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Abrasive wear and surface roughness of contemporary dental composite resin

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The purpose of this study was to evaluate the abrasive wear and surface roughness of 20 currently available commercial dental composite resins, including nanofilled, supra-nanofilled, nanohybrid and microhybrid composite resins. The volume loss, maximum vertical loss, surface roughness (R_a) and surface morphology [Scanning electron microscopy (SEM)] were determined after wear. The inorganic filler content was determined by thermogravimetric analysis. The result showed that the volume loss and vertical loss varied among the materials. The coefficients of determination (R^2) of wear volume loss and filler content (wt%) was 0.283. SEM micrographs revealed nanofilled composites displayed a relatively uniform wear surfaces with nanoclusters protrusion, while the performance of nanohybrid composites varied. The abrasive wear resistance of contemporary dental composite resins is material-dependent and cannot be deduced from its category, filler loading and composite matrix; The abrasive wear resistance of some flowable composites is comparable to the universal/posterior composite resins.

Keywords: Dental composite, Surface roughness, Abrasive wear

INTRODUCTION

In the last decade, considerable improvements have been made in the properties of dental composite resins. For example, new silorane monomers[1)] and modified urethane (meth) acrylates such as TCD-urethane[2)] that decrease polymerization shrinkage have been developed; filler refinement[3,4)] using nanotechnology has been widely applied not only to reduce particle size, but also to increase filler volume to enhance polishing and wear resistance. Also special fillers that release fluoride have been introduced[5)]. In addition, bulk fill composite restorations have been made possible with the development of new photoinitiators[6)] (such as Tetric-N-Ceram Bulk Fill, Ivoclar Vivadent), and flowable composite resins that can be directly inserted through a cannula to easily line the base of cavities with complicated shapes have been introduced. Manufacturers have used this technology to produce a variety of products to fulfill diverse clinical needs. However, the efficiency and long-term performance of these contemporary composite resins have not yet been established.

Although wear of conventional composite resin is no longer considered a major clinical problem for small and medium sized cavities[7,8)], new products with new monomer and/or filler technology are still at risk for extensive wear, and their wear behavior cannot be deduced from similar products. Laboratory methods may help to assess the wear resistance before the material is evaluated in a clinical trial, which would take years to yield results. However, little laboratory research has been undertaken to broadly compare the wear resistance of contemporary direct dental composite resins.

The International Standard Organization (ISO) published a technical specification "Wear by two- and/or three body contact" describing eight laboratory methods for simulating wear *in vitro*, without giving clear recommendations about them[9)]. Heintze[10)] conducted a round robin test using five methods to examine 10 materials. The findings of this study revealed that different wear simulator measure different wear mechanisms, and the results from one wear method to another were hardly comparable. Therefore, there are still no generally accepted wear evaluation methods. The CW3-1 wear machine is a laboratory wear testing machine developed by Xu *et al.*[11)]. This machine can rapidly evaluate the abrasive wear resistance of a composite resin (30 to 40 min for each specimen), with the mean coefficient of variation no larger than 5% in general. Most other wear machines produce a mean coefficient of variation in material loss greater than 20%, with some reported values as high as 70%[10,12)]. Lower coefficients of variation indicate a lower relative variability, which in turn may indicate a more reliable machine and a greater discriminating power between different materials.

The purpose of this study was to broadly investigate and compare the abrasive wear resistance and surface roughness following simulated wear of 20 contemporary direct composite resins using the CW3-1 wear machine. The tested composite resins include new matrix composite resins (Siloranes, TCD-urethane), conventional matrix composite resins (Bis-GMA, UDMA, *etc.*) in various categories (nanofilled, supra-nanofilled, nanohybrid and microhybrid) for different

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applications (posterior/packable, universal and flowable composites). The null hypotheses were that there would be no difference in abrasive wear resistance and surface roughness 1) between the resins with new matrix (Siloranes, TCD-urethane) and conventional matrix (Bis-GMA, UDMA) 2) among various categories (nanofilled, supra-nanofilled, nanohybrid and microhybrid) and indications for application (posterior/packable, universal and flowable composites) and 3) between flowable composites and universal/posterior composite resins.

MATERIAL AND METHODS

Detailed information about the materials tested is shown in Table 1.

Specimen preparation

Five cylindrical specimens (diameter: 10 mm, thickness: 6 mm) of each material were prepared in a standard split stainless steel mold. The composite resins were filled into the mold layer by layer. Each layer (thickness approximately 2 mm) was light cured separately according to the manufacturer's instructions with a polymerization unit (Elipar™2500, output: 550 mW/cm^2, 3M ESPE, Paul, USA). Finally, the cured specimens were pushed out of the mold and stored in distilled water at 37°C for 24 h prior to testing.

Abrasive wear

The abrasive wear of the materials was evaluated in the CW3-1 wear machine (Peking University, Beijing, China), which has been described in detail in previous studies[11,13]. The CW3-1 wear machine was equipped with an antagonist (6.5 mm thick rubber plate, diameter: 15 cm, Shore hardness 67) and an abrasive slurry of fluorite (fluorspar) powder mixed with distilled water. The specimen was fixed on the specimen clip and placed on the top of vertical axle. The grinding pool was filled with a mixture of 100 g fluorite powder (Mohs hardness 4, particle size 110–120 grit) and 25 g distilled water. During one wear cycle the specimen will freely fall from a distance of 4.5 mm on the rubber plate. Thereby the specimen will undergo compressive and impulsive forces. There is a layer of abrasive slurry between specimen and rubber plate, and then the rubber plate will rotate and abrade the specimen. The sliding distance is approximately 15 mm. After that, the specimen is lifted up again and a new cycle is initiated. Each cycle the specimen will rotate 90 degree, in order to equalizing abrasion. The specimen was first subjected to 100 cycles of preliminary wear under a 5 kgf load in order to remove the polymer-rich layer. Then 800 cycles of final wear were conducted with a total load of 17 kgf. 800 cycles will need approximately 35 min. Weight loss was determined by comparing the weight of the specimen before and after the 800 wear cycles, and the density was measured using a density meter (DT100, Beijing Optical Instrument Factory, Beijing, China). The volume loss was calculated according to weight loss and density of each specimen. The vertical loss was determined by means of a dial indicator (ID-C112AM, Mitutoyo, Kawasaki, Japan) with a 2-dimensional stepping apparatus before and after the 800 cycles of wear. Thirteen points on the wear surface were measured. The distribution of these points is shown in Fig. 1. The centre-point was considered as the fiducial mark. The maximum vertical loss of these 13 points represents the surface height of the wear surface.

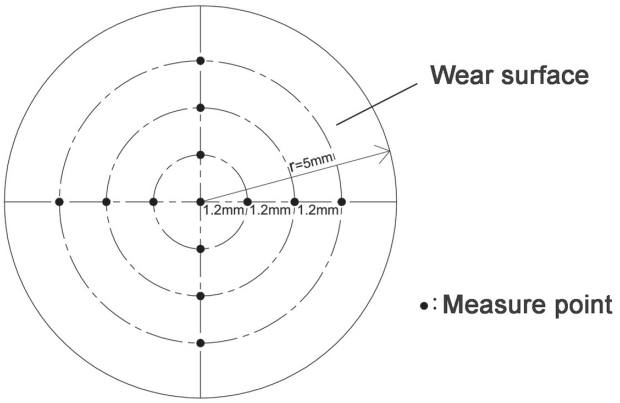

Fig. 1 The measurement points on the specimen wear surface.

Measurement of surface roughness after wear testing

After simulated three-body wear, the surface roughness (R_a) of three specimens of each material was measured by means of a contact stylus profilometer (SJ-400, Mitutoyo, Kawasaki, Japan) with a diamond stylus (tip radius: 2 μm, load: 0.75 mN; tracing length: 2.5 mm; stylus speed: 0.5 mm/s, cut-off length: 0.8 mm). Three measurements were performed for each worn specimen. The roughness parameter for each material was evaluated as the arithmetic mean over the 15 measurements.

Measurement of filler content

The inorganic filler weight was determined using thermogravimetric analysis, which eliminates the organic component of the composite by heating it at a constant temperature. A zirconia pan containing one of the tested wear specimens was placed in the Muffle furnace (KSY-4, Beijing Electric Furnace Factory, Beijing, China), and the temperature of furnace was raised from room temperature to 600ºC at the rate of 10ºC/min, and maintained at that temperature for 4 h, followed by air cooling to room temperature. The specimen was weighed with a balance (0.01 mg, XS105, Mettler Toledo, Columbus, USA) before and after burning, and the inorganic filler content was determined by comparing the two weights. Three samples were measured for each kind of composite resins.

Scanning electron microscopy (SEM) evaluation

One specimen of each material was sputter coated with gold using a JFC-1100 sputtering device (JEOL,

Table 1 Materials used in this study

Material name	Code	Filler content (wt%/vol%)	Shade	Type	Matrix resin	Filler	Manufacturer
Filtek™P60	P60	–/61	C2	Microhybrid	Bis-GMA,UDMA, Bis-EMA	Zirconia/silica (0.01–3.5 μm)	3M ESPE
Filtek™P90	P90	–/55	A3	Microhybrid	Silorane resin	Quartz, yttrium fluoride avg.0.47 μm	3M ESPE
Clearfil Majesty Esthetic	CM	78/66	A2	Microhybrid	Aromatic dimethacrylate, Bis-GMA	Barium glass filler, prepolymer	Kuraray
Filtek bulk fill flowable	FBFF	64.5/42.5	U	Microhybrid	BisGMA, UDMA, Bis-EMA	Zirconia/silica (0.01–3.5 μm)	3M ESPE
Flow-It ALC Flowable	FAF	66/51	B1	Microhybrid	ethoxilated Bis-GMA	Barium-boro-fluoro-silicate-glass (avg.1 μm)	Pentron
Revolution formula 2	RF2	60/–	A3	Hybrid	Bis-GMA	Glass filler	Kerr
Filtek™Z350XT	Z350	78.5/63.3	W	Nanofilled	Bis-GMA, UDMA, TEGDMA, PEGDMA, Bis-EMA	Zirconia, zirconia cluster filler (4–11 nm), silica cluster (20 nm)	3M ESPE
Filtek Supreme XT	FS	65/55	A3	Nanofilled	Bis-GMA, Bis-EMA, UDMA, TEGDMA	Zirconia and silica particles (nano cluster 0.6–1.4 μm, zirconia/silica 5–75 nm)	3M ESPE
Filtek™Z250XT	Z250	81.8/67.8	B1	Nanohybrid	Bis-GMA, UDMA, Bis-EMA, PEGDMA, TEGDMA	20nm silica, zirconia/silica (0.1–10 μm)	3M ESPE
Tetric®N-Ceram	TC	80.5/–	A3.5	Nanohybrid	UDMA, Bis-GMA, Bis-EMA	Barium glass, ytterbium trifluoride, mixed oxide, silicon dioxide, prepolymers	Ivoclar Vivadent
Tetric®N-Ceram Bulk Fill(IVA)	TIA	78/54	IVB	Nanohybrid	Dimethacrylates	Barium glass, ytterbium trifluoride, mixed oxide (0.04–3 μm), prepolymers	Ivoclar Vivadent
Tetric®N-Ceram Bulk Fill(IVB)	TIB	78/54	IVA	Nanohybrid	Dimethacrylates	Barium glass, ytterbium trifluoride, mixed oxide (0.04–3 μm), prepolymers	Ivoclar Vivadent
VENUS®Diamond	VD	–/64	OB	Nanohybrid	TCD-DI-HEA, UDMA	Barium-aluminium-Fluoride (5 nm–20 μm)	Heraeus
Premisa™ Packable	PP	84/70	A4	Nanohybrid	bis-phenol-A-dimethacrylate, TEGDMA	PPF filler, Point 4 filler, 0.02 μm	Kerr
Clearfil majesty posterior	CMP	92/82	A2	Nanohybrid	Bis-GMA, Hydrophobic aromatic dimethacrylate, TEGDMA	Glass ceramic (avg.1.5 μm), alumina (avg.20 nm)	Kuraray
Ceram x mono	CXM	76/57	M2	Nanohybrid	Methacrylate modified polysiloxane, Dimethacrylate	Barium-aluminium-borosilicate glass (1.1–1.5 μm), Silicon dioxide nano filler	Dentsply
Spectrum TPH 3	ST3	/	B1	Nanohybrid	Bis-GMA, DEMA, TEGDMA	Barium boronsilicate, barium boronsilicatealuminium fluosilicate<1 μm, silica10–20 nm	Dentsply
Fulfil extra	FE	/	A3.5	Nanohybrid	Bis-GMA, Bis-EMA, TEGDMA	Bariumfluoroaluminiumboros ilicate<1.5 μm, silicon dioxide (0.04 μm)	Dentsply
Wave mv	WM	65/–	A3	Nanohybrid	Multifunctional methacrylic ester	Inorganic filler	SDI
Estelite α	EL	82/71	A3	Supra-nano	Bis-GMA, Triethylene glycol Dimethacrylate	Silica zirconia spherical filler and composite filler 0.2 μm	Tokuyama

UDMA: urethane dimethacrylate, Bis-EMA: Bisphenol A polyetheylene glycol diether dimethacrylate, Bis-GMA: 2,2-bis[4(2-hydroxy-3-methacryloyloxy- propyloxy)- phenyl] propane; TEGDMA: Triethylene glycol dimethacrylate. PEGDMA: Poly(ethylene glycol) dimethacrylate, DEMA: 2-(Dimethylamino)ethyl methacrylate.

Tokyo, Japan) and examined by SEM (JSM-6390, JEOL) using secondary emission electron imaging at 2000-fold magnification.

Statistical analysis

Mean volume loss, maximum vertical loss and surface roughness of each material was analyzed by one-way ANOVA and Tukey's HSD test (α=0.05). The correlation of volume loss and filler weight content/volume content was tested by linear regression analysis. For all statistical evaluations, statistical software (SPSS 15.0 for Windows, SPSS Inc., Chicago, USA) was used.

RESULTS

Abrasive wear

The mean volume loss and maximum vertical loss with standard deviations after 800 wear cycles of all tested materials are presented in Table 2.

The nanohybrid composite resin Z250 showed the lowest wear loss, while the flowable composite resin RF2 exhibited the greatest wear loss. The posterior composite resin specially designed for stress-bearing areas did not display higher wear resistance than the universal composite resin. The new matrix composite VD (modified urethane hydroxyethylacrylate TCD-DI-HEA) exhibited superior abrasive wear resistance to all other tested composites except for Z250, while P90 recorded moderate abrasive wear resistance. Some of the flowable composites exhibited comparable abrasive wear resistance to the universal composites or posterior composites. For example, there was no significant difference in abrasive wear resistance between nanofilled composite FS and PP, TC, P90 and CM; and there was no significant difference in abrasive wear resistance between FBFF and P90, CM and TIA.

Surface roughness

The mean values and standard deviations of surface roughness of the tested materials are summarized

Table 2 Mean volume loss, maximum vertical loss, surface roughness and inorganic filler content of tested materials (means and standard deviation)

Materials	Volume loss (mm^3) N=5	Vertical loss (μm) N=5	Surface roughness (μm) N=15	Inorganic filler content (wt%) N=3
P60	35.39 (1.63) ^{bc}	519.0 (27.86) ^{ab}	0.54 (0.06) ^{ab}	78.51 (0.33)
P90	59.13 (4.48) ^{ef}	817.2 (93.59) ^{c}	0.63 (0.08) ^{abcdef}	78.06 (0.77)
FBFF	62.44 (2.89) ^{efg}	943.0 (67.62) ^{cde}	0.63 (0.06) ^{abcdef}	61.33 (0.69)
FAF	73.22 (1.54) ^{hi}	1071.3(61.5) ^{e}	0.62 (0.04) ^{abcde}	65.13 (1.46)
RF2	115.95 (5.93) ^{j}	1593.6 (143.45) ^{f}	0.76 (0.11) ^{def}	52.74 (2.26)
Z250	23.83 (2.38) ^{a}	260.8 (18.82) ^{a}	0.79 (0.27) ^{ef}	77.46 (1.72)
CM	62.77 (8.02) ^{efg}	864.6 (116.62) ^{cd}	0.79 (0.15) ^{f}	58.09 (0.23)
CMP	32.26 (0.34) ^{ab}	490.2 (13.08) ^{ab}	0.57 (0.03) ^{abc}	87.83 (1.13)
VD	38.79 (2.29) ^{bc}	563.0 (86.7) ^{b}	0.67 (0.23) ^{abcdef}	78.08 (0.34)
Z350	40.23 (2.42) ^{bc}	534.6 (49.99) ^{ab}	0.67 (0.07) ^{bcdef}	72.63 (0.33)
PP	44.47 (6.14) ^{cd}	614.0 (100.67) ^{b}	0.62 (0.11) ^{abcd}	77.86 (0.39)
FS	53.9 (2.64) ^{de}	603.0 (72.58) ^{b}	0.49 (0.07) ^{a}	61.82 (1.86)
TC	57.34 (8.05) ^{e}	818.8 (66.17) ^{c}	0.68 (0.14) ^{bcdef}	73.93 (0.29)
TIA	67.95 (3.49) ^{fgh}	978.6 (58.63) ^{cde}	0.74 (0.13) ^{cdef}	73.08 (0.35)
TIB	70.25 (2.04) ^{ghi}	979.0 (45.99) ^{cde}	0.66 (0.09) ^{abcdef}	72.74 (0.3)
ST3	71.42 (3.56) ^{ghi}	1001.6 (47.55) ^{de}	0.61 (0.07) ^{abcd}	74.53 (0.15)
FE	79.14 (2.49) ^{i}	1115.8 (42.16) ^{e}	0.69 (0.12) ^{bcdef}	75.37 (1.71)
CXM	109.65 (3.31) ^{j}	1474 (61.43) ^{f}	0.66 (0.07) ^{abcdef}	77.21 (2.03)
WM	116.07 (5.48) ^{j}	1537.8 (79.74) ^{f}	0.64 (0.08) ^{abcdef}	61.25 (1.32)
EL	40.68 (1.96) ^{bc}	619.0 (48.15) ^{b}	0.80 (0.18) ^{f}	69.64 (3.69)

Identical letters indicate no significant differences (p>0.05)

in Table 2. The surface roughness varied among the materials tested. Roughness was apparently material-dependent. The nanofilled flowable composite FS exhibited the lowest roughness, while the nanohybrid composite Z250 and microhybrid composite CM showed the highest roughness.

Filler content measurement

The inorganic filler content varied among the tested materials (Table 2). There were no obvious differences from the manufacturer's stated content except CM. The difference of CM is related to the pre-polymerized fillers that were burned out during heating by the thermogravimetric method. The material with the highest inorganic filler content was the posterior composite resin CMP with 87.83 wt%, while the manufacturer claimed the filler content was 92 wt% and 82 vol%. The lowest filler content was the flowable composite RF2 with 52.74 wt%.

SEM evaluation

SEM representative photographs of the tested materials after 800 wear cycles are presented in Fig. 2. Nanofilled composites (Fig. 2a: FS) displayed a relatively uniform wear surface, however, filler protrusions and plucked-out of nanocluster were still identified in the picture (see arrow). Microhybrid and hybrid composites demonstrated more surface irregularities in form of filler dislodgement and protrusions (Fig. 2b and c: FAF and RF2). The performance of nanohybrid composites varied, with some materials displaying a smooth surface (Fig. 2d: TIB), and some materials revealing larger filler particles protruding from the surrounding surface, apparently dislodged from the matrix (Fig. 2 e and f: ST3 and WM).

Regression analysis

Figure 3 shows the relationships between wear volume loss and inorganic filler content. There is a low correlation between filler loading and abrasive wear resistance. The determination coefficients (R^2) of wear volume loss and inorganic filler content (wt%) was 0.283.

DISCUSSION

Wear resistance is an important factor to be considered when selecting composite resin materials for clinical use.

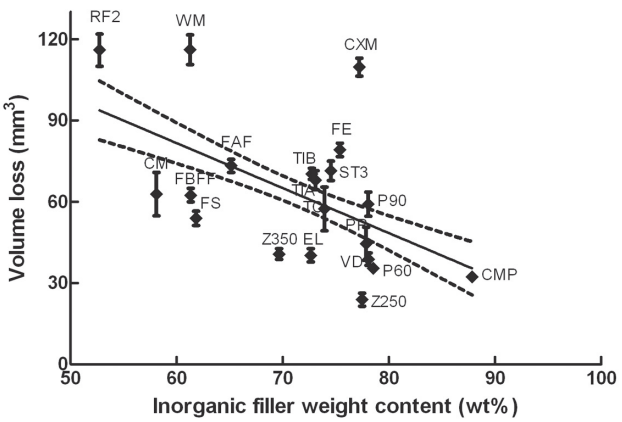

Fig. 3 Relationship between volume loss and inorganic filler content (wt%). Coefficient of determination: $R^2 = 0.283$. The dotted line is the 95% confidence interval.
The volume loss of each material is showed in mean and standard deviation.

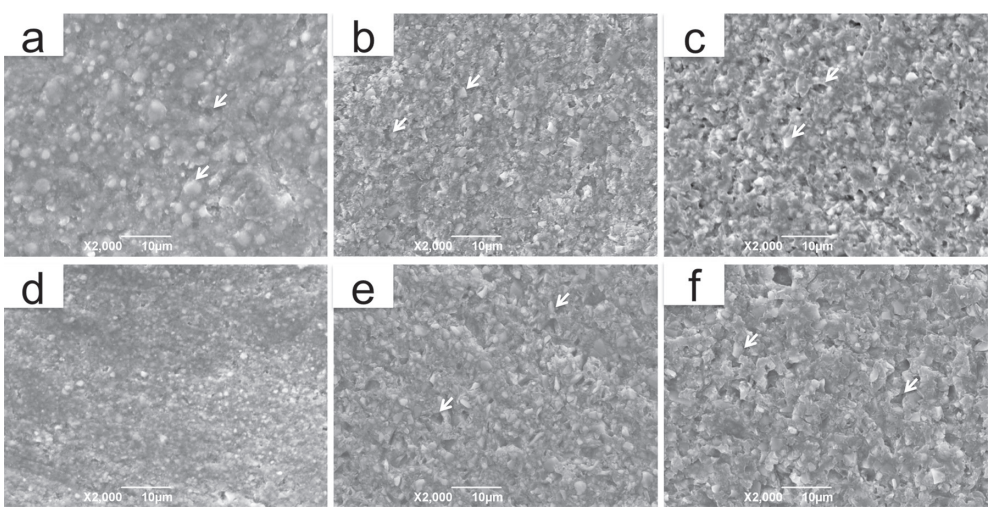

Fig. 2 Representative SEM photographs of tested materials after 800 wear cycles (magnification 2000×).
a: nanofilled composite FS; b: microhybrid composite FAF; c: hybrid composite RF2; d: nanohybrid composite TIB; e: nanohybrid composite ST3; f: nanohybrid composite WM.

Composites with lower wear resistance result in loss of anatomical form, especially in large restorations[7,14]. Therefore, it is essential to evaluate wear resistance when developing new composites, especially when the composite resin incorporates a new matrix, new filler technology, or when a conventional material is used for a broader application, such as when flowable composite is used for restoration of posterior teeth. This study compared abrasive wear resistance and surface roughness of direct composite resins introduced over the last decade.

In the past 30 years, numerous wear-testing devices have been developed to mimic their clinical wear resistance. However, none of these devices has been successful in accurately predicting the clinical performance of commercial restoratives. The complex wear process *in vivo* can hardly be simulated *in vitro*[15]. The wear testing devices used to date vary in antagonist, contact module, loading, abrasive type and size[9,16]. The unique characteristic of CW3-1 is a rubber plate as antagonist and fluorite slurry (Mohs hardness number 4) as abrasive. The abrasive used in this study is harder than the calcium carbonate (Mohs hardness number 3), PMMA beads and/or poppy seeds that were used in other set-ups[17-19]. In addition, the reported vertical loss of substance (range from 260 μm to 1593 μm) is much higher than the clinical wear loss. There is hardly any correlation between the duration of the wear cycles with the times under clinical function.

The most significant changes in commercial composites in recent years were modifications of the filler system[20]. The size of filler particles incorporated into the resin matrix of commercial composites has continuously decreased, resulting in nanohybrid and nanofilled materials with improved material properties. Some studies reported that nanocomposites (nanohybrid or nanofilled composites) have superior polishability[3] and lower abrasion[21-23] compared with conventional microhybrid or hybrid composite resins. However, not all the nanohybrid or nanofilled composite resins tested in the present study showed superior abrasive wear resistance to conventional microhybrid or hybrid composite resins. For example, the supra-nanofilled composite resin EL and the microhybrid P60 showed excellent abrasive wear resistance, similar to the nanofilled Z350 and nanohybrid composites Z250 and CMP. This is consistent with clinical studies, which is the gold standard for evaluating the properties of a new material. Palaniappan *et al.*[24,25] measured quantitatively the wear of a nanofilled composite (Filtek Supreme) and a microhybrid composite (Z100). There was no significant difference in terms of wear loss between the two materials. The vertical loss of substance of the nanofilled and the microhybrid composite were 75±27 μm and 64±26 μm after three years of clinical service, and 84±21 μm and 77±25 μm after five years of clinical service, respectively. In other two-year[26] and four-year[27] comparative clinical evaluations of a nanofilled composite and a fine hybrid resin composite, both types of composite resin showed similar clinical performance.

The posterior/packable composites were developed to limit wear and fracture of the restoration, reduce polymerization shrinkage and improve handling characteristics. However, the abrasive wear resistance of the posterior/packable composites varied among the materials tested, and not all the posterior/packable composites showed superior abrasive wear resistance to the universal or flowable composites in the present study. For example, the packable composite PP and the bulk filled composite TIA showed only moderate abrasive wear resistance. In another two-body wear evaluation, the packable composite resins did not exhibit superior wear compared to conventional hybrid composites[28]. These results are further confirmed by clinical research demonstrating that packable composites showed no significant difference compared to conventional hybrid composites for wear resistance[29-31].

Due to their limited filler loading, flowable composites typically display inferior physical properties and wear resistance than hybrid composites. However, according to the results of the present study, some of the flowable composites tested showed excellent abrasive wear resistance, such as FS and FBFF. A possible explanation of the excellent abrasive wear resistance for flowable composites is their higher toughness compared with conventional composite. Peutzfeldt[32] have previously reported that there is linear relationship between the modulus of resilience and clinical wear. According to the present study, the abrasive wear resistance of flowable composite appeared to be strongly material-dependent. This result is consistent with the reports of Bayne[33] and Sumino[34].

Another improvement of modern composite resins is related to the introduction of the low shrinkage matrices. One of these matrices is based on an innovative monomer system using silorane obtained from the reaction of oxirane and siloxane molecules (Filtek P90, 3M ESPE)[1]. The novel resin combines the two key advantages of the individual components: low polymerization shrinkage due to the ring-opening oxirane monomer and increased hydrophobicity due to the presence of the siloxane species. Another new matrix is composed of modified urethane (meth) acrylates TCD (Venus Diamond, Heraeus Kulzer)[2]. So far, little research has been conducted about the effect of the new resin matrix on wear resistance[35,36]. In the present study, P90 has a similar filler volume as FS, while VD has a similar filler volume as Z350; however, the wear loss of both composites including the new matrix monomer was not significantly different compared to conventional matrix composites with similar filler volume content. The lesser degree of subsurface polymerization of the silorane-based composites compared to the methacrylate-based composites may be responsible for the inferior wear resistance[37,38]. Schmidt and Ilie[39] investigated the flexural strength and modulus of the TCD-urethane based material, finding that the TCD-urethane based material performs similar as conventional Bis-GMA based composites. The effectiveness of these materials needs to be further investigated in long-term clinical

studies.

In terms of filler content, some *in vitro* wear studies have revealed that increased filler loading may enhance the wear resistance of dental composites[38,40,41]. However, the determination coefficient (R^2) for the relationships between volume loss and filler content (wt%) was 0.283 in the present study. Modern composite resins vary in filler size, morphology, volume, distribution, chemical composition, matrix and photopolymerization initiator, creating a large variation in composite properties. According to the present study, the abrasive wear resistance of composite resins is material-dependent, and it is difficult to determine the wear resistance of composite resins according to their category and filler loading.

Surface roughness after simulated wear was mainly associated with filler size and distribution of composite resins. Nanofilled composites contain both discrete nanomer and nanocluster particles, whereas microhybrid composites contain blends of microscopic and submicroscopic sized particles. Mitra[3] *et al.* reported that nanofilled composites wear by breaking out of individual primary particles or parts of the clusters rather than by debonding of larger particles, which induces a relatively smooth wear surface. For microhybrid composites, the relatively soft resin matrix is worn first, leaving the inorganic fillers protruding from the surface or plucked out. SEM observation of our study revealed that the nanofilled composites exhibited a relatively uniform wear surface. However, protrusion and pluck-out of nanocluster particles could be seen for the nanofilled composites, while Yap[42] and Suzuki[19] reported similar phenomena. Nanohybrid composites are hybrid resin composites containing finely milled glass fillers and discrete nanoparticles or nanofiller in prepolymerized filler form[43]. The performance of nanohybrid composites is material-dependent, which may be attributed to the fact that some composites with nanofillers added to conventionally filled hybrid type composites have been classified as nanohybrid composite resins.

The quantitative roughness data measured did not correspond to the qualitative investigation by SEM. Moreover, the roughness data (R_a) of the tested materials ranged from 0.49 to 0.79, which was considerably higher than those reported elsewhere[43-45]. This may be attributed to our accelerated wear testing method. The rapid wear of the specimens led to many buffing marks on the wear surfaces that may have interfered with the roughness measurement by the profilometer. Meanwhile, the buffing marks on the wear surfaces means that the potentially wear mechanism of CW3-1 wear machine is more likely abrasive or polishing. Moreover, a few filler of some composites showed squashing on the wear surface in the present study (see Fig. 2e). This phenomenon of filler squashing rarely occurs on clinic. The design and load used in this tested machine need to be improved in further study.

Within the limitations of this study, the following conclusions were drawn: 1) The abrasive wear resistance of contemporary dental composite resins is material-dependent and cannot be deduced from their category or filler loading; 2) The new silorane based and TCD-urethane based monomers did not exhibit superior abrasive wear resistance than conventional methacrylate matrix composites; 3) The abrasive wear resistance of some flowable composites is comparable to the universal/posterior composite resins.

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REFERENCES

1) Weinmann W, Thalacker C, Guggenberger R. Siloranes in dental composites. Dent Mater 2005; 21: 68-74.
2) Utterodt A, Ruppert K, Schaub M, Diefenbach C, Reischl K, Hohmann A, Eck M, Schönhof N. Dental composites with Tricyclo [5.2.02.6] decane derivatives. European Patent EP1935393, assignee: Heraeus Kulzer GmbH, 2008.
3) Mitra SB, Wu D, Holmes BN. An application of nanotechnology in advanced dental materials. J Am Dent Assoc 2003; 134: 1382-1390.
4) Ure D, Harris J. Nanotechnology in dentistry: reduction to practice. Dent Update 2003; 30: 10-15.
5) Weir MD, Moreau JL, Levine ED, Strassler HE, Chow LC, Xu HH. Nanocomposite containing CaF (2) nanoparticles: thermal cycling, wear and long-term water-aging. Dent Mater 2012; 28: 642-652.
6) Roggendorf MJ, Krämer N, Appelt A, Naumann M, Frankenberger R. Marginal quality of flowable 4-mm base vs. conventionally layered resin composite. J Dent 2011; 39: 643-647.
7) Ferracane JL. Is the wear of dental composites still a clinical concern? Is there still a need for in vitro wear simulating devices? Dent Mater 2006; 22: 689-692.
8) Ferracane JL. Resin composite state of the art. Dent Mater 2011; 27: 29-38.
9) ISO. Dental materials-guidance on testing of wear. Part 2. Wear by two- and/or three-body contact. Technical Specification No 14569-2, 2001.
10) Heintze SD. How to qualify and validate wear simulation devices and methods. Dent Mater 2006; 22: 712-734.
11) Xu HC, Vingerling PA, Liu WY, Zheng G, Wang T. Wear of composite resin in vitro: a testing machine with rubber plate. Preliminary results. J Oral Rehabil 1990; 17: 107-115.
12) Heintze SD, Zappini G, Rousson V. Wear of ten dental restorative materials in five wear simulators—Results of a round robin test. Dent Mater 2005; 21: 304-317.
13) Han JM, Lin H, Zheng G, Shinya A, Gomi H, Shinya A, Lin J. Effect of nanofiller on wear resistance and surface roughness of resin composites. Chin J Dent Res 2012; 15: 41-47.
14) Ferracane JL, Mitchem JC, Condon JR, Todd R. Wear and marginal breakdown of composites with various degree of cure. J Dent Res 1997; 76: 1508-1516.
15) Mair LH. Wear in dentistry—current terminology. J Dent 1992; 20: 140-144.
16) ISO. Dental materials - Guidance on testing of wear resistance - Part 1: Wear by tooth brushing. Technical Specification No 14569-1, 2007.

17) Leinfelder KF, Suzuki S. In vitro wear device for determining posterior composite wear. J Am Dent Assoc 1999; 130: 1347-1353.
18) DeGee AJ, Pallav P, Davidson CL. Effect of abrasion medium on wear of stress-bearing composites and amalgam in vitro. J Dent Res 1986; 65: 654-658.
19) Suzuki T, Kyoizumi H, Finger WJ, Kanehira M, Endo T, Utterodt A, Hisamitsu H, Komatsu M. Resistance of nanofill and nanohybrid resin composites to toothbrush abrasion with calcium carbonate slurry. Dent Mater J 2009; 28: 708-716.
20) Ferracane JL. Current trends in dental composites. Crit Rev Oral Biol Med 1995; 6: 302-318
21) Turssi CP, Saad JR, Duarte SL, Rodrigues AL. Composite surfaces after finishing and polishing techniques. Am J Dent 2000; 13: 136-138.
22) Turssi CP, Ferracane JL, Serra MC. Abrasive wear of resin composites as related to finishing and polishing procedures. Dent Mater 2005; 21: 641-648.
23) Yap AU, Tan CH, Chung SM. Wear behavior of new composite restoratives. Oper Dent 2004; 29: 269-274.
24) Palaniappan S, Bharadwaj D, Mattar DL, Peumans M, Van Meerbeek B, Lambrechts P. Three-year randomized clinical trial to evaluate the clinical performance and wear of a nanocomposite versus a hybrid composite. Dent Mater 2009; 25: 1302-1314.
25) Palaniappan S, Bharadwaj D, Mattar DL, Peumans M, Van Meerbeek B, Lambrechts P. Nanofilled and microhybrid composite restorations: Five-year clinical wear performances. Dent Mater 2011; 27: 692-700.
26) Ernst CP, Brandenbusch M, Meyer G, Canbek K, Gottschalk F, Willershausen B. Two-year clinical performance of a nanofiller vs a fine-particle hybrid resin composite. Clin Oral Invest 2006; 10: 119-125.
27) Krämer N, Reinelt C, Richter G, Petschelt A, Frankenberger R. Nanohybrid vs. fine hybrid composite in Class II cavities: Clinical results and margin analysis after four years. Dent Mater 2009; 25: 750-759.
28) Turssi CP, Faraoni-Romano JJ, de Menezes M, Serra MC. Comparative study of the wear behavior of composites for posterior restorations. J Mater Sci Mater Med 2007; 18: 143-147.
29) Poon EC, Smales RJ, Yip KH. Clinical evaluation of packable and conventional hybrid posterior resin-based composites: results at 3.5 years. J Am Dent Assoc 2005; 136: 1533-1540.
30) Yip KH, Poon BK, Chu FC, Poon EC, Kong FY, Smales RJ. Clinical evaluation of packable and conventional hybrid resin-based composites for posterior restorations in permanent teeth: results at 12 months. J Am Dent Assoc 2003; 134: 1581-1589.
31) Shi L, Wang X, Zhao Q, Zhang Y, Zhang L, Ren Y, Chen Z. Evaluation of packable and conventional hybrid resin composites in Class I restorations: three-year results of a randomized, double-blind and controlled clinical trial. Oper Dent 2010; 35: 11-19.
32) Peutzfeldt A, Asmussen E. Modulus of resilience as predictor for clinical wear of restorative resins. Dent Mater 1992; 8: 146-148.
33) Bayne SC, Thompson JY, Swift EJ Jr, Stamatiades P, Wilkerson M. A characterization of first-generation flowable composites. J Am Dent Assoc 1998; 129: 567-577.
34) Sumino N, Tsubota K, Takamizawa T, Shiratsuchi K, Miyazaki M, Latta MA. Comparison of the wear and flexural characteristics of flowable resin composites for posterior lesions. Acta Odontol Scand 2013; 71: 820-827.
35) Koottathape N, Takahashi H, Iwasaki N, Kanehira M, Finger WJ. Two- and three-body wear of composite resins. Dent Mater 2012; 28: 1261-1270.
36) Koottathape N, Takahashi H, Iwasaki N, Kanehira M, Finger WJ. Quantitative wear and wear damage analysis of composite resins in vitro. J Mech Behav Biomed Mater 2014; 29: 508-516.
37) Guiraldo RD, Consani S, Consani RL, Berger SB, Mendes WB, Sinhoreti MA, Correr-Sobrinho L. Comparison of silorane and methacrylate-based composite resins on the curing light transmission. Braz Dent J 2010; 21: 538-542.
38) Condon JR, Ferracane JL. In vitro wear of composite with varied cure, filler level, and filler treatment. J Dent Res 1997; 76: 1405-1411.
39) Schmidt C, Ilie N. The mechanical stability of nano-hybrid composites with new methacrylate monomers for matrix compositions. Dent Mater 2012; 28: 152-159.
40) Torii Y, Itou K, Itota T, Hama K, Konishi N, Nagamine M, Inoue K. Influence of filler content and gap dimension on wear resistance of resin composite luting cements around a CAD/CAM ceramic inlay restoration. Dent Mater J 1999; 18: 453-461.
41) Lim BS, Ferracane JL, Condon JR, Adey JD. Effect of filler fraction and filler surface treatment on wear of microfilled composites. Dent Mater 2002; 18: 1-11.
42) Yap AU, Yap SH, Teo Ck, Ng JJ. Comparison of surface finish of new aesthetic restorative materials. Oper Dent 2004; 29: 100-104
43) Senawongse P, Pongprueksa P. Surface roughness of nanofill and nanohybrid resin composites after polishing and brushing. J Esthet Restor Dent 2007; 19: 265-275.
44) Jung M, Sehr K, Klimek J. Surface texture of four nanofilled and one hybrid composite after finishing. Oper Dent 2007; 32: 45-52.
45) Heintze SD, Forjanic M. Roughness of different dental materials before and after simulated toothbrushing in vitro. Oper Dent 2005; 30: 617-626.