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Wear Simulation of Resin Composites and the Relationship to Clinical Wear

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Clinical Relevance

Laboratory wear simulation may be useful for estimating the relative clinical wear rates of new resin composite materials.

SUMMARY

This study used a new generalized wear model to examine the relationship between wear simulation and the clinical wear of two resin composites. Ten specimens each of P50 and Z100, were subjected to 100,000, 400,000 and 800,000 cycles in a spring-loaded piston-type wear simulator. Wear was generated using flat, cylindrically-shaped stainless steel antagonists on the resin composites, which were placed in custom stainless steel fixtures. A slurry of polymethyl methacrylate beads was used as the abrasive media. Wear was determined using profilometry, and the parameters examined included volume loss (mm^3), maximum depth (µm), mean maximum depth (µm) and mean depth (µm). Statistical analysis of the laboratory wear data using ANOVA and Tukey's post hoc test showed a significant difference ($p<0.05$) for wear between the two materials and the number of cycles. Mean maximum wear (µm) values (100K—P50—11.5 ± 1.8; Z100—4.9 ± 1.0; 400K—P50—17.2 ± 2.7; Z100—6.0 ± 1.7; 800K—P50—20.5 ± 4.6; Z100—9.6 ± 2.5) were used for comparisons with clinical data. Previous clinical studies of P50 and Z100 were used to examine the relationship between laboratory and clinical wear. Linear regression analysis was used to predict laboratory and clinical wear rates. The laboratory wear rate for P50 was 1.3 µm/100K cycles and the rate for Z100 was 0.7 µm/100K cycles. The clinical wear rates for P50 and Z100 were 8.3 µm/year and 4.0 µm/year, respectively. The ratio of wear rates of P50 to Z100 for wear simulation was 1.9 and the ratio of P50 to Z100 for clinical rates was 2.1. These ratios showed good agree-

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ment between the relative wear rates of laboratory and clinical wear. For the two composite materials examined, this new simulation model appears to be effective for evaluating the relative wear of resin composites.

INTRODUCTION

Resin composites are increasingly used for restoration of the posterior dentition. In evaluating the performance of posterior composites, wear characteristics are an important parameter. Clinical studies have been used over the years to assess the wear of resin composites. These studies are costly, take years to complete and often, before the clinical trials are completed, the manufacturers have introduced newer materials.

In recent years, wear simulation has been used to augment clinical trials and examine the wear characteristics of newer systems. Leinfelder and Suzuki[1] have used a spring-loaded, piston-type machine to simulate generalized or contact-free area (CFA) clinical wear. Their model utilizes a polyacetal antagonist against a restoration placed in an extracted human tooth. The antagonist is slightly larger than the restoration and contacts tooth structure around the circumference of the restoration. Leinfelder and Suzuki have reported that a close correlation exists between the laboratory and clinical wear of resin composites using their generalized wear model.[1]

In an effort to move away from extracted human teeth, a new generalized wear model, patterned after the Leinfelder-Suzuki model, was developed. This model used a polyacetal antagonist and a brass fixture to hold a resin composite specimen. Investigations using this model showed marked wear of the polyacetal stylus tips.[2] It also appears that the brass fixtures experienced wear, and the measured wear of resin composite materials did not show a logical progression. As a result of these issues, the model was further modified by using a stainless steel antagonist and a stainless steel custom fixture for placement of the restorative material being examined. This new model (Figure 1) has the benefits of not using extracted human teeth with their associated health risks and an antagonist tip that does not appear to exhibit wear when used against resin composites. The antagonist tip in the new model, as in the Leinfelder-Suzuki model, is slightly larger than the restorative material placed in the stainless steel fixture. This provides a stop for the antagonist outside the circumference of the restorative material and allows for an abrasive media (water slurry of polymethyl methacrylate beads or other media) to be squeezed out between the antagonist and restorative material, simulating clinical CFA wear.

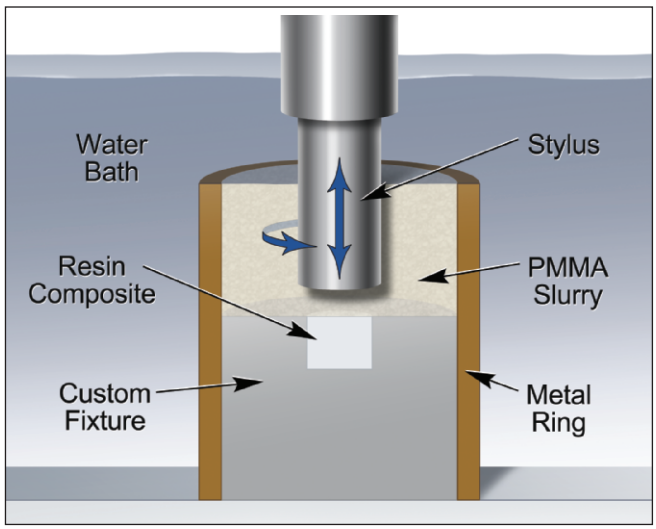

Figure 1. *Generalized wear model.*

Figure 2. *Stainless steel custom fixture for resin composite specimen.*

The benefits of a simulated wear measurement is that it can potentially provide a rapid way of examining relative wear rates between materials and provide a means for clinicians and product developers to assess expected clinical performance. However, these benefits must be validated through comparisons of simulated and clinical wear data until confidence in the simulation model is attained.

This study used the new generalized wear simulation model to ascertain laboratory wear rates for two resin composites and compare these wear rates to the clinical wear rates of the same two materials.

METHODS AND MATERIALS

Custom stainless steel fixtures (Figure 2) were used to place P50 (3M ESPE, St Paul MN, USA) and Z100 (3M ESPE) in a Leinfelder-Suzuki spring-loaded wear simulator for generalized wear testing. Thirty specimens each of P50 and Z100 were fabricated for wear testing (totaling 60 specimens). Ten specimens of each resin

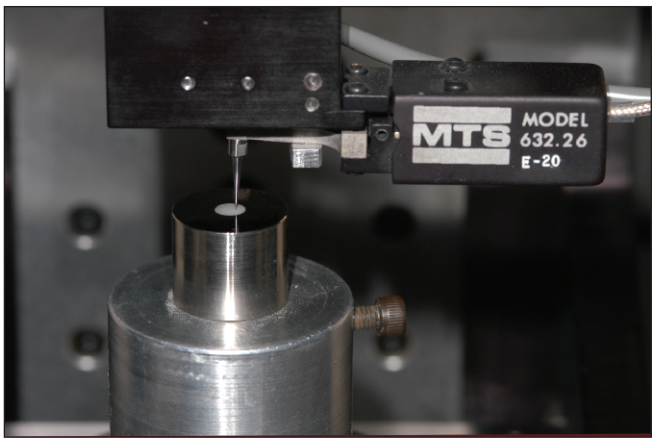

Figure 3. *Surface profilometry of resin composite specimen with MTS 3D Profiler.*

composite material were then randomly assigned for testing at 100,000, 400,000 and 800,000 cycles in the wear simulator.

Cavities 4.5 mm in diameter and 4 mm deep were lathe cut into the custom fixtures. The preparation sites were air abraded with 50 µm aluminum oxide at 70 psi. Prime & Bond NT (Caulk/Dentsply, Milford, DE, USA) was then applied to the sites and light polymerized for 10 seconds using an Elipar TriLight unit (3M ESPE). The composites were placed in two increments (each increment approximately 2 mm in thickness), and each increment was light cured for 40 seconds, followed by an additional 20 seconds of light exposure. After 24 hours, the surfaces of the composite materials were polished flat to 4000 grit using a sequence of silicon carbide papers (Struers Inc, Cleveland, OH, USA).

Prior to wear testing, pretest specimens of P50 and Z100 were surface profiled (Figure 3) with an MTS 3D Profiler (MTS Systems Corporation, Eden Prairie, MN, USA) using Capture software (MTS Systems Corporation). These profiles were used as the pre-test digitized surface for the test specimens of each respective material.

The specimens in custom fixtures were mounted in a water bath and a cylinder was placed around each sample. A water-slurry of polymethyl methacrylate (PMMA) was poured into each cylinder, covering the specimens. The stainless steel antagonists (6.5 mm diameter) were mounted in spring-loaded pistons and used with the PMMA slurry to simulate generalized clinical wear. At a rate of approximately 2Hz, the antagonist tips were vertically loaded onto the specimens at a 78.5 Newton force. As the maximum force was achieved, the antagonist tips rotated approximately 30 degrees, then counter-rotated and moved back to their original position.

Following the wear simulation procedure, the specimens were ultrasonically cleaned and profiled with the MTS 3D Profiler. The pre- and post-test digitized surfaces were compared using AnSur 3D software (Minnesota Dental Research Center for Biomaterials and Biomechanics, University of Minnesota, Minneapolis, MN, USA).

AnSur 3D software has the capability of determining four wear parameters: 1) Volume Loss (mm^3)—total volumetric loss of material from the profiled surface; 2) Maximum Depth (µm)—lowest or deepest point of all the profile scans; 3) Mean Maximum Depth (µm)—average of the lowest or deepest points from all the individual profile scans and 4) Mean Depth (µm)—average depth of all the profile scans. The wear measurements were calculated based on differences observed between the before and after data sets. For comparisons of laboratory wear simulation (machine wear) and clinical wear, the parameter of mean maximum depth was used. This wear parameter is the most relevant value for comparison to clinical wear, because it more closely approximates the type of measurement techniques used in clinical evaluations.

The data set for each of the four wear parameters determined in this laboratory study (volume loss, maximum depth, mean maximum depth and mean depth) were individually analyzed by two-way ANOVA using the factors of: 1) composite material and 2) number of cycles. Post-hoc tests were completed using Tukey's test. Linear regression was used to examine the relationship between the two variables in this study: 1) number of cycles and 2) resin composite wear. An r^2 value (square of the correlation coefficient) was determined to examine the strength of the association between the variables. A regression line was then used to predict the wear rates (generalized wear rates) of the resin composites using the wear parameter of mean maximum depth (µm).

Generalized wear values (contact free area wear—CFA) determined with the Moffa-Lugassy technique (ML Scale) from clinical studies on P50 and Z100 conducted at Creighton University were used for comparison to the simulated wear rates (machine wear) generated in this study. Linear regression lines were generated from the clinical data and the slopes of these lines were used to predict clinical wear rates.

RESULTS

The generalized wear values found for P50 and Z100 using the spring-loaded wear simulator are presented in Table 1. The clinical wear values (CFA) for P50 and Z100 are presented in Tables 2 and 3. Wear rates for the laboratory and clinical data generated by regression analysis (Figures 4-7) are presented in Table 4.

Two-way ANOVA of the laboratory data (volume loss, maximum depth, mean maximum depth and mean depth) revealed a significant effect (Table 5) for the

Table 1: *Generalized Wear Simulation Data for P50 and Z100*

Cycles X 10^5	Volume Loss (mm^3)		Maximum Depth (µm)		Mean Maximum Depth (µm)		Mean Depth (µm)	
	P50	Z100	P50	Z100	P50	Z100	P50	Z100
1	0.120 ± 0.039	0.015 ± 0.006	21.1 ± 4.9	11.4 ± 3.0	11.5 ± 1.8	4.9 ± 1.0	6.1 ± 1.6	2.0 ± 0.3
4	0.191 ± 0.031	0.035 ± 0.017	32.1 ± 9.3	14.1 ± 3.9	17.2 ± 2.7	6.0 ± 1.7	9.5 ± 1.5	2.5 ± 0.8
8	0.215 ± 0.041	0.063 ± 0.024	37.5 ± 11.1	22.8 ± 5.0	20.5 ± 4.6	9.6 ± 2.5	10.1 ± 1.9	4.1 ± 1.2

Groups connected by vertical line were not significantly different (p>0.05).
Pairwise comparisons between P50 and Z100 for all wear parameters at 100K, 400K and 800K were significantly different (p<0.05).

Table 2: *P50—Cumulative Generalized (CFA) Clinical Wear (Creighton)*

	6 Months	1 Year	2 Years	3 Years	5 Years
CFA Wear (µm)	5.2	6.4	12.2	29.7	39.5
# of restorations	43	42	39	37	33

Table 3: *Z100–Cumulative Generalized (CFA) Clinical Wear (Creighton)*

	6 Months	1 Year	2 Years	3 Years	4 Years
CFA Wear (µm)	4.8	9.9	10.1	17.0	19.6
# of restorations	52	34	31	25	23

Table 4: *Generalized Wear Rates From Regression Analysis*

Wear Data	P50	Z100
Simulation	1.3 µm/100K cycles	0.7 µm/100K cycles
Clinical	8.3 µm/year	4.0 µm/year

individual factors of composite material (p=0.000) and number of cycles (p=0.000). The interaction of composite material and number of cycles was not significant (p>0.05) for volume loss, maximum depth and mean maximum depth but was significant (p<0.05) for mean depth. Multiple pairwise comparisons with Tukey's post hoc test showed that the laboratory wear of Z100 was significantly less (p<0.05) than P50 after 100,000, 400,000 and 800,000 cycles for each of the four wear parameters determined in this study (Table 1).

Table 5: *Analysis of Variance*

Source	Sum-of-Squares	df	Mean-Square	F-Ratio	P
—Volume Loss—					
Material	0.246	1	0.246	226.173	0.000
Cycles	0.042	2	0.021	19.453	0.000
Material*Cycles	0.006	2	0.003	2.711	0.076
—Maximum Depth—					
Material	2572.212	1	2572.212	55.983	0.000
Cycles	1739.961	2	869.980	18.935	0.000
Material*Cycles	190.791	2	95.396	2.076	0.135
—Mean Maximum Depth—					
Material	1055.219	1	1055.219	125.731	0.000
Cycles	374.982	2	187.491	22.340	0.000
Material*Cycles	50.337	2	25.168	2.999	0.058
—Mean Depth—					
Material	412.566	1	412.566	189.389	0.000
Cycles	76.388	2	38.194	17.533	0.000
Material*Cycles	19.191	2	9.595	4.405	0.017

DISCUSSION

Previous studies in the laboratory (Creighton University), with the Leinfelder-Suzuki wear simulator equipped with a conical-shaped stainless steel stylus to generate localized wear, found that the wear of P50 and Z100 were in the same order as clinical trials of the same materials.[3-4] The wear facets generated were conical-shaped and wear of these two materials was compared using volumetric loss and maximum depth of the wear facets. Localized clinical wear is usually associated with an occlusal antagonist. Thus, the most indicative laboratory parameter for comparing resin composites using simulated localized wear is the loss of vertical height (facet depth) and the total volumetric loss of restorative material reflected by the wear parameters of maximum facet depth and volume loss.

Generalized (CFA) clinical wear is reported to occur at a much lower rate than localized wear.[5-6] This type of wear is typically observed independent of opposing occlusal contact and is often regarded as a kind of abrasive wear of a resin restoration caused by the mastication process.

With this new generalized wear model, the mean maximum depth of the worn surface (machine wear) of laboratory specimens was used to compare wear for two materials, P50 and Z100. The AnSur 3D software provided this value using the maximum depth of the worn composite surface for each of the profile tracings across the

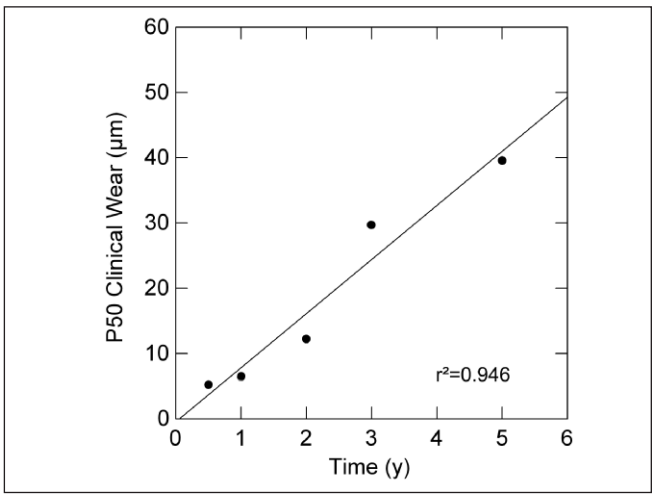

Figure 4. *P50—Generalized (CFA) clinical wear (µm) vs time (years).*

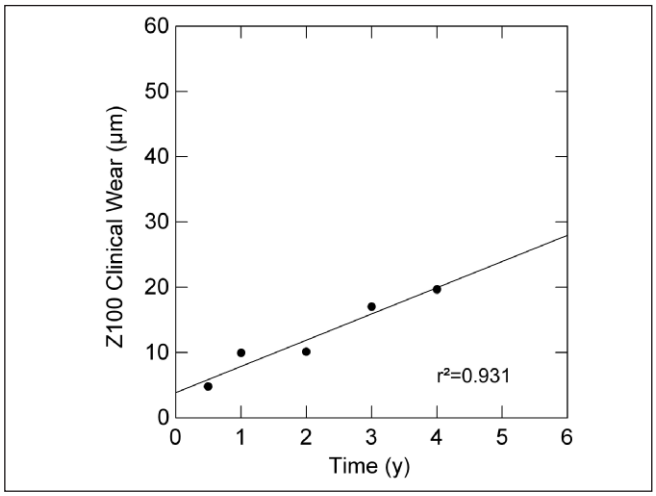

Figure 5. *Z100—Generalized (CFA) clinical wear (µm) vs time (years).*

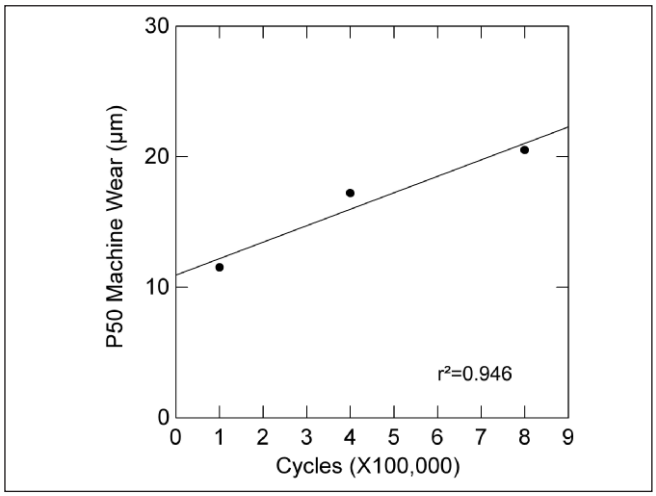

Figure 6. *P50–machine wear–mean maximum depth (µm) vs cycles (100,000x).*

surface, then it developed a mean maximum depth value for all the profiles for each specimen. This wear parameter was then used to compare P50 and Z100 composite materials to clinical wear for the same materials, because it approximated the evaluation method for determining clinical wear values using the Moffa-Lugussy (ML) technique.

Clinical studies at Creighton University School of Dentistry revealed that the cumulative wear (CFA) of P50 (29.7 µm) was nearly double that of Z100 (17.0 µm) after three years (Tables 2 and 3). The generalized wear simulation model also produced about twice the wear (mean maximum depth) for P50 (20.5 µm) when compared to Z100 (9.6 µm) after 800,000 cycles (Table 1). While it can be observed that these two methods give proportionally similar results, a detailed comparison of cumulative wear is complex and not recommended. It would require knowledge of the equivalence between the number of cycles in the simulator and the number of years of clinical wear. The comparison is further complicated, in part, by differences in the initial wear of materials. Initial wear can be influenced by differences in the curing method used, finishing technique and time of finishing (immediate or delayed).

An alternative approach would be to examine the wear rates for each type of measurement, generated by linear regression analysis of the wear data. This approach, which was used in this study, assumes that the time dependence of clinical wear, after an initial wear period (~ 6 months), may be described as approximately linear. If reasonable fits to linear regression are obtained, then the wear rates can be used for comparative purposes. Figures 4 through 7 show the likely influence of initial wear by the non-zero intercept of the regression lines.

Linear regression was used in this study to predict wear rates for both clinical wear and wear simulation of the two resin composites. The slope of the linear regression lines showed a good relationship between clinical wear and the number of years of service and between laboratory wear and the number of cycles in the wear simulator. The r^2 values for all regression analyses were greater than 0.90, indicating an excellent relationship between the variables.

In this study, the ratio of wear rates for P50 to Z100, obtained from regression analyses, was 1.9 for the simulation data and 2.1 for the clinical data. These results are in good agreement, considering the methods used. In particular, the accuracy of clinical wear may be affected by the subjective nature of the visual comparison method used in determining clinical wear. Use of the ML scale for assessing clinical wear has a tendency to underestimate the amount of wear.[7] The fact that the regression line for the P50 clinical wear data does

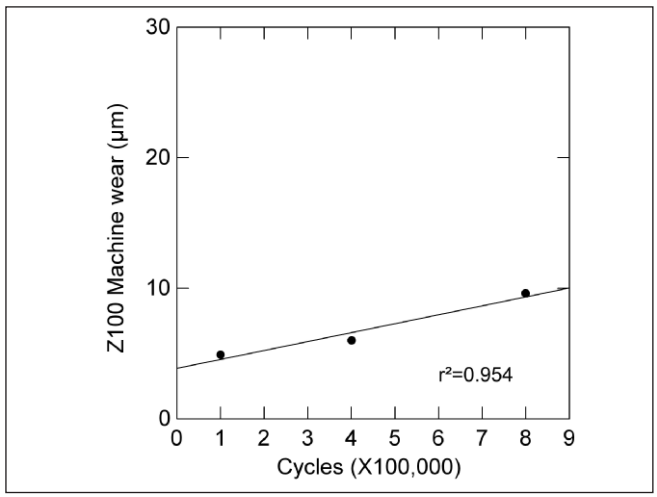

Figure 7. *Z100–machine wear–mean maximum depth (µm) vs cycles (100,000x).*

not have a positive intersection with the wear axis suggests that the wear values for the earlier stages of the study might have been underestimated. This could have caused the ratio of wear rates (2.1) to be higher than it should be, and a reduction might bring it closer to the value of 1.9 found with the simulation data. However, currently, the two values are only about 10% apart, which is good considering the subjective method for measuring clinical wear.

For the two materials examined, this new wear model, using stainless steel antagonists and stainless steel fixtures, appears to provide meaningful information for comparing clinical data to wear simulation. If these promising results are borne out in testing other materials, this new model could be useful as a fast, simple method for estimating the relative clinical wear characteristics of new resin composite materials. Testing of additional composite materials would help to strengthen the reliability of this model, but access to good clinical wear data is needed.

CONCLUSIONS

A new laboratory model for generalized wear was used to examine the relationship between wear simulation and clinical wear of two resin composites. The new model may provide meaningful information for comparing clinical CFA wear to simulated generalized wear.

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References

1. Leinfelder KF & Suzuki S (1999) *In vitro* wear device for determining posterior composite wear *Journal of the American Dental Association* **130(9)** 1347-1353.
2. Barkmeier, WW, Erickson RL, Latta MA, Wilwerding TM & Simister BG (2002) Evaluation of a generalized wear model for composite *Journal of Dental Research* **81(A)** Abstract #3844.
3. Barkmeier WW, Latta MA, Wilwerding TM & Blake SM (2001) Wear assessment of high viscosity and conventional composite restorative materials *Operative Dentistry* **26(2)** 152-156.
4. Barkmeier WW, Latta MA, Erickson RL & Lambrecths P (2004) Comparison of laboratory and clinical wear rates of resin composites *Quintessence International* **35(4)** 269-276.
5. Lutz F, Phillips RW, Roulet JF & Setcos JC (1984) *In vivo* and *in vitro* wear of potential posterior composites *Journal of Dental Research* **63(6)** 914-920.
6. Lambrechts P, Braem M & Vanherle G (1985) Accomplishments and expectations with posterior composite resins. In: Vanherle G & Smith DC (eds) *Posterior Composite Resin Dental Restorative Materials* Utrecht The Netherlands: Peter Sculz Publishing 521-540.
7. Bayne SC, Taylor DF, Rekow ED, Wilder AD & Heyman HO (1994) Confirmation of Leinfelder clinical wear standards *Dental Materials* **10(1)** 11-18.