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Effect of Power Toothbrushing on Simulated Wear of Dental Cement Margins

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Power toothbrushes (PTBs), in combination with abrasive dentifrices, may encourage wear of dental cements at crown margins.

Purpose.The objective of this in vitro simulation was to control the clinical variables associated with PTB use and measure the potential side effects of PTBs with mild and abrasive dentifrices.

Methods and Materials. Four PTBs (Braun-Oral-B-Professional Care at 150 g brushing force, Sonicare-Elite at 90 g, Colgate-Actibrush at 200 g and Crest-Spinbrush-Pro at 250 g) and 2 dentifrices mixed 1:1 with tap water (Mild= Colgate-Total, Colgate-Palmolive; Abrasive= Close-up, Chesebrough-Ponds) versus tap water alone (control) were used to abrade 2 cements (Fleck's Mizzy Zinc Phosphate [ZP]; 3M-ESPE Unicem universal cement [UC]) using cement-filled slots (160 m wide) cut into wear-resistant ceramic blocks. A custom fixture controlled PTB/block alignment, PTB loads, and other testing variables. Wear was measured (3 profilometer traces/slot, 5 slots/block/group, baseline to 5-year differences) and analyzed (3-way ANOVA, $p \leq 0.05$, Bonferroni)

Results. Wear for ZP was much greater than UC ($p<0.05$) for all 4 PTBs and both dentifrices. Brushing with water showed no effects ($p<0.05$). Cement-PTB-dentifrice interactions did occur. Only minor differences occurred among PTBs. Pooled 5y-wear levels for ZP for both dentifrices (~21 µm /5y) were similar to values for current-day posterior composite materials.

Conclusions. Combinations of PTBs with mild and abrasive dentifrices produced significant wear with ZP but not UC; thus, resin-composite cements seem to represent a better choice for wear resistance.

Keywords: power toothbrushes, dentifrices, wear, zinc phosphate, resin-composite cements, profilometer

Clinical Relevance Statement

The objective of this study was to measure wear produced by 4 power toothbrushes using 2 dentifrices on 2 dental cements at simulated restoration margins.

Introduction

Power toothbrushes (PTBs) are the latest technological device for oral hygiene care. PTB types and brands include: battery-operated oscillating, rechargeable oscillating, or rechargeable sonic action units (Table I and Figure 1a, 1b). Clinical studies have been published on both the effectiveness of plaque removal, stain removal, and biofilm removal, as well as some side effects such as tooth surface wear and production of dental hypersensitivity.[1,2,3,4] Both battery-operated PTBs and rechargeable PTBs are efficacious for plaque removal, but like manual toothbrushes (MTBs), may cause tooth surface or restoration wear when improperly used or combined with abrasive dentifrices. Tooth surface wear is greater for PTBs than MTB, depending on the amount of force and type of dentifrice used.[5-6]

Figure 1A. Examples of PTBs (Left-to-Right: Crest Spinbrush, Colgate Actibrush, Oral-B Professional Care, and Sonicare Elite).

Figure 1B. Magnified view of PTB heads (Left-to-Right: Colgate Actibrush, Crest Spinbrush, Oral-B Professional Care, and Sonicare Elite)

Table I. Summary of rechargeable and disposable battery-operated PTB features.

Category	*Types*	*Action*	*Motions per min*	*Characteristics*
Recharge	Sonicare Elite	Side to Side	31,000	Quadpacer; 2m timer
	Interplak	Counter Rotational	4,200	Auto-Flush; Dispenses Mouthrinse
	Braun Oral B Professional Care	Rotation-Oscillation	8,800	Two-speed option; 2m timer
	Roda-Dent	Circular	90,000	Rounded Head
	Teledyne Aqua Tech	Circular	No Data	Rounded Head
	Ultrasonex	Ultrasonic	90	Sonic Vibration
Battery	Crest Spinbrush Pro	Dual-Action Oscillation	No Data	Rounded head
	Colgate Actibrush	Oscillation	4,500	Small rounded head
	Colgate Motion	Dual Head Oscillation	4,500	Rounded head
	Braun Oral-B	Oscillation	3,800	Rounded head

There is limited research examining potential problems of using PTBs with cemented restorations. Potential side effects of PTBs on tooth surface wear and some restorative materials have been investigated.[7] There has been speculation within the literature that energy from sonic toothbrushes may affect the integrity of cements. Retentive strengths of crowns were evaluated by McDaniel et al[8] by comparing changes in resin, glass ionomer, or zinc phosphate cements; Hansen et al[9] evaluated effects of Sonicare, Interplak, and no exposure. Both studies simulated 2 years of sonic tooth brushing and found no effects. Gheewalla et al[10] examined Sonicare, Oral-B, and Rota-Dent effects on resin-bonded orthodontic brackets (n=1080) in a 6-month clinical trial and findings revealed no failures. Buchalla et al[11] assessed the wear of 11 different dental cements after exposures to neutral versus acidic pH solutions by using regular toothbrushes loaded onto 4 mm (4000 µm) wide slots of the cement. Results demonstrate that resin cement displayed the most abrasion resistance and acidic conditions had a greater effect on conventional cements than resin cements. A limitation to the Buchalla et al study was the wide slots for cement exposure did not realistically represent clinical cement margins. Shinkai et al[12] tried to test the effects of 4 different particle-size filled composite resins on the marginal wear and toothbrush abrasion of cemented Cerec inlays, revealing that wear decreased with smaller particle size. Yet, the authors did not maintain equal loading levels of the experimental cements, so it was impossible to separate particle size and loading level effects.

Studies have explored some possible degradation mechanisms, but none have carefully evaluated effects of PTBs on cement abrasion/erosion (wear). Cement margins may be at risk to more effective surface cleaning methods. The objective of this *in vitro* simulation was to measure the effects of PTBs with mild and abrasive dentifrices on the wear of 2 dental cements at the margins of restorations.

Method and Materials

Slots cut into ceramic blocks simulated cement margins of restorations (ProCad, Ivoclar, Vivadent Inc, Amherst, NY) and provided a stable reference system for measuring the effects of PTB and dentifrice combinations. After polishing the surfaces, wear was monitored over time by profiling the slots.

Four PTBs, including 2 categories (battery-powered and rechargeable) and several different bristle actions, were evaluated. The PTBs with 2-minute timers were modified to run "continuously" for the experiments. PTB effectiveness depends on charge or battery life, thus, only freshly recharged or new battery-powered PTBs were used. The Crest Spinbrush Pro and Colgate Actibrush were modified to allow an AC 3-volt (500 mA) adapter to be used as the power source. The Sonicare Elite was modified by attaching a timer box to the circuit in order to monitor the 2-minute cycles and allow the brush to continue after a 2-second delay, allowing the Sonicare Elite to run continuously. The Oral B Professional Care 7850 DLX has a 2-minute timer but ran continuously for an hour fully charged.

Two dentifrices (Colgate Total, RDA = 60-75, mild abrasivity) and (Close-Up Gel, RDA = 161, medium abrasivity) were used to measure the wear of each dental cement at the simulated margins (Baker, 1999). Dentifrices were compared to brushing with tap water alone. To mimic the action of dentifrice mixing with saliva and being diluted, dentifrice was mixed 1:1 by volume with tap water. The pH for each mixture was measured initially (Model AP61, Fisher Scientific, Pittsburgh, Pa) and was approximately neutral (tap water = 7.18, CT solution = 7.6, CU solution = 7.5).

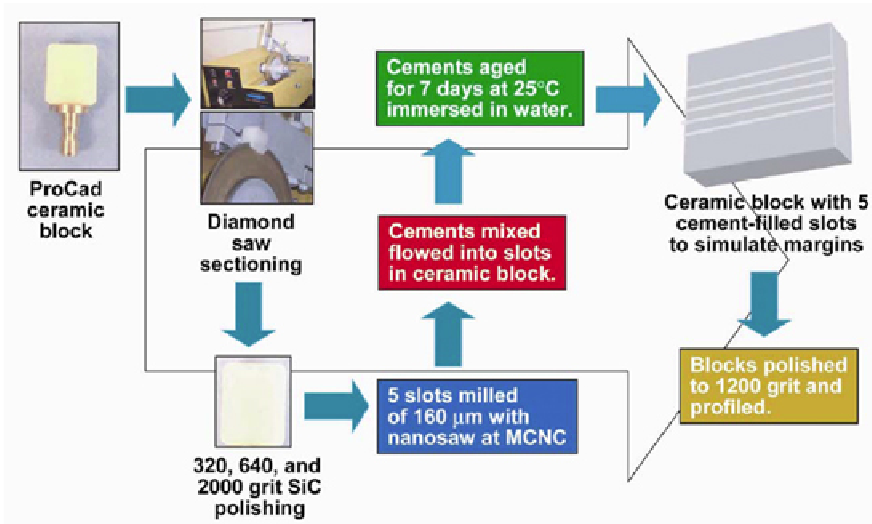
Fleck's Mizzy Zinc Phosphate (ZP) and 3M-ESPE Unicem resin-composite cement (UC) were evaluated. ZP represents the "gold standard" for all other cement comparisons, but is not currently in wide use. Resin-modified glass ionomer cement is commonly used for cementing materials with metal substructures (cast crowns, PFM, metal bridges). Normally, composite resin is used with all-ceramic or indirect composite restorations. Recently, universal cements have been promoted for cementing both metal substructures and all-ceramic restorations. Clinicians are interested in being able to use one cement for all applications. Information on the cements and their handling conditions are reported in Table II.

Table II. Sources and handling conditions for dental cements.

Cement: (Abbrev)	Manufacturer and Address:	Lot Number:	Manipulation:
Flecks Mizzy (ZP)	Mizzy, Inc. Cherry Hill, NJ	P8682608 L648091808	> Glass slab chilled with running water for 2 minutes and dried with paper towel. > Powder (0.8g) proportioned into 1/16, 1/16, 1/8, ¼, ¼, ¼ increments. > Liquid proportioned with glass micropipette (24 drops). > Smallest-to-largest powder increments added to liquid mixture over 2 minutes. > Cement added and flowed into slots by from one end to other.
UniCem (UC)	3M-ESPE St. Paul, Minn	162647	> Capsule activated and amalgamated 15 seconds. > Capsule beak bent open and cement dispensed onto wax-coated paper pad. > Cement added and flowed into slots from one end to other.

Cement margins were simulated as slots within all-ceramic blocks to mimic an all-ceramic restoration adjacent to tooth structure. ProCad ceramic blocks (2mm x 12mm x 10mm) designed originally for CAD-CAM milling, were cut on a diamond wafering saw (Buehler, Lake Bluff, Ill) and manually polished through a 320, 600, and 1200 grit series of SiC abrasives (Carbimet, Buehler, Lake Bluff, Ill) to produce smooth faces (Figure 2). Five slots were milled accurately into each face (160 µm wide about 350 µm deep) using a high-speed nano-saw (Model DAD 341, Disco Corporation, Japan).

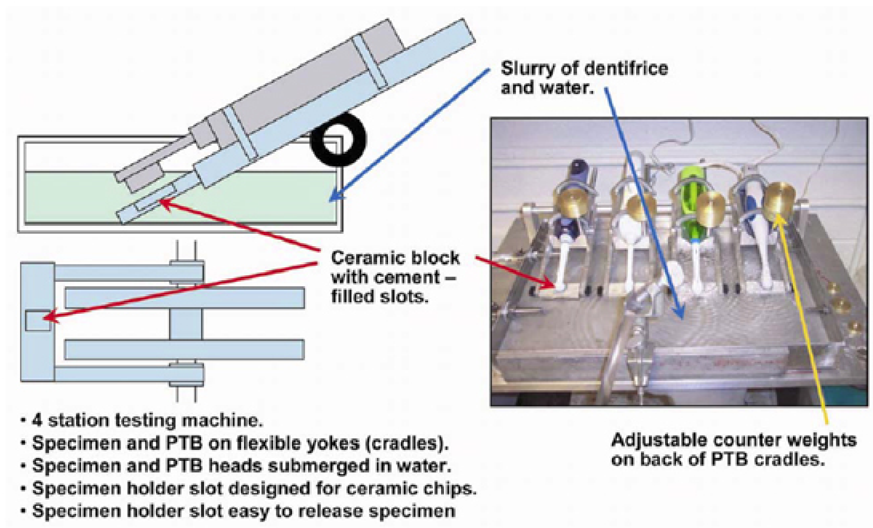
Figure 2. Flow chart for the preparation and testing of specimens.



Cements were mixed and manipulated according to manufacturer's directions (Table II) and flowed carefully from one end to the other of each slot. Blocks with cement-filled slots were conditioned in water for 7 days to insure that setting reactions were complete and that any potential water absorption (and any expansion) would have occurred. Ceramic block surfaces were polished with 1200 grit SiC to level the cements with the block surface and profiled to obtain baseline readings. Blocks with cements were then tested for a total of 3 hours and re-profiled. To minimize the time for longer-term absorption or swelling of cements in water that might cause slow but continued expansion, testing was accomplished in a few hours after 7 days of conditioning in water.

To control variables associated with PTBs use, custom equipment was designed to hold 4 PTBs (Figure 3) during the course of the experiments. Each PTB handle was secured with spring ties to a yoke permitting access to the on-off switches on the bottom surfaces of each handle. A second yoke held a 10x12mm ceramic block with its cement-filled slots, and was adjusted to align the specimen surfaces parallel to the PTB heads. Both yokes were articulated on a common rail. Each PTB yoke was equipped with weights to adjust loads on the PTB head against the block. Each load in grams was adjusted by using a calibrated spring scale (Science and Surplus, Milwaukee, Wis). Yokes were tipped forward to remain submerged in the solution of dentifrice/water, which was pumped continuously to the equipment reservoir from a constant temperature water bath (Figure 3). The relatively rapid circulation of the mixture provided sufficient agitation to keep the abrasive particles from settling out to any degree.

Figure 3. PTB simulation equipment that holds 4 PTBs.



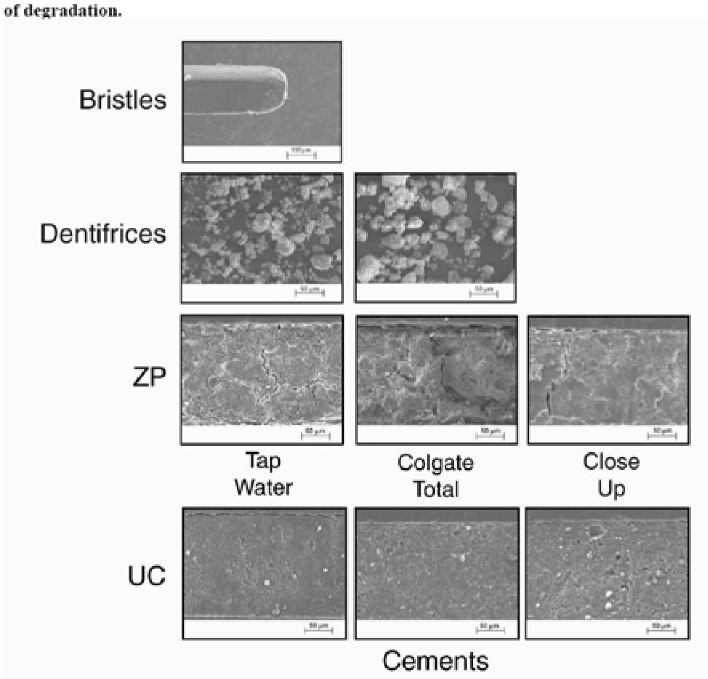
Most PTB recommendations call for a contact time of 30 seconds per quadrant (3 surfaces twice daily). Most PTBs contact approximately 2 teeth simultaneously. From these assumptions, it is possible to calculate the contact time per tooth surface. Contact time = (2x/d) x (30s/quadrant) x (2 teeth/brushhead) (3 surfaces/tooth) (7 teeth/quadrant) = 5.7 seconds/surface/day. This corresponds to 2085s/y (= 35m/y = or 0.58 h/y). To simulate ~5 years of PTB exposure for these experiments required (5y)(0.58 h/y) = 2.9h 3hours.

Profilometry was used to monitor cement changes during the experiments and 3 small fiduciary lines were scribed on each block near the cement-filled slots to provide a simple, although approximate, referencing system (Surfanalyzer System 5000, Esterline-Federal Products, Providence, RI). The profilometer utilized a contact stylus with a precision of 0.2 µm and a travel of up to 10 cm. The sample was positioned so that the stylus could track across 5 slots at once.

Tracings were examined on a computer screen, enlarged to focus on one slot at a time, and analyzed by manual integration of the area of wear. A clear Mylar mask with a printed grid was placed over the computer screen to count areas from the original surface to the profiled surface. The grid area was divided by the width of the slot to calculate the average depth of wear for each location. Wear values from 3 locations for each of the 5 slots were averaged together (n=15) to calculate mean wear values of PTB, dentifrice, and cement type.

Following the conclusion of the wear experiments, SEM analysis (JEM 6300, Jeol USA, Peabody, Mass) was conducted on dentifrice abrasives, PTB bristles, and worn cements (Figure 5). Abrasive material from the dentifrices was separated by shaking with water, allowing the abrasive to settle, and decanting the superficial solution. This elution was repeated 5 times before collecting the abrasive. Dried abrasive particles were attached to double-stick tape on an SEM stub, sputter-coated with Au-Pd (Polaron E5200, Quorum Technologies, Houston, Tex), and examined for particle size and distribution. Bristles were collected from the inner portions of each PTB head to examine effects of exposure to tap water, Colgate-Total, and Close-Up in comparison to unused PTB bristles. Each bristle was attached to double-stick tape on an SEM stub, sputtered-coated with Au-Pd, and examined at 200X and 500X. Cements in slots were examined as well. To avoid artifacts from dehydration during sputter coating, blocks containing the ZP and UC cement specimens were processed by critical-point drying. After subsequent sputter coating, cements were examined at 15X and 500X.

Figure 5. SEM analysis of bristles, dentifrices, and cements. A) Example of bristle size and geometry for Sonicare; B) Typical particle size of abrasive particles and evidence of some agglomeration for both CT and CU dentifrices; C) Examples of the microstructures of ZP and UC cements in the test slots after PTB experiments. ZP showed much more evidence of degradation.

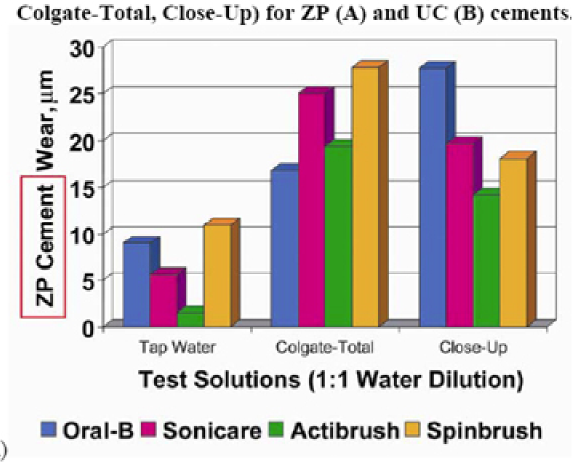


The experiments recorded cement wear as a function of 4 PTBs, 3 test solutions, and 2 cement types. SAS software (SAS, Cary, NC) was used to conduct nonlinear modeling analyses of all experimental effects to determine potential interactions and main effects. After determining the major effects from the models, Analyse-It (Analyse-It Software Ltd, PO Box 103, Leeds LS27 7WZ, England, UK) was employed for analysis of variance (ANOVA) to detect differences ($p \leq 0.05$) among all groups within smaller collections and pooled groups. ANOVAs for collections and pooled groups were performed using Bonferroni adjustments.

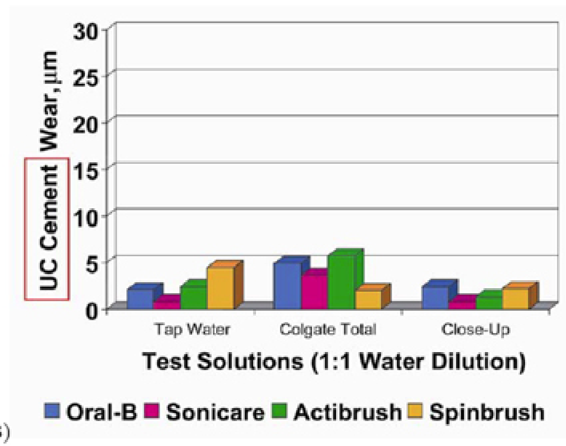
Results

Differences in wear (µm) between the start and finish of the 5-year simulation of PTB brushing are presented in Table III and Figure 4 for different combinations of cement-PTB-dentifrices.

Figure 4. Comparisons of the four individual PTBs in combination with different test solutions (water, Colgate-Total, Close-Up) for ZP (A) and UC (B) cements.



(A)



(B)

Table III. 5-year cement wear for different cements, PTBs, and test solutions.

Summary of 5-Year Simulated PTB Wear of Cements (µm, mean ± sd)				
		Tap Water:	*Colgate-Total:*	*Close-Up:*
ZP	PTB1 Pro	9.0±7.5 µm [ab,A]	16.8±8.7 µm [bc,B]	27.7±8.4 µm [c,C]
	PTB2 Elite	5.6±6.3 µm [a,A]	25.0±17.0 µm [b,B]	19.7±14.9 µm [b,C]
	PTB3 Actibrush	1.5±3.2 µm [a,A]	19.4±12.5 µm [b,B]	14.2±6.3 µm [ab,C]
	PTB4 Spinbrush	11.0±9.1 µm [a,A]	27.8±9.1 µm [b,B]	18.1±13.9 µm [ab,C]
UC	PTB1 Pro	2.1±2.6 µm [a,AB]	4.9±2.3 µm [a,AB]	2.4±2.6 µm [a,A]
	PTB2 Sonicare	0.8±0.7 µm [a,A]	3.7±2.0 µm [b,AB]	0.8±3.2 µm [ac,A]
	PTB3 Actibrush	2.4±1.8 µm [a,AB]	5.7±3.7 µm [a,A]	1.3±1.4 µm [a,A]
	PTB4 Spinbrush	4.5±3.5 µm [a,B]	2.0±2.0 µm [a,B]	2.2±1.6 µm [a,A]

* Statistical analysis: For the 4PTBs for a single cement, small letters (=INTER-column) and capital letters (= INTRA column) show the differences for $p<0.05$.

There were significant differences among test solutions and between cements, but not among PTBs (Table IV). ZP experienced much greater wear ($p<0.05$) than UC for all test solutions, including small differences even within tap water. Both dentifrice test solutions produced significantly more cement wear than with tap water alone ($p<0.05$).

Table IV. 5-year cement wear for different cements, pooled PTBs, and test solutions.

Groups:		*Tap Water:*	*Colgate-Total:*	*Close-Up:*
ZP	All PTBs	6.8 ± 4.2 μm [a,A]	22.3 ± 5.0 μm [a,B]	19.9 ± 5.7 μm [a,B]
UC	All PTBs	2.5 ± 1.5 μm [a,A]	4.1 ± 1.6 μm [b,B]	1.7 ± 0.8 μm [b,A]

Durability of the bristles was assessed by comparing bristle size and geometry before and after the simulated 5-year use. PTB bristles were approximately round in shape and almost exactly 150 μm in diameter, except the Sonicare bristles typically appeared about 25% larger in diameter. There were no apparent changes in bristle tip roundedness of diameter after 5-year simulated use. Bristle densities were calculated for each of the PTBs and were almost identical (Colgate Actibrush=6.1 bristles/mm2, Spinbrush=7.6, Oral-B=7.6, Sonicare=6.4).

Abrasive particles isolated from the dentifrices were primarily in the 1-40 μm range and often appeared to be agglomerates of smaller particles, although no formal particle size analysis was conducted. The mean particle size was approximately 1-5 μm range. Actual compositions of the abrasives and the amount of abrasive in each dentifrice was not determined. The SEM observations demonstrated that particles were sufficiently small and easily made contact with the cement, even after some wear might have taken place.

Microstructures of the 2 dental cements were different. ZP contains a reaction product matrix of tertiary zinc phosphate crystals wrapped around a large volume of residual ZnO powder.[14] The ZnO particle sizes varied from about 1-10 μm and the interparticle spacing was on the order of about 2-5 μm. UC cement is based on the free radial reaction of matrix monomers that surround reinforcing silicate filler particles. The silicate filler averaged about 1-5 μm in diameter. The interparticle spacing was much less than 2 μm.

Approximately one month after recording the planned wear measurements, and after continued storage of the specimen blocks in water, the cements were profiled again. The depths of wear had decreased (5-20 μm), indicating that water absorption continued to occur within the samples.

Discussion

The PTBs producing equivalent results was not anticipated. This may be due to the experimental design, interpretation of the results, comparisons of results to published literature, clinical interpretation of the value of the results, and proposed future research areas.

Slurries of dentifrice were made using tap water (pH=7.2). In retrospect, it would have been more controlled to use water that was starting at a neutral pH. Buchalla et al11 earlier reported that for conventional cements, such as zinc phosphate, markedly acidic conditions (pH=3) produced more wear on exposure.

A presumption of this research was that the specimens were only affected by water absorption during the conditioning phase. However, differences in pH, ions from fluoride, or dentifrice additives may have caused minor osmotic differences between the inside and outside of cements that contributed to volumetric changes during the PTB testing phase. At the present time, no controls were analyzed to detect such changes. However, there is at least some evidence that these types of changes may be occurring. The cement specimens were remeasured after another week and there was at least some noticeable expansion continuing to occur. While these effects were avoided in this experiment by polishing, measuring, and testing all the specimens within 24 hours at the end of the 7-day conditioning phase, this is a potential problem for other measurement techniques that require any substantial delay. This would also indicate that SEM or similar microscopy techniques might not produce accurate reflections of volumetric changes.

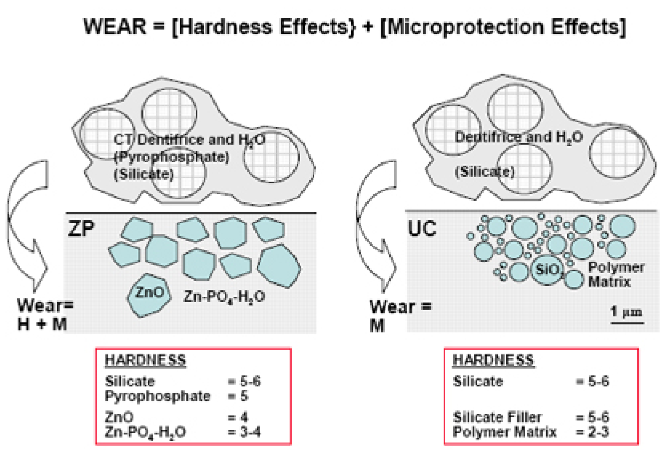
PTB simulation was designed so that PTB bristles were being used only in the wet state during the experiments. Patients would most likely store their PTB brush head in air and bristles would dry out between uses. Nylon tends to absorb water and become plasticized or softened. In a softened state, bristles may not produce as much 2-body wear of cement surfaces.

However, there did not seem to be a simple method to simulate the fact that bristles might behave harder during the initial phase of each PTB brushing.

Biofilm is omnipresent in the oral environment and would normally be present over dental cement margins. Most likely the biofilm would be an initial barrier to cement wear, although the effect could be minor. In any case, this effect would delay or decrease the extent of wear under clinical conditions.

It appeared that the dominating factor influencing observed cement wear was the resistance of the actual cements, and that abrasive particles in the dentifrices produced most of the observed wear. The results were not the effects of the differences in PTBs or other differences in dentifrice compositions. In both Colgate-Total and Close-Up, typical abrasive particles (1-5 µm range) seemed to easily contact the cement within the margin (160 µm wide), affect the weak ZP cement matrix, and produce wear. SEM views agreed with the wear measured by profilometry. These observations are consistent with the "protection theory" of wear for dental composites.[15] Macro-protection is the sheltering of restorative material by the cavosurface margins of tooth structure. Micro-protection is the sheltering of the weaker restorative material matrix by the harder filler phase particles, and this theory applies in this situation for cements (Figure 6). Materials with small-sized dispersed reinforcing filler phases, such as the residual powder particles in cements or composites, which create small interparticle separations, demonstrate good wear resistance.[15] Rankings of wear equated to rankings of interparticle separation and matrix resistance to wear. In this particular experiment, the smaller interparticle separation associated with smaller filler particles, and greater wear resistance of the UC matrix generated better overall wear resistance. Despite this apparent agreement with theory, more extensive investigation is warranted to confirm this explanation.

Figure 6. Proposed mechanism of wear of dental cements based on varying contributions of hardness (HE) and microprotection (MP) factors. CT in contact with ZP is shown to the left, and CU in contact with UC is shown to the right, as examples of experimental test situations. Hardness values are expressed in terms of Mohs scale (and estimated from online mineral data).



Greater wear was observed with ZP cement. Buchalla et al[11] noted that zinc phosphate was less wear-resistant than resin-based cements. One would logically expect that stronger materials would also provide more wear resistance and retentive strength as well, although the reasons may not be exactly the same.

Mean wear levels ranged from 14-28 µm. There was no information in the literature available for direct comparison, but some important suggestions that measured in vitro values are consistent with clinical wear. Wear-resistant, dental composite, Class 2 restorations typically display 5-15 µm of wear in 3-year simulation tests of food abrasion.[15] Four-year cement wear levels on occlusal surfaces for a clinical trial of bonded CAD-CAM inlay restorations were 55 µm16 for patients not using PTBs but which were subject to food abrasion.

PTBs may be recommended to patients with extensive cemented crown and bridge restorations, however, one should be cautious with ZP cement. It appeared that UC had excellent wear resistance. One also should be cautious in over-interpreting these results since only 2 cements have been directly evaluated. One might expect that other commercial cements should fall in between the results for ZP and UC, but that is not yet known.

The PTB machine and model of testing materials in slots in ceramic blocks offer a good method to investigate a range of other experimental questions. For example, what is the effect of different PTB loading levels on cement wear? Is there an upper limit in wear that occurs due to macro-protection? Do other cements with small dispersed particle sizes demonstrate micro-protection? These will all help to further understand the wear mechanism and rates for dental cements.

Conclusions

In summary, within the limitations of this 5-year simulation of dental cement wear by different PTBs and different test solutions, the following can be concluded:

1. ZP underwent much greater wear than UC ($p \leq 0.05$) for all 4 PTBs and both dentifrices.
2. There were relatively minor differences among individual PTBs ($p>0.05$ for most comparisons).
3. Relatively minor differences occurred between mild and abrasive dentifrices ($p>0.05$ for most comparisons).

Abbreviations:

power toothbrushes (PTBs), manual toothbrushes (MTBs), Colgate-Total (CT), Close-Up (CU), zinc phosphate (ZP), resin-composite (UC).

Trade Names:

Crest Spinbrush, Colgate Actibrush, Oral-B Professional Care, Sonicare Elite, Fleck's Mizzy Zinc Phosphate Cement, 3M-ESPE Unicem resin-composite cement, Colgate-Total, Close-Up, ProCad ceramic blocks.

Notes

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