Basic Science Research

In Vitro Wear of Nano-Composite Denture Teeth

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Purpose: **Few laboratory tests have been able to substantiate and quantify the wear resistances of polymeric denture teeth. This study evaluated the relative wear resistance of several types of denture teeth using an in vitro wear testing device.**

Material and Methods: **Four different types of denture teeth [nano-filled (Veracia) and micro-filled composites (SR-Orthosit, Endura, Duradent, Surpass), cross-linked acrylic (SR-Postaris, Genios-P, Creapearl, Vitapan Physiodens, Premium 8, Integral), and a conventional acrylic (Biotone)] were used. The flattened buccal surface of each denture tooth was subjected to the evaluation of Knoop hardness (n = 5) and localized wear for 100,000 cycles (n = 10). Wear values were determined in micrometers using a profilometer. The data for the hardness, wear depth, and worn surface areas were individually analyzed by one-way ANOVA.**

Results: **Knoop hardness values (KHN) ranged from 28.2 to 29.8 for micro-filled composite, 18.9 to 21.6 for cross-linked acrylic, 22.7 for nano-composite, and 18.6 for conventional acrylic teeth. All micro-filled composite teeth were significantly harder than other teeth ($p < 0.0001$). The wear depth values were 90.5 μm for the nano-composite, 69.8 to 93.0 μm for the micro-filled composite, 80.8 to 104.0 μm for the cross-linked acrylic, and 162.5 μm for conventional acrylic teeth. The worn surface areas were 5.1 mm^2 for the nano-composite, 2.6 to 3.6 mm^2 for the micro-filled composite, 4.4 to 5.7 mm^2 for the cross-linked acrylic, and 10.1 mm^2 for conventional acrylic teeth. The wear values of the acrylic control were significantly different from all other denture teeth ($p < 0.001$).**

Conclusion: **The nano-composite tooth was harder and more wear resistant than the acrylic teeth but not significantly different from most of the cross-linked and micro-filled composite teeth tested.**

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INDEX WORDS: denture teeth, nano-composite, wear, in vitro wear test

ONE OF the most important physical properties of denture teeth used in the restoration of the edentulous patient is wear resistance, as the material works to maintain the properly established vertical dimension and chewing efficiency. Porcelain denture teeth have been considered the most wear resistant;[1] however, porcelain possesses a number of major disadvantages, including brittleness, lack of bonding to the denture base, and difficulty in polishing.[1] Abrasiveness of porcelain is often considered to be a concern; therefore, the material is generally not used in opposition to natural teeth or cast metal restorations.[2-6] Acrylic resin denture teeth are easier to recontour when the interocclusal distance is less than ideal. Excessive wear of acrylic resin teeth has been a concern to both the patient and the dentist because of unfavorable associated sequelae. While porcelain teeth seldom need replacement due to occlusal wear, acrylic denture teeth commonly undergo substantial attrition in relatively short periods of time. Clinical experience has shown that acrylic teeth are extremely compatible with opposing natural dentition. Also, resin teeth are considered to be advantageous when resin denture teeth are used for the upper structure of an implant because of their greater shock absorbing capacity.[7-10]

In an effort to retain the acceptable clinical characteristics of acrylic resin teeth while gaining acceptable wear resistance, several new types of resin denture teeth have been introduced. These include those made of cross-linked acrylic and micro-filled composite resins. Cross-linked acrylic denture teeth have been developed

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by utilizing various polymer technologies including blend polymer, interpenetrating polymer networks (IPN),[11] and double cross-linking (DCL). Micro-filled composite has been introduced as a wear resistant material and used as a denture tooth material for more than a decade.[12] Several studies on wear evaluation for these materials have been conducted.[13-19] A wide variety of abrasives, measuring instruments, and methods of wear testing make it difficult to assess study results that compare these materials. The results indicate that the micro-filled composite teeth possess superior wear resistance compared to conventional acrylic, although data vary depending upon the evaluation designs.[20-22]

Although clinical trials will help establish a standard laboratory testing regimen, they include a variety of factors that affect the results of prosthetic tooth wear.[23] Two 3-year clinical studies showed no clear tendency of wear and no significant differences among the commercial denture teeth evaluated.[24,25] Other clinical problems of resin composite denture teeth include poor bonding to denture bases,[26] brittle properties,[27] and superficial staining.[28]

A new type of denture tooth, fabricated of nano-composite resin, has recently been developed as a highly polishable, stain and impact resistant material.[29] It consists of a comonomer of urethane dimethacrylate (UDMA) and methylmethacrylate (MMA), polymethylmethacrylate (PMMA), and uniformly dispersed nano-sized filler particles. As the material contains PMMA, even cross-linked with UDMA and reinforced by inorganic fillers, excellent wear resistance might not be expected. Therefore, the hypothesis of this study is that wear resistance of the nano-composite tooth is superior to conventional acrylic resin prosthetic teeth but inferior to micro-filled composite teeth.

The purpose of this study was to evaluate the hardness and wear rates of a recently developed nano-composite denture tooth in comparison to various types of resin denture teeth including micro-filled composite teeth, cross-linked acrylic resin teeth, and traditional acrylic resin denture teeth.

Materials and Methods

Twelve denture tooth materials (Table 1) were evaluated for wear resistance in this study. They were divided into 4 groups (nano-composite, micro-filled composite, cross-linked acrylic resin, and conventional acrylic resin denture teeth) according to type of material. They included: a nano-composite tooth, Veracia (Shofu, Kyoto, Japan); 4 micro-filled composite teeth, SR-Orthosit (Ivoclar/Vivadent, Schaan, Liechtenstein), Endura (Shofu, Kyoto, Japan), Duradent, and Surpass (GC, Tokyo, Japan); 6 cross-linked acrylic resin teeth, SR-Postaris (Ivoclar/Vivadent, Schaan, Liechtenstein), Genios-P (Dentsply/De Trey, York, PA), Creapearl (Klema Dental, Meiningen, Germany), Vitapan Physiodens (Vita/Vident, Brea, CA), Premium 8 (Heraeus/Kulzer, Hanau, Germany), and Integral (Merz Dental, Lütjenburg, Germany); and a conventional acrylic resin tooth, Biotone (Dentsply, York, PA) as a control.

A maxillary molar was aligned to its tooth axis parallel to the horizontal plane in a brass cup and secured with an auto-polymerized acrylic resin. The buccal surface of the cusp was ground flat with a 600-grit SiC paper under water irrigation. The specimen was mounted onto the University of Alabama wear device[30-35] and surrounded by a tightly fitting cylinder. The specimens

Table 1. Materials Tested

Type of Denture Teeth	*Products*	*Manufacturers*	*Lot Number*
Nano-composite	Veracia	Shofu	0902
Micro-filled composite	Endura	Shofu	0197
	SR-Orthosit	Ivoclar/Vivadent	—
	Duradent	GC	173821
	Surpass	GC	0109021
Cross-linked (DCL)	SR-Postaris	Ivoclar/Vivadent	J61
Cross-linked (IPN)	Genios-P	Dentsply/De Trey	100799
	Creapearl	Klema Dental	—
	Vitapan Physiodens	Vita/Vident	JO17A6A324E00
	Premium 8	Heraeus/Kulzer	C3
	Integral	Mertz Dental	3029
Acrylic (control)	Biotone	Dentsply	—

—: No lot number registered.

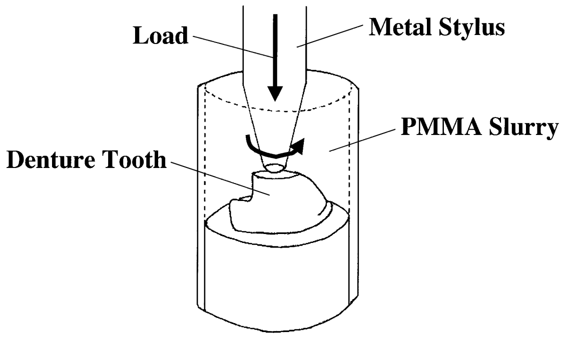

Figure 1. Schematic illustration for localized wear test. A hemispherical stainless steel stylus was loaded on the specimen surrounded by PMMA/water slurry with 75 N and 1.2 Hz for 100,000 cycles.

were then subjected to a 3-body localized wear test (Fig 1).[33–35] A cusp-simulated metal stylus with a stainless steel ball (1/8 inch diameter) on the tip was used in the presence of an artificial food bolus. In this testing, the food bolus consisted of a mixture of equal weight unplasticized PMMA powders (HG-5, Dentsply) and tap water. The stylus was vertically loaded onto the specimen surface and rotated 15 degrees; after counter-rotating, it was moved upward vertically to its original position. The stylus was loaded with 75 N and 1.2 Hz for 100,000 cycles. After the wear test, the specimens were removed from the apparatus, and the surfaces were cleaned with tap water by toothbrushing.

Wear depth was determined by a profilometer (Surfanalyzer 4000, Federal Corp, Providence, RI). Two profilometric tracings at each 90-degree angle were generated across the deepest part of the wear facet for each specimen. Mean wear depths were calculated by averaging two readings on each specimen. Ten specimens were evaluated for each material, and mean wear values were calculated by averaging all results on each material. Worn surface areas were obtained by tracing the profilometric tracings and were calculated by a computerized system (Canvas 3.0, Deneba System, Inc., Miami, FL). The values of worn surface areas were calculated in square millimeters by averaging with the same method used for the wear depth.

For surface hardness evaluation, the buccal surface of the cusp was also ground flat within the enamel layer with a 1000-grit SiC paper and polished with 3 μm of wet alumina. The Knoop micro-hardness tester (Wilson Tuskon Hardness Tester, Instron/Wilson Instruments, New York, NY) was used to determine the surface hardness of specimens. A diamond indenter was pressed into the specimens under a load of 25 g for 30 seconds. The areas of indentation were then measured using a ruler under microscope. Knoop hardness number (KHN) was calculated as the load divided by the area of indentation. The measurements were made at 5 points for each specimen. Five specimens were evaluated for each material, and mean wear values were calculated by averaging all results on each material.

The data for Knoop hardness, wear depth, and worn surface areas were individually analyzed by 1-way ANOVA, and the differences among the materials were determined by Scheffé's F-test ($p < 0.05$).

For surface evaluation, the worn specimens were gold-platinum coated by an ion-sputter (Hummer Sputter Coaters, Anatech, Alexandria, KY), and observed by scanning electron microscopy (SEM, ISI-100B, International Scientific Instruments AKA/HI, Japan).

Results

The mean surface hardness, wear depths, and worn surface areas for the denture teeth tested in this study are presented in Table 2. The results of Knoop hardness tests (KHN) of micro-filled composite teeth were 28.2 (Duradent), 28.7 (Orthosit and Surpass), and 29.8 (Endura); those of cross-linked teeth were 18.9 (Integral), 19.3 (Premium), 20.1 (Genios-P), 21.0 (Postaris), 21.3 (Creapearl), and 21.6 (Vitapan Physiodens). The hardness of the nano-composite was 22.7, and the hardness of the acrylic control was 18.6. The results indicated that all micro-filled composite teeth were significantly harder than other teeth ($p < 0.0001$). There were no significant differences among micro-filled composite teeth Orthosit, Duradent, and Surpass ($p = 0.9797{\sim}0.999$). Endura was significantly harder than the other micro-filled composite teeth ($p = 0.001{\sim}0.397$). There were no significant differences in hardness among the Premium and Integral cross-linked teeth and acrylic denture teeth ($p = 0.7428{\sim}0.9999$). The surface hardness of the nano-composite tooth, Veracia, was not significantly different from that of Physiodens ($p = 0.834$).

The results of wear depth showed that all of the tested denture teeth exhibited less wear compared to the acrylic control (162.5 μm). The value of the nano-composite teeth was 90.5 μm; those of the micro-filled composite teeth were 69.8 μm (Surpass), 70.0 μm (Duradent), 71.5 μm (Endura), and 93.0 μm (Orthosit); and those of cross-linked acrylic teeth were 80.8 μm (Portaris), 82.8 μm (Genios-P), 88.8 μm (Creapearl), 93.8 μm (Vitapan Physiodens), 99.3 μm (Premium),

Table 2. Wear Depths and Worn Surface Areas of Denture Teeth

Denture Teeth	*Knoop Hardness*	*Wear Depth (μm)*	*Surface Area (mm²)*
Veracia	22.7 ± 0.4 a	90.5 ± 10.2 a, b	5.1 ± 0.3 a, b
Endura	29.8 ± 0.8 b	71.5 ± 6.8 a, c	3.1 ± 0.2 c, d
SR-Orthosit	28.7 ± 0.6 c	93.0 ± 16.4 a, d	3.6 ± 1.1 a, c
Duradent	28.2 ± 1.0 c	70.0 ± 11.1 a	2.6 ± 0.4 c
Surpass	28.7 ± 0.5 c	69.8 ± 3.3 a	2.7 ± 0.2 c
SR-Postaris	21.0 ± 0.3 d, e	80.8 ± 14.4 a, e	4.1 ± 0.5 b, c
Genios-P	20.1 ± 0.3 e, f	82.8 ± 7.2 a, f	4.4 ± 0.2 a, b, d
Creapearl	21.3 ± 0.5 d	88.8 ± 8.5 a, g	4.4 ± 0.9 a, b, d
Vitapan Physiodens	21.6 ± 0.3 a, d	93.8 ± 7.0 b, c, d, e, f, g	5.0 ± 0.4 a, b
Premium	19.3 ± 0.4 f, h	99.3 ± 8.5 b, d, e, f, g	4.9 ± 0.6 a, b
Integral	18.9 ± 0.5 g, h	104.0 ± 10.7 b, d, e, f, g	5.7 ± 0.8 b
Biotone	18.6 ± 0.7 g, h	162.5 ± 22.0 h	10.1 ± 1.9 e

Data with the same letters are not statistically different within the same measuring item ($p \geq 0.05$).

and 104.0 μm (Integral). The wear value of the nano-composite tooth was not statistically different from the micro-filled composite teeth and the cross-linked denture teeth ($p = 0.1538 \sim 0.9999$). The acrylic control was significantly different from all tested denture teeth ($p \leq 0.0001$).

The results of worn surface areas exhibited similar tendencies. The value of the nano-composite tooth was 5.1 mm^2; those of the micro-filled composite teeth were 2.6 mm^2 (Duradent), 2.7 mm^2 (Surpass), 3.1 mm^2 (Endura), and 3.6 mm^2, (Orthosit); those of the cross-linked acrylic teeth were 4.1 mm^2 (Postaris), 4.4 mm^2 (Genios-P and Creapearl), 4.9 mm^2 (Premium), 5.0 mm^2 (Vitapan Physiodens), and 5.7 mm^2 (Integral). The value of the nano-composite tooth was not statistically different from that of micro-filled composite tooth, Orthosit ($p = 0.0937$) and those of cross-linked teeth ($p = 0.7023 \sim 0.9999$). The value of the acrylic control (10.1 mm^2) was twice that of the nano-composite tooth and significantly different from all tested denture teeth ($p < 0.0001$).

A series of SEM photographs of representative specimens after the wear test are presented in Figure 2. The worn surfaces of the micro-filled composite teeth (Fig 2A–D) were quite coarse compared to those of the other materials (Fig 2E–L). The worn surface of the nano-composite tooth was extremely smooth (Fig 2E) compared to those of the cross-linked acrylic teeth. One of the cross-linked acrylic teeth exhibited inclusion of spherical particles, presumably PMMA beads in the matrix (Fig 2I). The acrylic control specimen showed a smooth surface, but its worn area was quite extensive (Fig 2L).

Discussion

The major difference between acrylic and modified resin teeth is the microstructure. The acrylic has a linear polymer chain structure, while all modified resin teeth have cross-linked structure. An optimal amount of cross-linking improves the mechanical properties of acrylic resin. Besides adding cross-linking agents to MMA monomer, acrylic resin can be improved by IPN, which sinters the cross-linking agent into acrylic polymer chain.[11] In this study, the surface hardness of the micro-filled composite teeth was significantly higher than those of other denture teeth. The micro-filled composite teeth obtain greater surface hardness as the consequence of inclusion of inorganic filler particles in addition to the highly cross-linked polymer structure. They appear to be brittle when they are subjected to impact stresses, however.[27] From the results of the SEM evaluation, the worn surface of micro-filled composite teeth exhibited a rather brittle wear pattern with superficial chipping (Fig 2A–C). Bulk fracture or even chipping is of greater concern to clinicians as compared to superficial wear. Therefore, clinicians prefer durable denture teeth for better clinical services.

Nano-composite denture teeth possess unique characteristics in terms of homogeneity, as the material is not highly cross-linked but contains nano-sized inorganic fillers that are well dispersed without agglomeration in the matrix resin. The smooth worn surface of nano-composite teeth (Fig 2E) is probably attributable to a unique polymer structure consisting of well-dispersed nano-sized fillers; however, limited wear resistance is

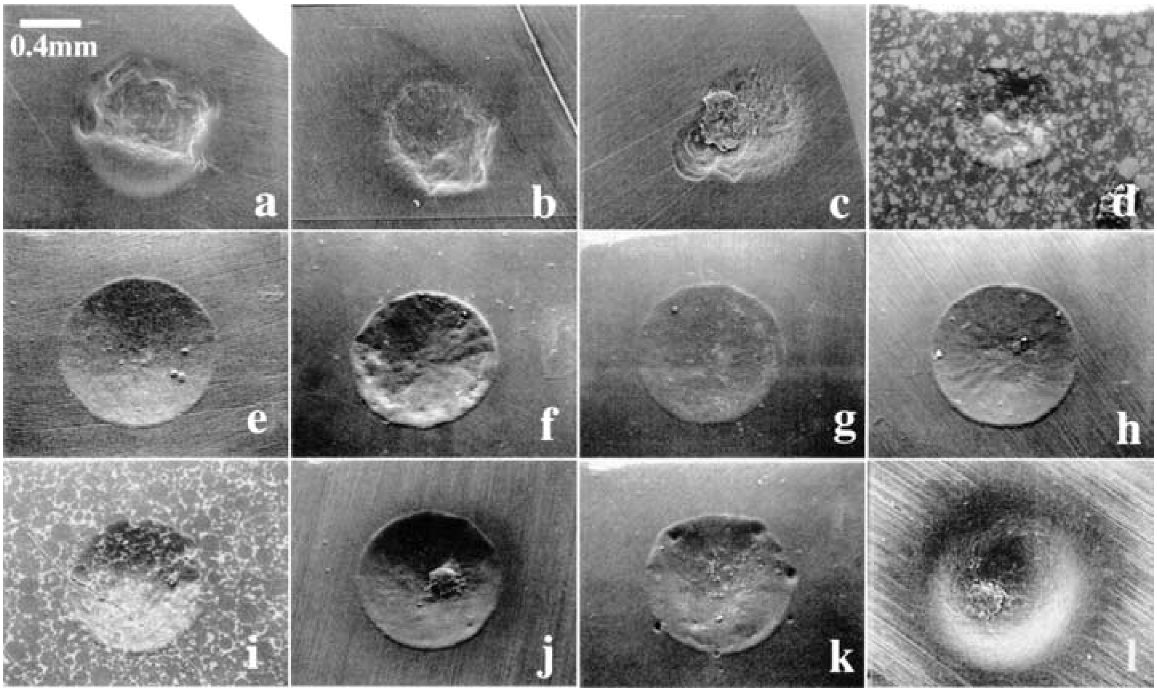

Figure 2. SEM photographs of worn surfaces (original magnification 50×). (*A*)–(*D*): Micro-filled composite teeth. [(*A*) SR-Orthosit. (*B*) Endura. (*C*) Duradent. (*D*) Surpass]. Note that the worn surfaces showed a brittle pattern. (*E*) Nano-composite tooth (Veracia). Note that the worn surface is very smooth. (*F*)–(*K*): Cross-linked teeth [(*F*) SR Postaris. (*G*) Genios-P. (*H*) Creapearl. (*I*) Vitapan Physiodens. (*J*) Premium 8. (*K*) Integral]. Note that the worn surfaces are smooth. Various sized spherical particles are seen in Physiodens specimen. (*L*) Acrylic control (Biotone) Note that the worn area is smooth but quite extended.

anticipated for this material, as it contains PMMA. Therefore, it was hypothesized that the wear resistance of this material would be superior to the conventional acrylic, but inferior to micro-filled composite. This hypothesis was partially confirmed as the results showed the wear resistance of nano-composite teeth to be superior to conventional acrylic. The anticipated inferiority to micro-filled composite was not seen, as there were no significant differences among nano-composite, micro-filled composite, and cross-linked acrylic denture teeth. Considering these results, nano-composite denture teeth may be promising selections for denture teeth, as this material has wear resistance equivalent to most micro-filled composite teeth and improved impact resistance and anti-staining properties.[29]

Conclusion

Based upon the limited aspect of in vitro study results, and for the range of representative materials tested, it appears that the nano-composite denture tooth used in this study possesses superior surface hardness and wear resistance compared to the conventional acrylic denture tooth, and its wear depth was not statistically different from those of the micro-filled composite and cross-linked acrylic denture teeth.

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