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Wear Rates of Resin Composites

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Clinical Relevance

Laboratory wear testing of resin composites provides valuable information for clinicians in selecting materials for clinical use.

SUMMARY

A laboratory study was conducted to examine the wear of resin composite materials using a generalized wear simulation model. Ten specimens each of five resin composites (Esthet•X [EX], Filtek Supreme Plus [SP], Filtek Z250 [Z2], Tetric EvoCeram [EC], and Z100 Restorative [Z1]) were subjected to wear challenges of 100,000, 400,000, 800,000, and 1,200,000 cycles. The materials were placed in cylinder-shaped stainless-steel fixtures, and wear was generated using a flat stainless-steel antagonist in a slurry of polymethylmethacrylate beads. Wear (mean facet depth [μm] and volume loss [mm^3]) was determined using a non-contact profilometer (Proscan 2000) with Proscan and ProForm software. Statistical analysis of the laboratory data using analysis of variance and Tukey's post hoc test showed a significant difference ($p<0.05$) for mean wear facet depth and volume loss for both the number of cycles and resin composite material. Linear regression analysis was used to develop predictive wear rates and volume loss rates. Linear wear was demonstrated with correlation coefficients (R^2) ranging from 0.914 to 0.995. Mean wear values (mean facet depth [μm]) and standard deviations (SD) for 1200K cycles were as follows: Z1 13.9 (2.0), Z2 26.7 (2.7), SP 30.1 (4.1), EC 31.8 (2.3), and EX 67.5 (8.2). Volume loss (mm^3) and SDs for 1200K cycles were as follows: Z1 0.248 (0.036), Z2 0.477 (0.044), SP 0.541 (0.072), EC 0.584 (0.037), and EX 1.162 (0.139). The wear rate (μm) and volume loss rate (mm^3) per 100,000 cycles for the five resin composites were as follows: wear rate Z1 0.58, EC 1.27, Z2 1.49, SP 1.62, and EX 4.35, and volume loss rate Z1 0.009, EC 0.024, Z2 0.028, SP 0.029, and EX 0.075. The generalized wear model appears to be an excellent method for measuring relative wear of resin composite materials.

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INTRODUCTION

Resin composite materials are now routinely used for the restoration of the posterior dentition. In evaluat-

Table 1: *Resin Composite Materials*

Material	Manufacturer	Lot	Shade	Study Code
Esthet•X	DENTSPLY Caulk, Milford, DE, USA	061206	A2	EX
Filtek Supreme Plus	3M ESPE Dental Products, St Paul, MN, USA	8WU	A2 Body Shade	SP
Filtek Z250	3M ESPE Dental Products, St Paul, MN, USA	9JE	A2	Z2
Tetric EvoCeram	Ivoclar Vivadent AG Schaan, Liechtenstein	L56579	A2	EC
Z100 Restorative	3M ESPE Dental Products, St Paul, MN, USA	7PP	A2	Z1

ing the performance of posterior composites, wear characteristics are an important parameter. While resin composites are now generally accepted for use in the posterior region, the materials currently available are very different in formulation and may not exhibit similar clinical performance. There is significant value in knowing how materials perform relative to others available. Clinicians need good scientific data to provide optimal care for their patients.

Clinical and laboratory studies have been used over the years to assess the wear characteristics of resin composite materials. Trying to relate clinical and laboratory wear data is a significant challenge because adequate clinical data are not available. In addition, clinical testing should ideally be done with multiple materials in the same study and with a large number of patients. To gain even more information, multiple-site studies should also be conducted. This approach is very expensive, takes years to complete, and before the clinical trials are over, the materials in the studies may be obsolete.

An alternate approach is to look at the relative wear of a number of materials in a laboratory wear simulation study and compare the rates of wear among the materials. The wear rates could be further compared with a benchmark material with demonstrated low wear in both clinical and laboratory studies. This approach has been used by Barkmeier and others[1] in reporting the generalized clinical wear rates (contact-free area [CFA]) for Z100 and P50 (3M ESPE, St Paul, MN, USA) and comparing the clinical wear rates to simulated wear rates using a laboratory model to simulate generalized wear. Linear regression was employed to predict both clinical and laboratory wear rates of these two materials. Z100 demonstrated minimal clinical and laboratory wear and would certainly qualify as a benchmark material for further studies. This study showed a similar relationship for the ratios of wear rates between the two materials in both laboratory and clinical testing, indicating that this is a promising approach for examining and comparing wear rates of resin composite materials.

Wear simulation provides an efficient means to develop relative wear rates among materials and to compare these results to a benchmark material that has exhibited good laboratory and clinical performance. Because of the void in clinical wear data available, additional wear simulation data are required to expand the information base needed to examine and compare the performance of resin composite materials. The purpose of this laboratory study was to continue developing data related to simulated generalized wear of resin composite materials and provide additional information to clinicians for the selection of materials for clinical practice. A reference (benchmark) resin composite material (Z100), with previously published laboratory and clinical data,[1,2] was selected for comparison to four other composite materials with different formulations that are commonly used for restoration of the posterior dentition.

METHODS AND MATERIALS

Five resin composite materials were evaluated in this study and are listed in Table 1. Ten specimens for each of the five resin composite materials (total of 50 specimens) were prepared for wear challenges of 100,000, 400,000, 800,000, and 1,200,000 cycles using a generalized wear model (CFA wear) in a Leinfelder-Suzuki wear simulation device (Alabama machine). The methodology for sample preparation and the generalized wear model has been previously described by Barkmeier and others.[1] In summary, stainless-steel custom fixtures with cavities 4.5 mm in diameter and 4 mm deep were used to hold the

Figure 1. *Stainless-steel custom fixture with resin composite material.*

test materials. The resin composites were cured in two increments of approximately 2 mm for 40 seconds with a Spectrum 800 curing unit (DENTSPLY Caulk, Milford, DE, USA) set at 600 mW/cm^2. After 24 hours, the composite surfaces were polished flat to 4000 grit (Figure 1) using a sequence of silicon carbide papers (Struers Inc, Cleveland, OH, USA). The custom fixtures were mounted inside a plastic water bath, and a cylinder was placed around each fixture. A water slurry of polymethyl methacrylate was used as the abrasive media and placed inside the cylinders over the resin composite specimens. Stainless-steel antagonists 6.5 mm diameter (Figure 2), mounted in spring-loaded pistons, were then used to deliver the wear challenges in the wear simulation machine. The pistons rotated approximately 30° as the load was applied (maximum load of 78.5 N) at a rate of 2 Hz.

Prior to wear testing, the specimens for each resin composite material were profiled using a Proscan 2000 noncontact optical profilometer (Scantron Industrial Products Ltd, Taunton, England) with Proscan software. The individual scanned surfaces were used as the pretest digitalized surface (Figure 3) for each individual specimen.

Following each cycling period (100K, 400K, 800K, and 1200K), the specimens were ultrasonically cleaned (L&R Solid State Ultrasonic T-14B, South Orange, NJ, USA) for three minutes in distilled

Figure 2. *Stainless-steel antagonist tip.*

water and then profiled using the Proscan 2000 unit (Figures 4 and 5). The pre- and posttest digitalized surfaces were compared using ProForm and Proscan software (Scantron Industrial Products Ltd).

The individual pretest scan and posttest scan for each material, after each cycling period, were loaded in ProForm. The pretest and posttest scans were manually fitted (X, Y, and Z parameters) using the ProForm software. Following the fitting, a "difference file" was created (saved) and then opened in the Proscan software program for analysis of the differences between the pretest and posttest digitalized surfaces. Two wear measurements were determined using the difference files in Proscan: 1) mean wear depth (μm) and 2) volume loss (mm^3). The wear measurements were determined from differences between the before and after data sets.

Volume loss and mean wear depth data were analyzed using a two-way analysis of variance (ANOVA) and Tukey's post hoc test. Factors for the

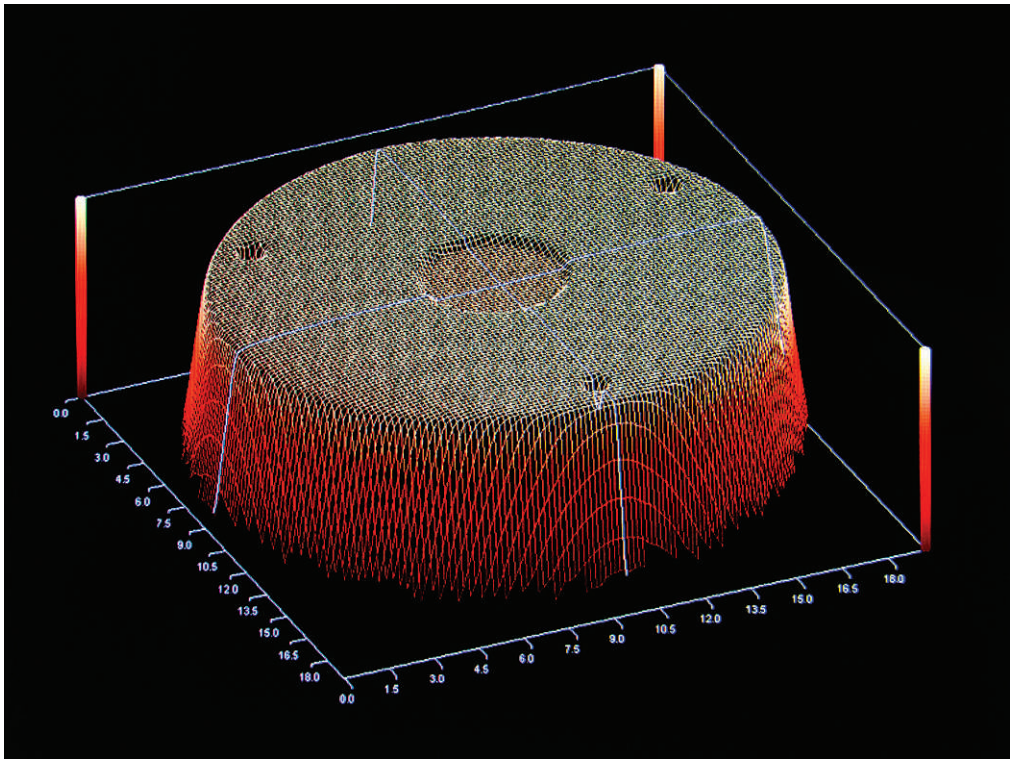

Figure 3. *Scanned surface of custom fixture with polished resin composite material before wear challenge.*

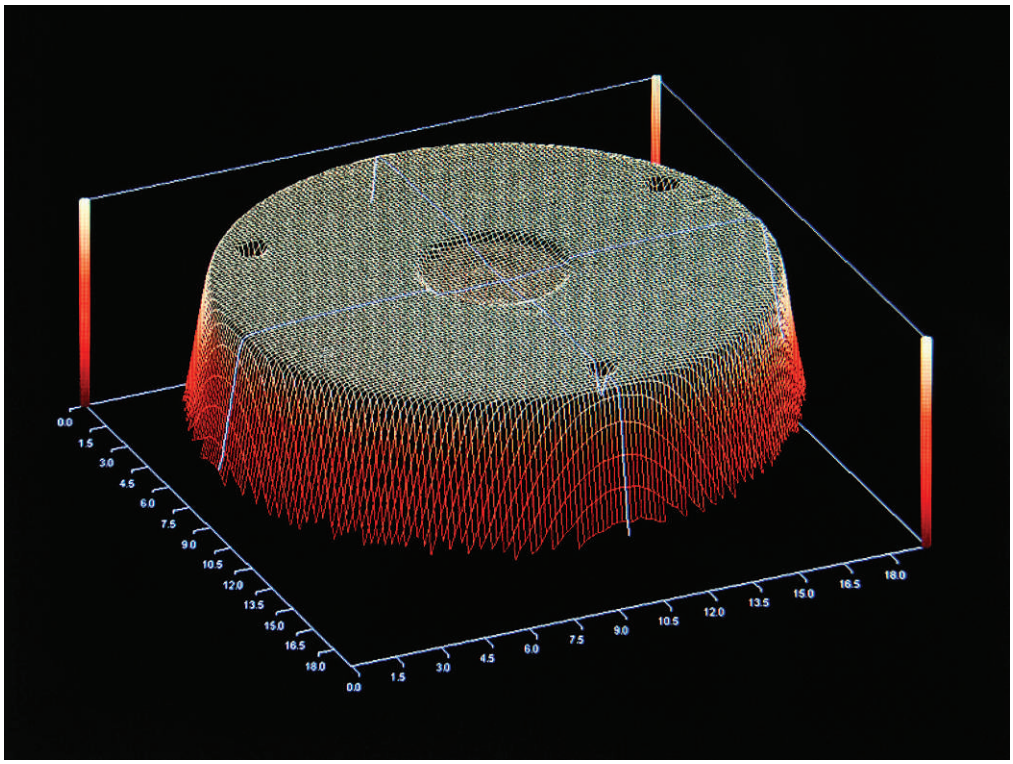

Figure 4. *Scanned surface of resin material with minimal wear after 1200K cycles of generalized wear simulation.*

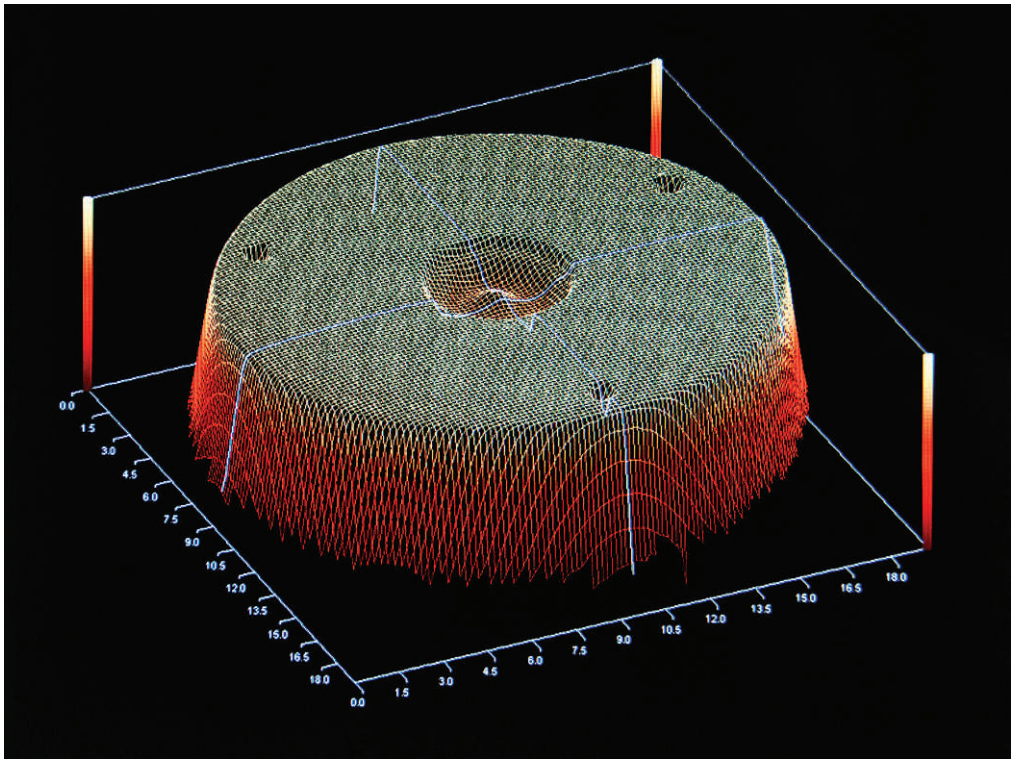

Figure 5. *Scanned surface of resin material with moderate wear after 1200K cycles of generalized wear simulation.*

ANOVA tests were 1) resin composite material and 2) number of cycles. Linear regression analysis of mean wear depth and volume loss data was used to examine the relationship of the variables in this study: 1) resin composite material and 2) number of cycles. The association strength between the variables, R^2 (square of the correlation coefficient), was determined for each resin composite material at the four cycling periods (100K, 400K, 800K, and 1200K). A regression line was also developed to predict wear rates and volume loss rates for the resin composites.

RESULTS

The two-way ANOVA of the laboratory data, for both volume loss and mean wear depth, revealed a significant effect for the factors of resin composite material (p=0.000) and number of cycles (p=0.000), as well as for the interaction of resin composite material and number of cycles (p=0.000). The ANOVA results are presented in Tables 2 and 3.

The generalized wear values (mean wear depth and volume loss) for the five resin composite materials at the four cycling periods (100K, 400K, 800K, and 1200K) are summarized in Tables 4 and 5. The statistical differences (p<0.05) for wear depth and volume loss for each material at the four cycling periods, as well as difference among materials at each cycling period, are also presented in Tables 4 and 5 (multiple pairwise comparison with Tukey's post hoc test). As the number of cycles increased, the occurrence of significant differences (p<0.05) for the individual resin composites tested also increased. The data also showed differences (p<0.05) among materials at the various cycling periods (Table 4 and 5).

Regression lines for wear depth and volume loss vs cycling periods for the five resin composites are presented in Figures 6 and 7. The regression lines for both wear depth and volume loss all had slopes that were significant at the 0.05 level. The strength of association (R^2) between the variables of resin composite material and number of cycles for both wear depth and volume loss are presented in Table 6. A strong association was found between the variables for both wear depth and volume loss. Predicted wear rates and volume loss rates determined by linear regression are also presented in Table 6.

DISCUSSION

Limited clinical data are available in the dental literature for clinicians to assess the performance of resin composite materials. In the 1970s and 1980s, when resin composite materials were first being

Table 2: *Analysis of Variance—Mean Facet Depth*

Source	Sum-of-Squares	*df*	Mean Square	*F*-Ratio	*p*
Material	23334.071	4	5833.518	438.825	0.000
Cycles	11564.731	3	3854.910	289.985	0.000
Material*Cycles	5837.278	12	486.440	36.592	0.000
Error	2326.361	175	13.293		

Table 3: *Analysis of Variance—Volume Loss*

Source	Sum-of-Squares	*df*	Mean Square	*F*-Ratio	*p*
Material	6.770	4	1.692	366.490	0.000
Cycles	3.774	3	1.258	272.420	0.000
Material*Cycles	1.681	12	0.140	30.329	0.000
Error	0.808	175	0.005		

Table 4: *Generalized Wear—Mean Wear Depth (SD)*[a]

Cycles	Mean Facet Depth, μm				
	Z1	Z2	SP	EC	EX
100K	7.5 (1.3) aA	9.7 (1.2) aA	12.8 (2.2) aAB	17.3 (1.8) aB	18.5 (4.8) aB
400K	9.6 (1.6) abA	15.6 (2.2) bB	17.8 (3.1) aBC	22.8 (2.2) abC	35.8 (6.4) bD
800K	11.9 (1.8) abA	19.6 (2.2) bB	25.9 (2.2) bC	26.5 (2.4) bcC	50.6 (6.7) cD
1200K	13.9 (2.0) bA	26.7 (2.7) cB	30.1 (4.1) bB	31.8 (2.3) cB	67.5 (8.2) dC

[a] *Groups in vertical columns with the same small-case letter are not different at the 5% significance level. Groups in different columns with same number of cycles and same capital case letter are not different at the 5% significance level.*

advocated for the posterior region, early evidence suggested significant wear compared to amalgam.[3] Because of the skepticism surrounding the use of resin composites in the posterior dentition, acceptance guidelines were developed by the American Dental Association,[4] and manufacturers conducted clinical studies to gain product acceptance for the posterior area. As materials improved and resin composites were more widely accepted for the posterior region, manufacturers have been more reluctant to invest in clinical studies. Limited quantitative wear data are available in the dental literature for resin composite restorative materials.

Various approaches have been taken by researchers to fill the void in clinical data by conducting wear simulation studies in the laboratory. Wear simulation studies have been used to develop the wear rates of laboratory specimens and then compare the rates against values determined from reported clinical studies.[1,5] Heintze and others[5] recently published a

Table 5: *Generalized Wear—Volume Loss (SD)*[a]

Cycles	Volume Loss (mm^3)				
	Z1	Z2	SP	EC	EX
100K	0.135 (0.025) aA	0.173 (0.020) aA	0.226 (0.039) aAB	0.309 (0.032) aB	0.320 (0.085) aB
400K	0.196 (0.030) abA	0.275 (0.035) abAB	0.319 (0.063) aBC	0.411 (0.039) abC	0.618 (0.100) bD
800K	0.212 (0.031) abA	0.347 (0.031) bB	0.464 (0.045) bC	0.480 (0.049) bcC	0.886 (0.117) cD
1200K	0.248 (0.036) bA	0.477 (0.044) cB	0.541 (0.072) bB	0.584 (0.037) cB	1.162 (0.139) dC

[a] *Groups in vertical columns with same small-case letter are not different at the 5% significance level. Groups in different columns with the same number of cycles and same capital case letter are not different at the 5% significance level.*

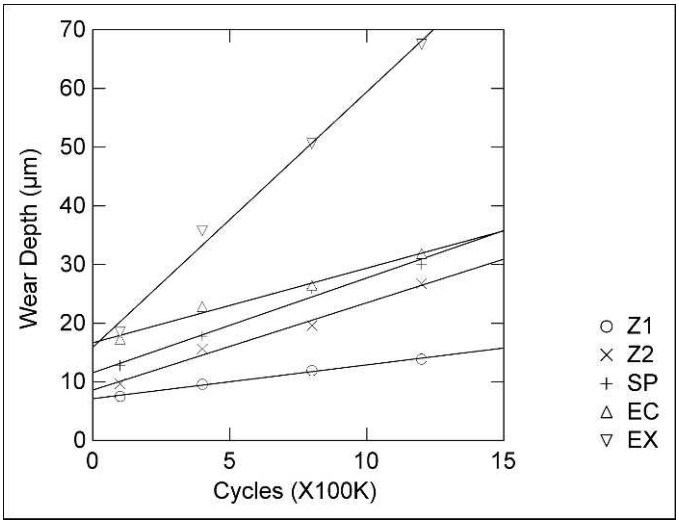

Figure 6. *Wear depth of resin composites (µm) vs cycles (X100K).*

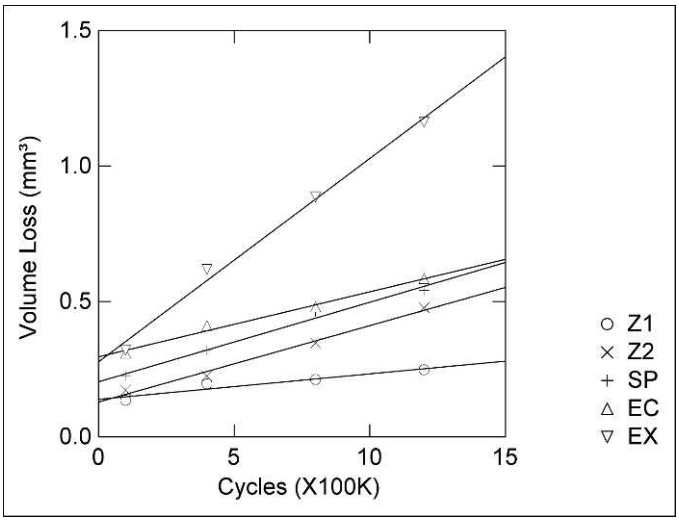

Figure 7. *Volume loss of resin composites (µm) vs cycles (X100K).*

Table 6: *Regression Analysis—Wear (μm) and Volume Loss (mm^3) per 100K Cycles and* R^2 *Value*

Resin Composite	Wear Rate	R^2	Volume Loss Rate	R^2
Z1	0.58	0.995	0.009	0.914
EC	1.27	0.985	0.024	0.986
Z2	1.49	0.986	0.028	0.988
SP	1.62	0.983	0.029	0.985
EX	4.35	0.993	0.075	0.992

summary of information regarding the use of six different approaches for wear simulation.

In 2008, Barkmeier and other[1] examined the relationship of simulated generalized wear to CFA clinical wear. Clinical wear was estimated using the Moffa-Lugussy (M-L) technique[6,7] (M-L Scale, Joseph P. Moffa, Las Vegas, NV, USA), and cumulative wear after three years for P50 was 29.7 μm and 17.0 μm for Z100. Wear measurements using the M-L scale are estimates of CFA wear. Simulated wear (mean maximum depth and mean depth) was approximately twice as much for P50 when compared with Z100, which paralleled the clinical findings. There was good agreement between the relationship of simulated and clinical wear. Because of the proven clinical performance and paralleled low laboratory simulation wear rates of Z100, this material is an ideal candidate to be selected as a benchmark material when examining the wear characteristics of resin composite materials.

In the present study, simulated generalized (CFA) wear values were developed to help expand the information base related to resin composite materials. Dental manufacturers, as well as clinicians, are in need of information to assess the wear characteristics of resin composite materials. Linear regression was used to provide predicted wear rates for the five materials evaluated in this study (Table 6). The regression lines (Figures 6 and 7) for both wear depth and volume loss show three materials (EC, SP, and Z2) clustered in the middle of the graph. The Z1 line exhibits the lowest wear rate for depth (Figure 6) and volume loss (Figure 7), and the line for EX reveals the greatest wear rate for depth and volume loss. It should be noted that the regression lines do not converge on the origin of the graph. This is because each material initially loses a small but different amount of material. This can cause confusion if wear values are examined and compared instead of wear rates. For example, EC has initial wear that is greater than SP (Tables 4–5) but a lower wear rate (Table 6). Over a long time period, EC would presumably perform better. While wear is just one parameter for consideration in the selection of a restorative material, the predicted rates for wear and volume loss should provide valuable information for both resin composite developers and clinicians.

CONCLUSIONS

Wear simulation was used to develop relative wear rates of five resin composite materials. The results demonstrated significant differences ($p<0.05$) among materials and the number of cycles used. Simulated wear in the laboratory using a benchmark material, with good clinical and simulated wear performance, may provide an avenue for predicting the clinical performance of resin composite materials.

Conflict of Interest Declaration

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.

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