measurement

The results of this study for flexural properties of the tested materials are shown in Table 2. The flexural strength ranged from 68.2 to 150.6 MPa, and the elastic modulus ranged from 2.0 to 15.9 GPa. The one-way ANOVA revealed that a significantly higher flexural strength and elastic modulus were found for Z1. For PP, IG, and LX, there was no significant difference ($p>0.05$) in flexural strength and elastic modulus among the materials. For UF, a signifi-

Table 2: *Flexural Strength and Elastic Modulus Mean (SD)*

Code	Flexural Strength, MPa	Post Hoc Test Group[a]	Flexural Modulus, GPa	Post Hoc Test Group[a]
Z1	150.6 (5.2)	a	15.9 (1.2)	a
LX	87.7 (4.7)	b	3.3 (0.3)	b
PP	84.0 (4.3)	b	3.0 (0.1)	b
IG	80.6 (6.9)	b	3.2 (0.2)	b
UF	68.2 (5.5)	c	2.0 (0.1)	c

Abbreviations: IG, Integrity; LX, Luxatemp Automix Plus; PP, Protemp Plus; UF, UniFast III; ZI, Z100 Restorative.
[a] *Same lowercase letter indicates no difference at the 5% significance level.*

cantly ($p<0.05$) lower value was found among the tested materials in flexural strength and elastic modulus.

Generalized Wear Simulation

The ANOVA results for wear simulation are presented in Tables 3 and 4. The two-way ANOVA of generalized wear data, for both mean depth and volume loss, revealed a significant effect for the factors of test materials ($p<0.001$) and number of cycles ($p<0.001$) as well as for the interaction of test materials and number of cycles ($p<0.001$).

The generalized wear values (mean wear depth and volume loss) for the five test materials at the four cycling periods (25,000, 50,000, 100,000 and 200,000) are summarized in Tables 5 and 6. The statistical differences ($p<0.05$) for mean depth and volume loss for each material at the four cycling periods, as well as differences among the materials at each cycling period, are also presented in Tables 5 and 6. As the number of cycles increased, the occurrence of significant differences ($p<0.05$) for the individual test materials also increased, except for Z1. The data also showed differences ($p<0.05$) among materials at the various cycling periods.

Regression lines for wear depth and volume loss vs cycling periods for the five test materials are presented in Figures 1 and 2. The strength of association (R^2) between the variables of the tested materials and number of cycles for both mean depth and volume loss are presented in Table 7. A strong association was found between the variables for both mean depth and volume loss. Predicted wear rates and volume loss rates determined by linear regression are also presented in Table 7.

Table 3: *Analysis of Variance: Facet Depth*

Factor	Sum of Squares	*df*	Mean Square	*F* Ratio	*p*
Material	46,761.31	4	11,690.33	853.34	<0.001
Cycles	24,734.61	3	8244.86	601.84	<0.001
Materials × Cycles	11,627.73	12	968.98	70.73	<0.001

Table 4: *Analysis of Variance: Volume Loss*

Factor	Sum of Squares	*df*	Mean Square	*F* Ratio	*p*
Material	10.37	4	2.60	1241.96	<0.001
Cycles	5.07	3	1.69	809.30	<0.001
Materials × Cycles	2.50	12	0.21	99.73	<0.001

SEM Observations

SEM examinations of the five test materials evaluated by argon-ion etching are presented in Figures 3a-e. The argon-ion etching demonstrated clear differences in filler particle size, shape, and distribution. For PP, approximately 50- to 200-nm size spherical filler particles were observed (Figure 3a). For IG and LX, 0.5- to 2-μm irregular-shaped glass filler particles were observed (Figure 3b,c). The conventional PMMA resin UF contains approximately 20-50 μm round polymer particles. The SEM observations of the resin composite (Z1) showed aggregated nanosize spherical filler particles, which are more densely distributed than the other test materials.

SEM examinations of the generalized wear facets (Figures 4a-e) after 200,000 cycles also demonstrated differences in the filler systems of the materials tested in this study. After wear testing of PP, the SEM examinations revealed relatively flat and smooth surfaces (Figures 4a), and there were some fine wrinkles observed on the worn surfaces. IG and LX exhibited a similar wear pattern with some plucking of irregular-shaped glass filler particles from the surface (Figure 4b,c). For UF, obvious cracks were observed on the worn surfaces, and some evidence of plucking of polymer particles was found (Figure 4d). Z1 showed a relatively flat and smooth worn surface, and some plucking of the fine filler particles was observed from the simulated generalized wear testing (Figure 4e).

DISCUSSION

Provisional restorations are required to fulfill several functions for the duration of their use in the oral environment. The mechanical properties of provisional materials may influence the integrity of provisional restorations *in situ* when exposed to functional loads.[10-15] One of the major causes for the replacement of provisional restorations have been

Table 5: *Generalized Wear: Facet Depth (SD)*[a]

Cycle	Mean Facet Depth, μm				
	Z1	PP	IG	LX	UF
25,000	5.0 (1.3) aA	14.1 (1.7) aB	19.9 (1.3) aC	23.2 (2.1) aCD	25.3 (2.8) aD
50,000	5.7 (1.2) aA	14.4 (2.4) aB	25.0 (3.1) bC	26.3 (3.3) aC	33.2 (3.8) bD
100,000	6.3 (1.5) aA	17.1 (3.0) aB	34.8 (3.6) cC	40.5 (3.8) bD	41.6 (4.2) cD
200,000	7.6 (1.2) aA	22.4 (5.0) bB	51.0 (6.5) dC	63.7 (4.5) cD	70.5 (8.0) dE

Abbreviations: IG, Integrity; LX, Luxatemp Automix Plus; PP, Protemp Plus; UF, UniFast III; ZI, Z100 Restorative.
[a] *Groups in vertical columns with the same lowercase letter are not different at the 5% significance level. Groups in different columns with the same number of cycles and same capital letter are not different at the 5% significance level.*

cited as fractures in the body and at the margins.[6,19] Interim restoration failures are a concern for both the clinician and patient because of additional cost and time associated with these complications. Fracture-related material properties, such as fracture resistance, elasticity, and marginal degradation of materials under stress, have typically been evaluated by determining material parameters such as flexural strength, flexural modulus, and fracture toughness.[20,21] Clinicians need to be knowledgeable regarding the flexural properties of provisional materials in order to deliver optimal treatment, especially when patients are required to use the provisional restorations for an extended time due to complicating conditions such as severe periodontal disease, parafunctional disorders, or dental implant therapy.[5-8] Although laboratory flexural strength values under constant loading may not reflect intraoral conditions, these values are nevertheless helpful in comparing materials under controlled situations and may be a useful predictor of clinical performance.[13]

The results of this study showed that bis-acryl provisional materials demonstrated significantly higher ($p<0.05$) flexural strength than conventional PMMA resin. These results are consistent with those of past studies that compared bis-acryl provisional materials with conventional PMMA resins.[12,14] Bis-acryl provisional resins contain multifunctional monomers, which increase strength due to cross-linking with other monomers and also include inorganic fillers that may have the capability of distributing the load stress and inhibiting the progress of crack propagation.[12,13] The bis-acryl provisional materials used in this study were in cartridge-based dispensing systems, which may contribute to superior flexural strength because of a more accurately proportioned and consistent mix.[22] In addition, methacrylate-based resins typically used in provisional materials are not cross-linked, and without polymerization under pressure, air entrapment may occur and result in lower strength values.[10]

The flexural modulus or the modulus of elasticity is a measure of the material stiffness: the higher the modulus, the stiffer the materials. Marginal breakdown and loss of marginal seal are more likely to occur in products with a lower modulus of elasticity. In the present study, the bis-acryl provisional resins (PP, IG, LX) did not show a higher elastic modulus value than the resin composite (Z1); however, they demonstrated a significantly higher elastic modulus than the PMMA resin (UF). Therefore, the hypothesis that bis-acryl base provisional resins will demonstrate significantly higher flexural properties than the PMMA resin was not rejected.

The SEM observations of the polished surfaces after argon-ion etching revealed that bis-acryl provisional resins showed a heterogeneous structure due to the inclusion of silane-treated inorganic fillers

Table 6: *Generalized Wear: Volume Loss (SD)*[a]

Cycle	Volume Loss, mm^3				
	Z1	PP	IG	LX	UF
25,000	0.067 (0.018) aA	0.206 (0.020) aB	0.297 (0.016) aC	0.341 (0.031) aCD	0.377 (0.037) aD
50,000	0.081 (0.020) aA	0.218 (0.018) aB	0.352 (0.024) bC	0.386 (0.049) aC	0.501 (0.035) bD
100,000	0.091 (0.022) aA	0.249 (0.034) aB	0.578 (0.034) cC	0.586 (0.050) bD	0.635 (0.039) cD
200,000	0.111 (0.017) aA	0.311 (0.049) bB	0.737 (0.074) dC	0.919 (0.053) cD	1.046 (0.127) dE

Abbreviations: IG, Integrity; LX, Luxatemp Automix Plus; PP, Protemp Plus; UF, UniFast III; ZI, Z100 Restorative.
[a] *Groups in vertical columns with the same lowercase letter are not different at the 5% significance level. Groups in different columns with the same number of cycles and the same capital letter are not different at the 5% significance level.*

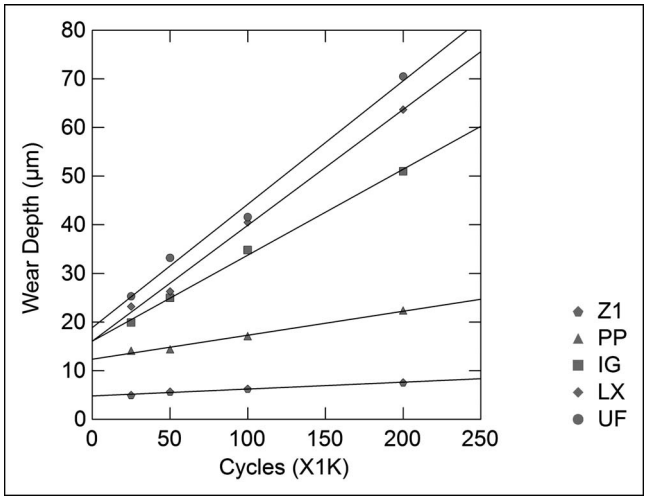

Figure 1. *Wear depth (μm) of tested materials vs cycles (X1K).*

or glass fillers (Figure 3a-c). The inorganic fillers contribute to enhancing not only the strength but also elastic modulus. A previously reported study of resin composites revealed correlations between filler content, filler size, distribution of filler particles, and material strength and elastic modulus.[23] However, a comparison among the three bis-acryl provisional resins in the present study did not show a significant difference ($p>0.05$) in flexural strength and elastic modulus among the three materials. PP employs approximately 50- to 200-nm size spherical silica filler particles (Table 1); IG and LX employ 0.5- to 2-μm irregular-shaped glass filler particles (Figure 3b,c). Although increasing the filler load of resin materials purportedly increases the ultimate strength and elastic modulus, there does not seem to be a clear relationship in the present study

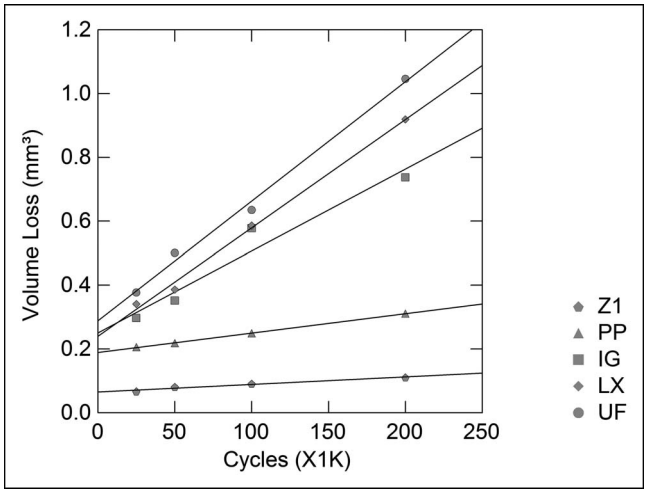

Figure 2. *Volume loss (mm³) of tested materials vs cycles (X1K).*

Table 7: *Regression Analysis: Wear (μm) and Volume Loss (mm³) per 100,000 Cycles and R^2 Value*

Code	Wear Rate	R^2	Volume Loss Rate	R^2
Z1	1.4	0.973	0.023	0.942
PP	4.9	0.983	0.061	0.999
IG	17.7	0.996	0.257	0.919
LX	23.8	0.993	0.339	0.994
UF	25.4	0.987	0.374	0.991

Abbreviations: IG, Integrity; LX, Luxatemp Automix Plus; PP, Protemp Plus; UF, UniFast III; ZI, Z100 Restorative.

regarding filler size or filler shape and mechanical properties of bis-acryl provisional resins. It is speculated that the type of resin matrix, degree of conversion, surface treatment of filler, and interparticle spacing of bis-acryl materials might contribute to mechanical property characteristics in the same manner as resin composites.[24]

Even if provisional restorations are used for a limited time period, it is important from a wear perspective to maintain occlusal relationships over the time span of the interim restoration. Loss of occlusal anatomy and support changes the vertical dimension of restored teeth, which may result in parafunction. In addition, wear progression of provisional restorations may lead to deteriorated surface texture and provide foci for crack propagation from the masticatory function.

To date, various approaches have been taken by researchers to fill the void in clinical data by conducting wear simulation studies in the laboratory for resin composites. Although trying to relate clinical and laboratory wear data is still a significant challenge, Barkmeier and others[17,18] have examined the relationship of simulated localized and generalized wear to CFA clinical wear using Z1 as benchmark resin composite. They reported that Z1 showed 17.0 μm of cumulative wear (CFA) after three years in the oral cavity, and there was good agreement between the relationship of simulated and clinical wear.[16,17] However, there is little information available regarding the relationship between clinical wear data and laboratory data of provisional materials. Therefore, to evaluate the relationship between the simulated and clinical wear of provisional materials, Z1 was employed as a benchmark material in the present study. From the results of generalized wear testing, the wear rates of the provisional resins tested appeared to be dependent on the material and the number of cycles. UF demonstrated significantly higher wear values than the three bis-acryl resins in wear

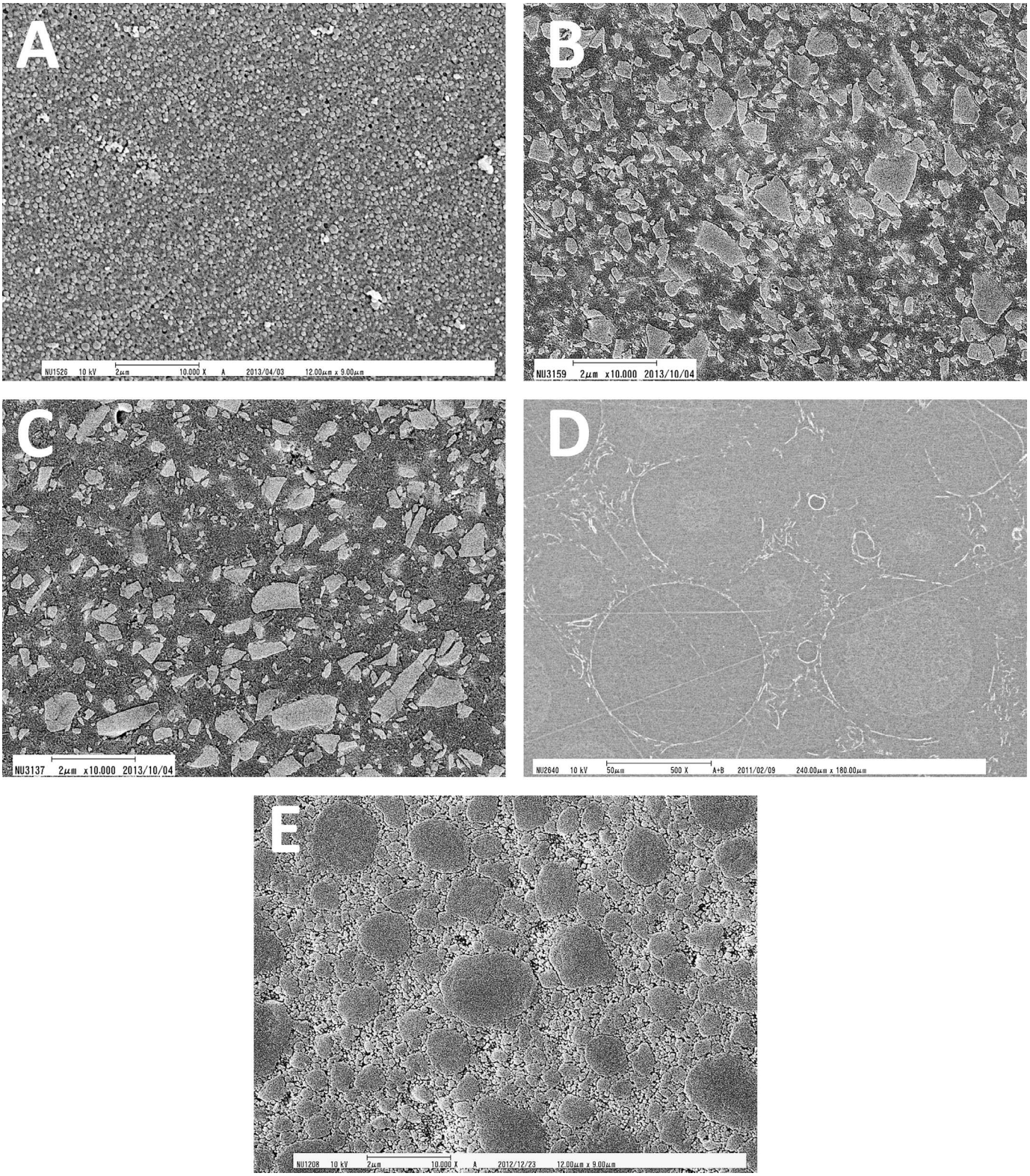

Figure 3. *(A): Protemp Plus, argon-ion etched surface (10,000×). (B): Integrity, argon-ion etched surface (10,000×). (C): Luxatemp Automix Plus, argon-ion etched surface (10,000×). (D) Unifast III, argon-ion etched surface (500×). (E) Z100 Restorative, argon-ion etched surface (500×).*

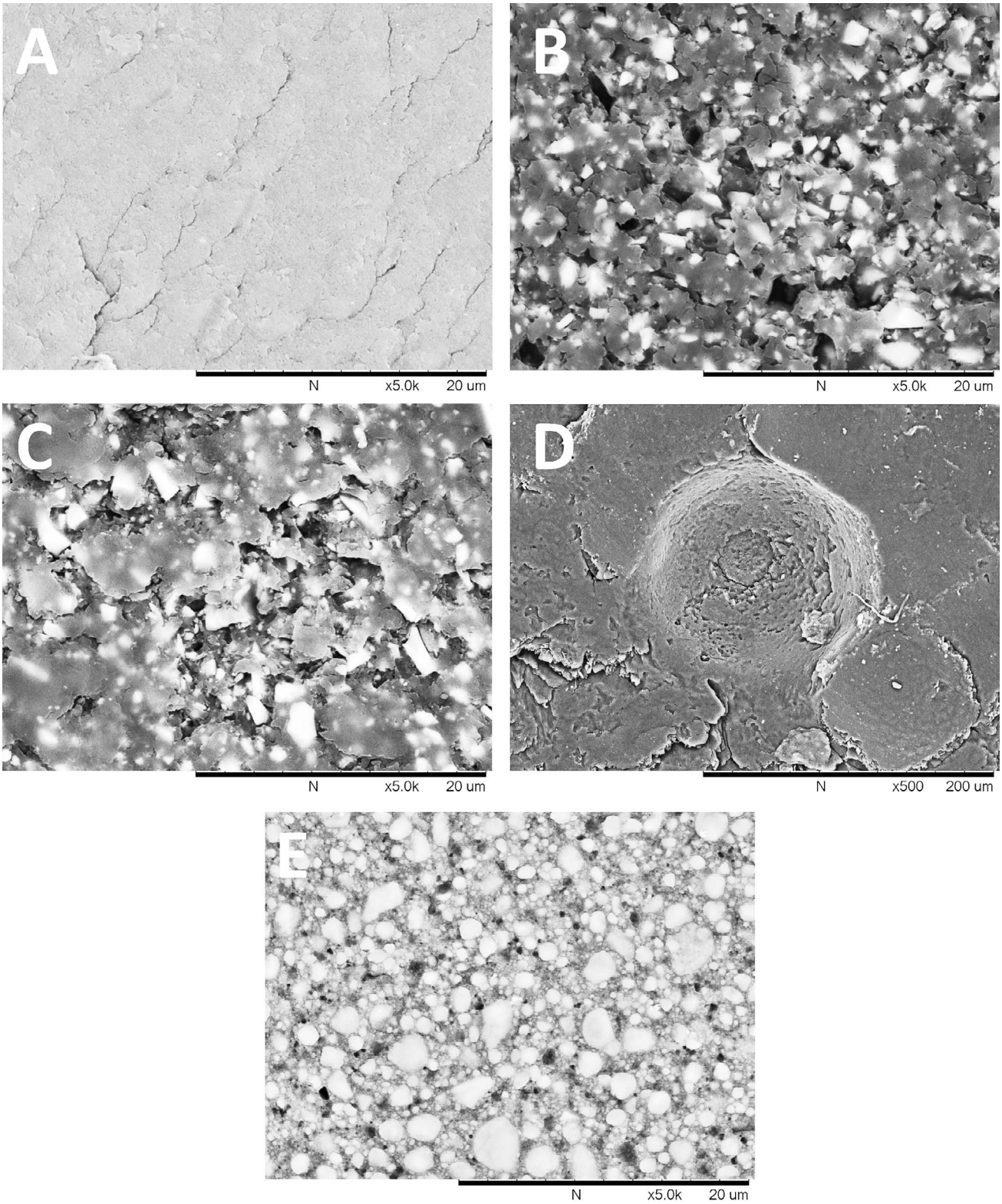

Figure 4. *(A): Protemp Plus, generalized wear near center of facet (5000×). (B) Integrity, generalized wear near center of facet (5000×). (C) Luxatemp Automix Plus, generalized wear near center of facet (5000×). (D) Unifast III, generalized wear near center of facet (500×). (E) Z100 Restorative, generalized wear near center of facet (5000×).*

mean depth and volume loss at 200,000 cycles. Therefore, the proposed hypothesis that bis-acryl provisional resins would demonstrate significantly higher wear resistance than the PMMA resin was not rejected.

PMMA provisional resins primarily consist of polymer particles and monomers that are considered as a relatively homogenous composition. Therefore, the wear of PMMA resins might be expected to occur uniformly in generalized wear simulation. However, the SEM observations in this study revealed that some polymer particles appeared to pull out from the surface, resulting in dark holes in the worn areas (Figure 4d). It is speculated that there were flaws between the polymer particles and resin matrix interfacial bond due to incomplete mixing that led to pull out of the PMMA particles.

On the other hand, bis-acryl provisional resins consist of inorganic fillers and multifunctional monomers, which possess different hardness characteristics. The wear behavior of this type of material may induce plucking and uncovering of filler particles, which project from the surface due to selective abrasion of the resin matrix. Although there was no significant difference between PP and the other bis-acryl resins in flexural properties, the mean wear depth and volume loss of PP was significantly lower ($p<0.05$) than the other bis-acryl–based resins for all of the cycling periods. The difference in wear rates between PP and the other bis-acryl resins is most likely related to inorganic filler size, shape, and distribution. From the SEM observations, PP and Z1 demonstrated relatively flat and smooth worn surfaces after wear testing compared with the other provisional resins (Figure 4a-e). PP and Z1 are made by the same manufacturer and appear to employ similar spherical nano-sized filler particles, which have the benefit of maintaining the surface texture even if plucking of fillers from the resin matrix occurs.[25,26] In addition, finer particles for a fixed-volume fraction of filler have been suggested to result in decreased inter-particle spacing and reduced wear.[27]

Linear regression was used to provide predicted wear rates for the five materials evaluated in this study (Table 6). The wear rates of the materials in this study, as defined by the slopes, can be categorized into three groups (Figures 1 and 2) for both wear depth and volume loss. Z1 exhibits the lowest wear rate (depth and volume loss); IG, LX, and UF exhibit similar wear rates and were in the highest wear category; and PP shows a wear rate between the two groups. When comparing the reported clinical data for Z1 after three years in oral cavity[16,17] to the wear rate of mean depth in the present study, the data suggest that provisional resins would reach the same wear depth reported for Z1 in 2 to 10 months. Therefore, there is a marked difference in wear resistance between the resin composite (Z1) and the provisional resins evaluated in this study, regardless of the inorganic fillers and multifunctional monomers incorporated into the provisional resin materials.

There may be a number of features affecting the selection of provisional restorative materials by clinicians; however, the flexural properties and the predicted rates for wear and volume loss, as described here, should provide valuable information for the selection of a provisional restorative resin material.

CONCLUSIONS

The results of this study demonstrated significantly higher ($p<0.05$) flexural strength and elastic modulus values for three bis-acryl provisional resins when compared with a conventional PMMA resin, and there was no significant difference ($p>0.05$) among the three bis-acryl base provisional resins in flexural strength and elastic modulus. Simulated wear of bis-acryl provisional resin materials also demonstrated significantly higher ($p<0.05$) wear resistance when compared with a conventional PMMA resin. The wear rates of bis-acryl provisional resins tested appeared to be dependent on the material and the number of cycles. The benchmark resin composite material, Z1, exhibited the highest flexural strength properties and the least amount of wear in generalized wear simulation.

The study results provide valuable comparisons of physical property values and wear resistance of a resin composite to three bis-acryl and one PMMA provisional restorative resin materials. This study augments both clinical and laboratory wear data of a benchmark resin composite (Z1) and provides valuable comparisons with provisional resin materials. The data reported provide guidance for clinicians in the selection of provisional resin materials.

Conflict of Interest

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

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