Clin Oral Invest (2012) 16:181–190
DOI 10.1007/s00784-010-0500-0

ORIGINAL ARTICLE

Nanohybrid and microfilled hybrid versus conventional hybrid composite restorations: 5-year clinical wear performance

Senthamaraiselvi Palaniappan · Liesbeth Elsen · Inge Lijnen · Marleen Peumans · Bart Van Meerbeek · Paul Lambrechts

Received: 23 December 2009 / Accepted: 27 December 2010 / Published online: 11 January 2011

Abstract The 5-year findings of a randomized clinical trial testing the null hypothesis that there are no differences between the clinical-wear performances of nano-, microfilled-, and conventional hybrids placed in class I and class II cavities are reported. Effects of subject-, operator-, and restoration-related variables on wear were assessed. Sixteen Tetric-C, 17 Tetric-EC, and 16 Gradia-DP restorations were placed in human molars and recalled at baseline, 6 months and at yearly intervals. The gypsum replicas at each recall were scanned (3D laser scanning), epoxy resin replicas were observed under scanning electron microscope and linear mixed models were used to study the influence of different variables on wear. The generalized vertical wear rate/month were (1.4 µm Tetric-C and Tetric-EC; 1.8 µm Gradia-DP) and volume wear rate/month were (0.017 mm^3 Tetric-EC; 0.018 mm^3 Gradia-DP, and 0.011 mm^3 Tetric-EC). Operator-cavity type interaction and surface area of restorations did significantly influence the volume wear rates ($p<0.05$). The three wear patterns: fatigue cracks at heavy occlusal contact area/OCA, pitting at light OCA, and scratches/striations along the food escape pathways were evident. The three hybrids differed significantly in volume wear due to material and operator variables. Clinical relevance: Clinically, operators and cavity type can affect restorations' wear magnitude but do not contribute to increased functional risk of fracture or harmful effect on pulp and periodontal biocompatibility.

Keywords Wear · Composite restorations · Nanocomposites · Microfilled hybrid · Clinical trial

S. Palaniappan · L. Elsen · I. Lijnen · M. Peumans · B. Van Meerbeek · P. Lambrechts (✉)
Leuven BIOMAT Research Cluster,
Department of Conservative Dentistry,
School of Dentistry, Oral Pathology and Maxillo-Facial Surgery,
Catholic University of Leuven,
Kapucijnenvoer 7,
3000 Leuven, Belgium
e-mail: Paul.Lambrechts@med.kuleuven.be

Introduction

An ideal dental composite has to replace the biological and functional properties of healthy tooth structures while matching the esthetic properties to those of natural teeth. Although the composites have undergone significant development since their advent, their relatively poor resistance to wear in stress-bearing occlusal contact areas is still a major source of concern [1]. Excessive wear or biotribocorrosion [2] has implications for the esthetics, function, and biocompatibility of teeth. Human enamel has been considered ideal as a reference material in in vivo studies and as a reference standard in in vitro studies to compare and evaluate the wear–tribology of restorative materials [3, 4]. Manufacturers of dental composites promote the novel nanocomposites with modifications in filler system and monomer system as having ideal wear-resistant characteristics for posterior use.

A 3-year trial using the nano-, microfilled-, and conventional hybrids has already been published [5]. The clinical performance and wear behavior of the three hybrids were investigated against the ADA acceptance guidelines [6] using USPHS criteria [7] and sophisticated 3D laser scanning [8]. Micromorphological wear was analyzed with scanning electron microscope (SEM). The initial 3-year findings demonstrated that the clinical performance of nano-, micro-, and conventional hybrids were satisfactory and not significantly different when they were placed in class I and class II cavities. At that stage, although the three hybrid composites showed enamel-like vertical wear with relatively smooth surface at light occlusal contact area (OCA) wear facets, they did demonstrate significantly higher volume loss in comparison to enamel. Few among the different variables influencing the clinical wear behavior, as described in the literature, are differences between materials in terms of resin chemistry and filler systems [9–11], skills of the clinician/operator [12], dental quadrant [13], and size of the restoration [14].

Solely focusing on the clinical wear performance, our present study tests the null hypothesis that after 5 years, there are no significant differences between the clinical wear performances of nano-, microfilled-, and conventional hybrids placed in class I and class II cavities. The influence of any material-, clinician-, and tooth-related variable on the clinical wear behavior of different composites was also assessed.

Materials and methods

In this 5 year longitudinal, prospective randomized controlled clinical trial, the nanohybrid (Tetric EvoCeram/Tetric-EC), microfilled hybrid (Gradia Direct Posterior/Gradia-DP), and the conventional hybrid (Tetric Ceram/Tetric-C) were compared. They are listed in Table 1.

Study population

Following the approval of the study protocol by the medical ethics committee, a group of 32 dental student volunteers were screened. After informed consent and complete information on the study set up and study goals, a brief clinical examination of subjects was performed for failed restorations or primary caries.

Sample size

A total of 49 teeth in 1 male and 14 female patients were selected, requiring normally three restorations per subject, but 4 patients received some extra restorations because of treatment need. The inclusion and exclusion criteria involved in patient selection have been described previously [5, 15].

Restoration placement

Two restorative dentists placed 49 restorations. The 49 teeth to be treated were structured in advance according to the type of restoration in two blocks (class I and class II). The filling materials, Tetric-EC or Gradia-DP or Tetric-C were randomly assigned to teeth in these two blocks with the use of random number-generating functions in Excel. This followed a percent distribution of class I versus class II as 76:24 for Tetric-EC, 81:19 for Gradia-DP, and 69:31 for Tetric-C. Table 2 summarizes the attributes of restorations and patients of this study.

A strict placement technique was followed. The dentists were blinded to the type of restorative composite. The restorations were placed under local anesthesia and rubber dam. Diamond instruments in a high-speed handpiece with water spray were used to make all cavity preparations. All enamel margins were beveled for maximum adhesive retention and optical blending using the Sonic-Sys (KaVo Company) torpedo and hemisphere diamond-coated bevel tips.

Appropriate enamel and dentin shades were selected using the Vita shade guide under ambient lighting condition. The teeth needing $CaOH_2$ basing, i.e., preparations closer than 0.5 mm to the pulp, were covered with a glass ionomer light-cured liner before bonding procedures. Enamel and dentin conditioning were performed with a self-etching adhesive system (AdheSe for Tetric-C and Tetric-EC restorations, UniFil Bond for Gradia-DP restorations) of each composite

Table 1 Description of materials used in this study

Material	Type	Polymer	Fillers	Filler size		Filler content (% by volume)
				Range	Mean	
Tetric-C	Conventional hybrid	Bis-GMA, UDMA, TEGDMA	Ba glass, Ba-Al fluorsilicate glass, ytterbium trifluoride, dispersed SiO_2, and spheroid mixed oxide	1–3 µm	1 µm	58
Tetric-EC	Nanohybrid	Dimethacrylate	Ba glass, ytterbium trifluoride, mixed oxide, prepolymers	[a]	0.6 µm	68
Gradia-DP	Microfilled hybrid	Urethane dimethacrylate comonomer matrix	Silica, pre-polymerised fillers, fluoro-alumino-silicate glass	[a]	0.85 µm	65

[a] data not available in the manufacturer's technical information sheet

Table 2 Distribution of attributes of restorations and patients

Attributes	Tetric-C		Tetric-EC		Gradia-DP	
	Baseline	5 years	Baseline	5 years	Baseline	5 years
Restoration characteristic						
Nr	16	15	17	17	16	16
Mandibular molar	11	10	8	8	13	13
Maxillary molar	5	5	9	9	3	3
Class I	11	11	13	13	14	14
Class II	5		4	4	2	2
Patient characteristic						
Male	1	1	1	1	1	1
Female	14	14	14	14	14	14
Mean age	23.4	28.4	23.4	28.4	23.4	28.4

resin manufacturer, according to their directions. The primer was applied for 30 s, excess solvent dispersed with a strong stream of air and the bonding agent was applied subsequently and light cured for 10 s (Astralis 10, Ivoclar Vivadent; 1200 mW/cm^2). Placement of resin composites followed the incremental technique (2-mm thick layer) and each increment was cured for 40 s with the light according to the manufacturer's instruction for use. The light tip was held approximately 1.0 mm away from the tooth surface during curing. The pulse program of Astralis 10 was used in this study. This program starts with a light intensity of 150 mW/cm^2, gradually increases to 600 mW/cm^2 within 10 s. Then the intensity switches back and forth between 600 mW/cm^2 and 1200 mW/cm^2 every 2 s. After 20 s, the Astralis 10 unit automatically switches off the pulse program. A sectional matrix system (3M ESPE) wedged firmly against the approximal sides of the teeth was used for all class II restorations. The restorations were finished and polished as described previously [5].

Clinical recall

At baseline, this means after 1 month of clinical service (in order to allow running-in wear for occlusal adaptation), and at subsequent recalls, every patient was insisted to brush his or her teeth immediately prior to start of the assessment. Subsequent to a brief soft tissue survey and recording of gingival conditions, intraoral radiographs were taken, and postoperative sensitivity, if present, was also evaluated with CO_2 snow (Fricar, Odontotest), and the sensitivity was scored as positive or negative. An alginate impression was made first and then a gypsum cast, from which acrylic posterior custom trays were fabricated. The same custom trays were used for impression procedures at each registration session. Each restoration was documented photographically (with and without articulation paper), and radiographs were taken to detect any incidence of secondary caries. Impressions of restoration were made at baseline. At each recall, two impressions per air-dried, cotton-roll isolated tooth were taken with polyvinyl siloxane impression material using individualized custom trays. One impression was poured with white stone gypsum GC Fujirock EP White (Dental stone type IV, GC Europe, Leuven, Belgium) for laser scanning and another impression in Araldite D, Ciba Geigy (Belgium) for morphological observation complemented with SEM study. All replicas were uniformly trimmed and mounted on aluminum stubs for easy handling and repositioning.

Wear analysis

The gypsum replicas were scanned three-dimensionally by using a 3D laser scanner; the details of the technique are described elsewhere [8]. In this technique, Match 3D, specially developed image analysis software (volume, mean vertical loss, 0.5% quantiles) superimposed follow-up (6–60 months) images on baseline images, by aligning the three user-defined references. If the standard deviation was less than 20 μm, the match was accepted [12], following which the software performed digital subtraction of follow-up image from the baseline image. This digital subtraction resulted in a differential image used to quantify the wear magnitude (see reference 12 for details on matching procedure). In literature, large, dark occlusion paper marks have been advocated to indicate heavy occlusal load (OCA-heavy) and smaller, lighter marks have been advocated to indicate lesser loads (OCA-light) [16–18]. So, based on the size and intensity of blue articulation spots in the clinical pictures at baseline and at the different recall sessions, the following wear facets were identified and measured on the difference image: Occlusal contact area on enamel (OCAE)-heavy and light, Occlusal contact area on composite (OCAC), differential wear (shared OCAE and OCAC), contact-free occlusal area (CFOA), and degradation of restoration margins (see reference 15 for details on measurement technique). The volume loss calculations were performed after eliminating the material excess along the vestibular, lingual fissures and beveled cavosurface margins. By multiplying the number of pixels contained in the digitally cut restorative area (from the surrounding enamel) with the size of the x coordinates, the restorative surface area (RSA) and the enamel surface area (ESA) were calculated. To determine the volumetric wear, the statistic mode of the difference images was used to quantify the total surface volume loss (TSV loss), restorative surface volume loss (RSV Loss), and enamel surface volume loss (ESV loss) in mm^3. Three Tetric-EC and one Tetric-C restorations were excluded from the wear analysis after 36-month recall, as they were subjected to polishing by the patient's dentist for the removal of heavy surface staining.

Statistical analysis

The different materials were compared with each other by means of pairwise contrasts using an F-test. Based on a 60-month time period, vertical wear rate (μm/month) and volume loss rate (mm^3/month) [rho] with standard error were estimated for the three composites based on a linear relation; i.e., wear=rho×time+error. Linear mixed model, using PROC MIXED in SAS (version 9.2; Cary, NC, USA) was used for investigating the effect of different variables (time, age, gender, cavity type, surface area, quadrant type, and operator) on the vertical and volume wear values. This models regresses the outcome variables (vertical wear/volume loss) to the aforementioned variables (e.g., time, surface area) while taking into account the correlation between the measurements coming from the same patients. Model building (in Q5) was based on Akaike's information criteria (AIC). The following covariates were then included in the model cavity type, quadrant type, operator, surface area, tooth (upper/lower), and operator x cavity type interaction. The variables gender and age were not considered given the fact that the sample contains only one male subject and that most subjects have very similar ages (except one aged 57). The analyses were performed for the three restorative materials separately. For each analysis, a model building was performed to arrive at the best fitting model (lowest AIC), with 'operator' as a fixed effect and 'patient' as a random effect. An operator effect can then only be interpreted for the two specific operators in the study. In a second analysis, 'operator' was considered as a random variable. This corresponds to the idea that any operator (out of a population of operators) could be randomly sampled. Then the results of the analysis can be generalized to any sample of operators.

Micromorphological wear

The epoxy replicas were gold-sputtered, subjected to high magnification dental surgical optical microscopy (OPMI Pro ergo, Carl Zeiss surgical GMBH, Oberkochen, Germany), prior to SEM imaging. The potential samples demonstrating interesting micromorphologic features, such as defined wear facets, differential wear steps, degrading margins, and fractures were further explored under SEM. Quadrant-wise photomicrographs of each sample were made, initially followed by thorough scanning area by area up to the magnification of ×200.

Results

Recall rate was 100% at the 5-year follow-up as none of the patients was lost to the follow-up. However, maintenance treatments, such as prophylaxis and polishing of the occlusal surfaces done in one Tetric-C and three Tetric-EC restorations at 36-month recall, were excluded from the wear analysis. The present study reports wear data on 60 months in Table 3, as a continuation of previously published 6-, 12-, 24-0and 36-months data [5]. Until the 36-month, the three restorative materials did not differ significantly in both vertical and volume wear. While vertical wear data at 60 months did follow a similar trend, Tetric-EC resulted in significantly lower volume loss compared to both Gradia-DP and Tetric-C. There was no difference between the latter two. Irrespective of the type of composite, at 60 months, the volume loss of class I restorations were significantly lesser than class II restorations (Tetric-C (p=0.051); Tetric-EC (p=0.043); Gradia-DP (p=0.027)). For the wear data from entire period of baseline to 60 months, area of restoration did not have any significant effect on vertical wear but had a significant

Table 3 Mean and SD of the measured vertical (μm) and volume loss (mm^3) at 60 months

		Tetric-C	Tetric-EC	Gradia-DP
Vertical wear		124 (29)	111 (23)	139 (44)
Volume loss	TSV loss	1.72 (0.6)	1.29 (0.4)	1.89 (1.0)
	RSV loss	1.40 (0.5)	0.97 (0.3)	1.41 (0.7)
	ESV loss	0.38 (0.2)	0.32 (0.1)	0.47 (0.2)
Class I				
Vertical wear		112 (29)	108 (21)	138 (47)
Volume loss	TSV loss	1.58 (0.5)	1.24 (0.4)	1.66 (0.5)
	RSV loss	1.29 (0.4)	0.93 (0.3)	1.24 (0.4)
	ESV loss	0.39 (0.2)	0.31 (0.1)	0.41 (0.1)
Class II				
Vertical wear		128 (18)	120 (32)	148 (42)
Volume loss	TSV loss	2.01 (0.4)	1.45 (0.3)	3.48 (2)
	RSV loss	1.65 (0.2)	1.09 (0.2)	2.61 (1)
	ESV loss	0.35 (0.1)	0.36 (0.1)	0.87 (0.6)

TSV loss total surface volume loss; *RSV loss* restorative surface volume loss; *ESV loss* enamel surface volume loss effect on the volume wear. As evident in the scatter plots (Fig. 1 a–c) together with the regression line, the volume loss *increases* significantly with the increase in the surface area of Gradia-DP, Tetric-EC restorations, and Tetric-C restorations. However, there was no indication for any quadratic (nonlinear) relationship between volume loss and surface area.

Table 4 summarizes the estimated vertical wear rate (μm/month) and volume loss rate (mm^3/month) [rho] with standard error for the three materials based on a linear relation, i.e., wear=rho×time+error. Figure 2a–f shows the graphs with the observed mean values, the red lines, which are the model predictions for a linear model and the blue lines for nonlinear model. For vertical wear, the deviation of red line from the observed means indicate that a linear relationship is not adequate. Therefore, the nonlinear model describes the data much better. The wear rate is large in the first 6 months; thereafter it slows down. For this reason, the wear data from the 6 to 60-month period were evaluated separately in three different time periods—period 1 (baseline to 6 months), period 2 (6–36 months), and period 3 (36–60 months). The nonlinear model is then: wear=rho1× month+rho2 x month (period 2)+rho3×month (period 3)+ error, so that for period 1: wear=rho1×month+error; period 2: wear=(rho1+rho2)×month+error and period 3: wear=(rho1+rho2+rho3)×month+error. Table 4 summarizes the wear rates for the three time periods. The difference between the slopes for periods 2 and 3 is mostly small (with Gradia-DP and Tetric-C for vertical wear as two exceptions). In the remaining cases, a simpler model with only two periods (0–6 months and 6–60 months) would probably fit the data equally well.

For volume loss, it is less obvious that the nonlinear model is better than the linear model. The volume loss rate is smaller within period 1, and seems to increase in period 3. In addition to the very large impact of time, volume wear of the three restorative materials were significantly influenced by the factors such as operator, cavity type, operator cavity type interaction and surface area (*p* values in Table 5). The restorations (irrespective of the type of composite) placed by operator A had significantly low volume wear rates than those placed by operator B. Class I restorations wore significantly lower (low volume loss) than class II. Class I restorations placed by operator A wore significantly lower in volume, indicating a cavity type–operator interaction. None of these factors had a significant

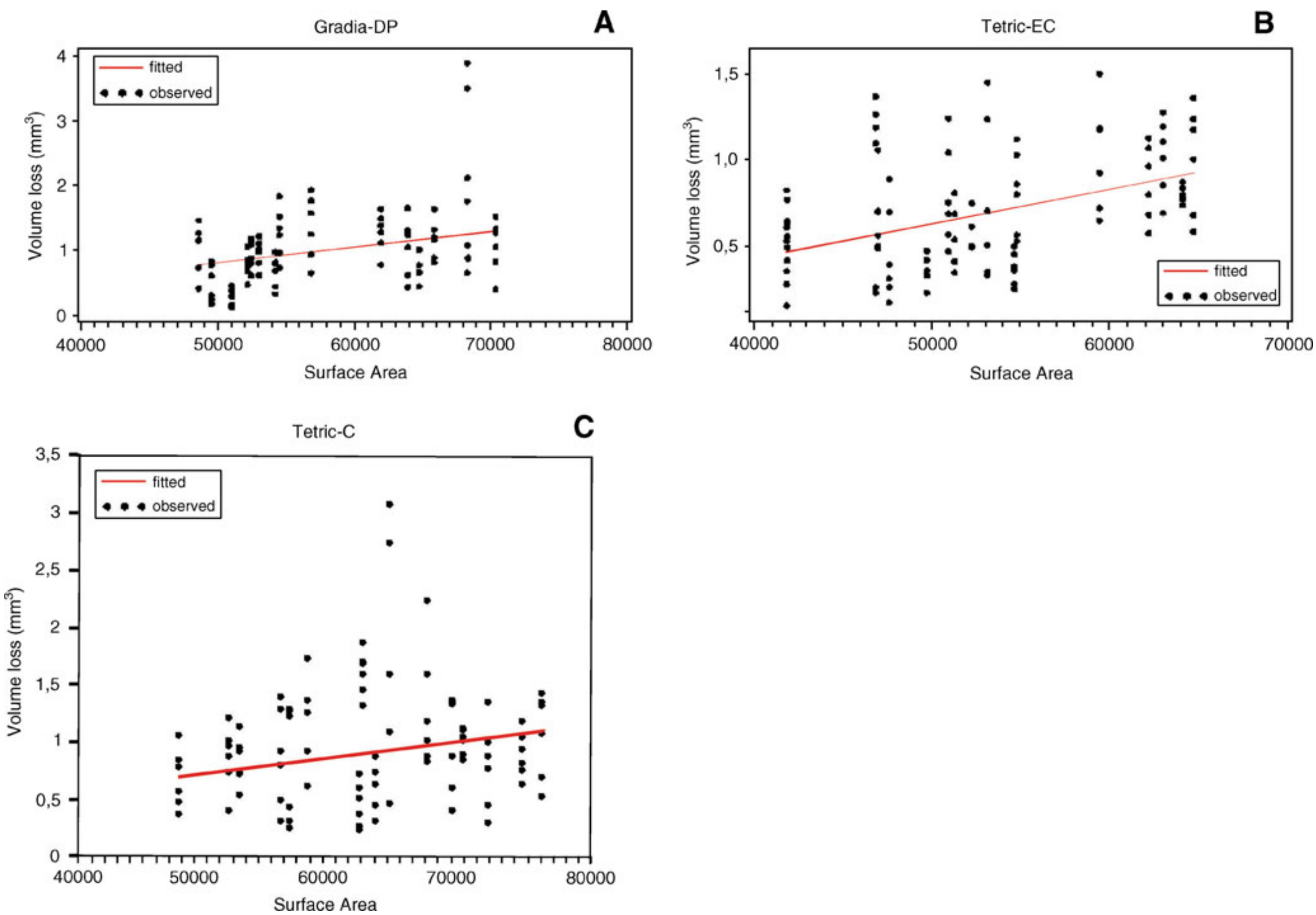

Fig. 1 Scatter plots with corresponding regression lines of restorative surface volume loss and restorative surface area

Table 4 Mean and SD of the estimated rate of vertical wear (μm/month) and volume loss (mm^3/month)

		Tetric-C	Tetric-EC	Gradia-DP
Vertical wear	Generalized	1.411 (0.089)	1.401 (0.062)	1.830 (0.100)
Vertical wear	0–6 m	6.848 (0.990)	8.236 (0.856)	8.281 (1.526)
	6–36 m	1.413 (1.068)	1.625 (0.905)	2.494 (1.578)
	36–60 m	1.282 (0.352)	0.94 (0.254)	0.691 (0.351)
Volume loss	Generalized	0.017 (0.001)	0.011 (0.001)	0.018 (0.002)
Volume loss	0–6 m	0.096 (0.18)	0.068 (0.009)	0.087 (0.020)
	6–36 m	0.019 (0.19)	0.012 (0.10)	0.021 (0.021)
	36–60 m	0.010 (0.005)	0.007 (0.003)	0.009 (0.006)

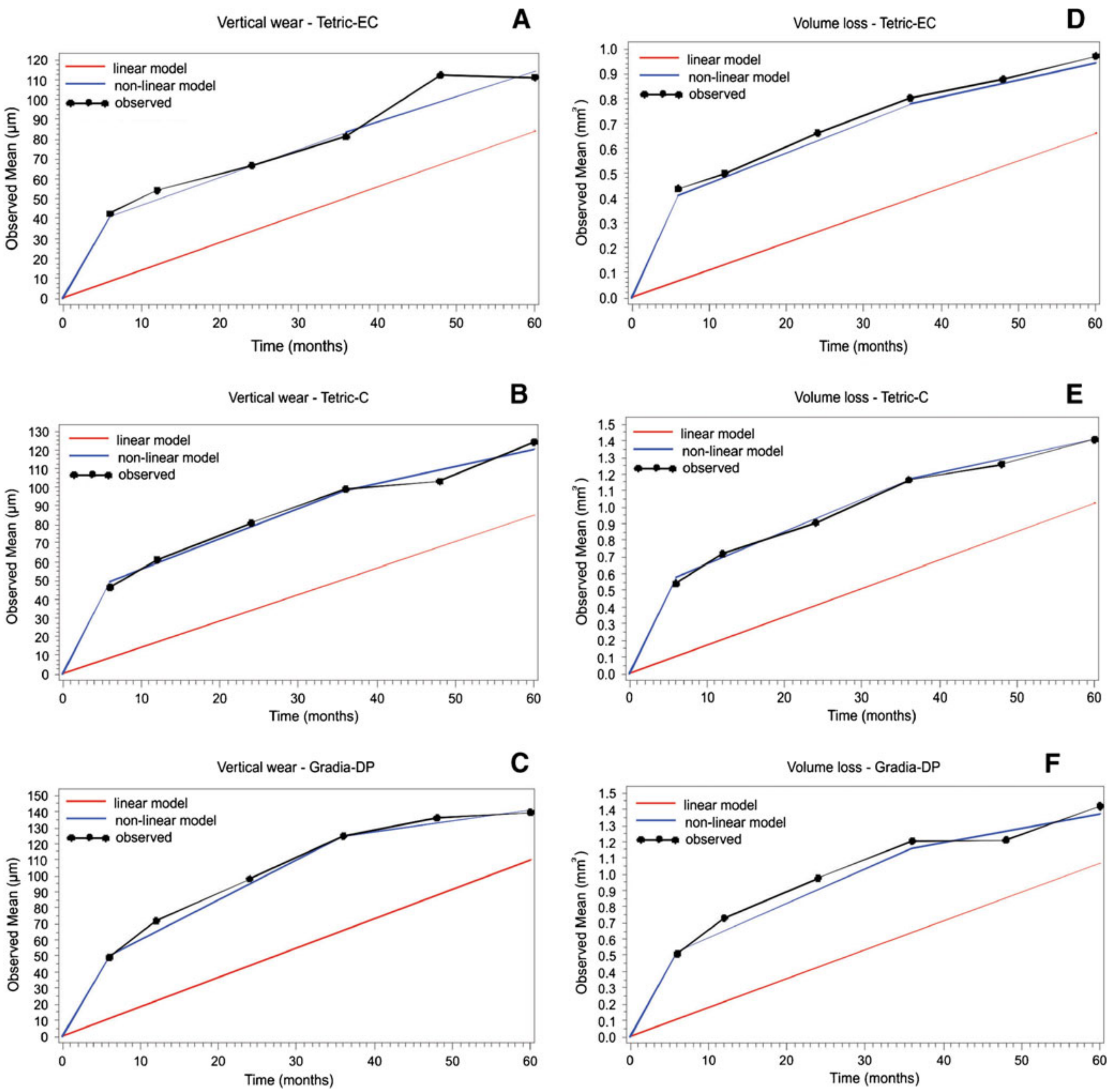

Fig. 2 Results of model fitting analysis for vertical and volume wear data versus time series

Table 5 Effect of different variables on wear

Effect	Outcome	Probability (p value)		
		Tetric-EC	Tetric-C	Gradia-DP
Operator	Vertical wear	0.056*	0.053*	0.055*
	Volume wear	0.028*	0.051*	0.041*
Cavity type	Vertical wear	0.413	0.813	0.725
	Volume wear	0.020*	0.0465*	0.0315*
Operator×Cavity type	Vertical wear	0.059*	0.063*	0.060*
	Volume wear	0.047*	0.038*	0.041*
Quadrant type	Vertical wear	0.941	0.993	0.820
	Volume wear	0.096	0.084	0.084
Surface area	Vertical wear	0.188	0.063	0.484
	Volume wear	<0.0001*	<0.0001*	0.0005*

*Statistically significant values

effect on vertical wear rates of any of the three restorative materials. However, on removing the nonsignificant factor 'quadrant type' from the analyses, the factor 'operator' demonstrated a borderline significant effect on the vertical wear of Tetric-EC, Tetric-C, and Gradia-DP. Nevertheless, as a random variable, the factor operator could never improve the model fit (indicated by the AIC). This means that very little of the observed variability is explained by variability between the operators.

Micromorphological wear

The three wear patterns—fatigue cracks at heavy OCA (Fig. 3 (c, h , m)), pitting at light OCA (Fig. 3 d, i, n), and scratches/striations at CFOA (Fig. 3 e, j, o) along the food escape pathways—that were evident within the first 3-year recall [5] did not deteriorate further until 5 years. While within 1 year, almost half of the restorations in each group exhibited local marginal irregularities; there was progressive degradation in the next 3 years, and after 5 years, the perfect margin disappeared in almost all restorations. Wear was predominant as negative step formation, progressive surface roughness, and overhang fractures.

Discussion

The three hybrid composites evaluated in this study appeared to meet the occlusal wear (vertical loss) requirements of the ADA [6]. While ADA's set of guidelines has wear standards for vertical wear, no reference standards are available to date for volume loss. Absence of significant difference in vertical wear between Tetric-EC, Tetric-C, and Gradia-DP could be attributed to the fact that the reported matrix composition and volume percent of fillers of the three materials used in the present study remain not very different. However, the null hypothesis is partially rejected as the volume loss of Tetric-EC was significantly lower than the Tetric-C and Gradia-DP. The densely packed nanofillers in Tetric-EC might have sheltered the resin matrix, thereby protecting the softer resin matrix from the abrasive action of food particles, as proposed by the protection [19] theory.

The estimated wear rates of the three materials in the present study remain relatively lower in comparison to other studies [12, 20–23]. However, wear quantified in these studies cannot be directly compared with the values obtained in this study because of the variability in study designs, precision, and accuracy, associated with the quantification methods, technical excellence of evaluated materials, and the great variety of reported wear specifications (e.g., height loss, volume wear, and area) [24]. On the other hand, the relatively low wear rate for the population studied at present compared with the subjects of other in vivo studies [20, 21] could also be the result of biologic variation between the study populations in terms of strength exerted by the masticatory muscles [24, 25], chewing patterns [26], nutrition, salivary, and environmental factors [27].

Wear reported as depth/vertical loss measurements is a morphological parameter indicating a decrease in vertical dimension [28], and volume loss measurement is a material property describing the amount of material removed [29]. Vertical wear is a morphological parameter due to the direct relationship between the depth of the wear facet and the vertical dimension of occlusion or facial height. Likewise, volume wear, measured as occlusal force times the total sliding distance, is an indirect measure of the work done in removing the material along the entire occlusal table. Describing the entire process of occlusal wear of restorative materials requires reporting of wear by both volume and depth [29]. The vertical and volume wear rate of the three restorative materials in the present study did show

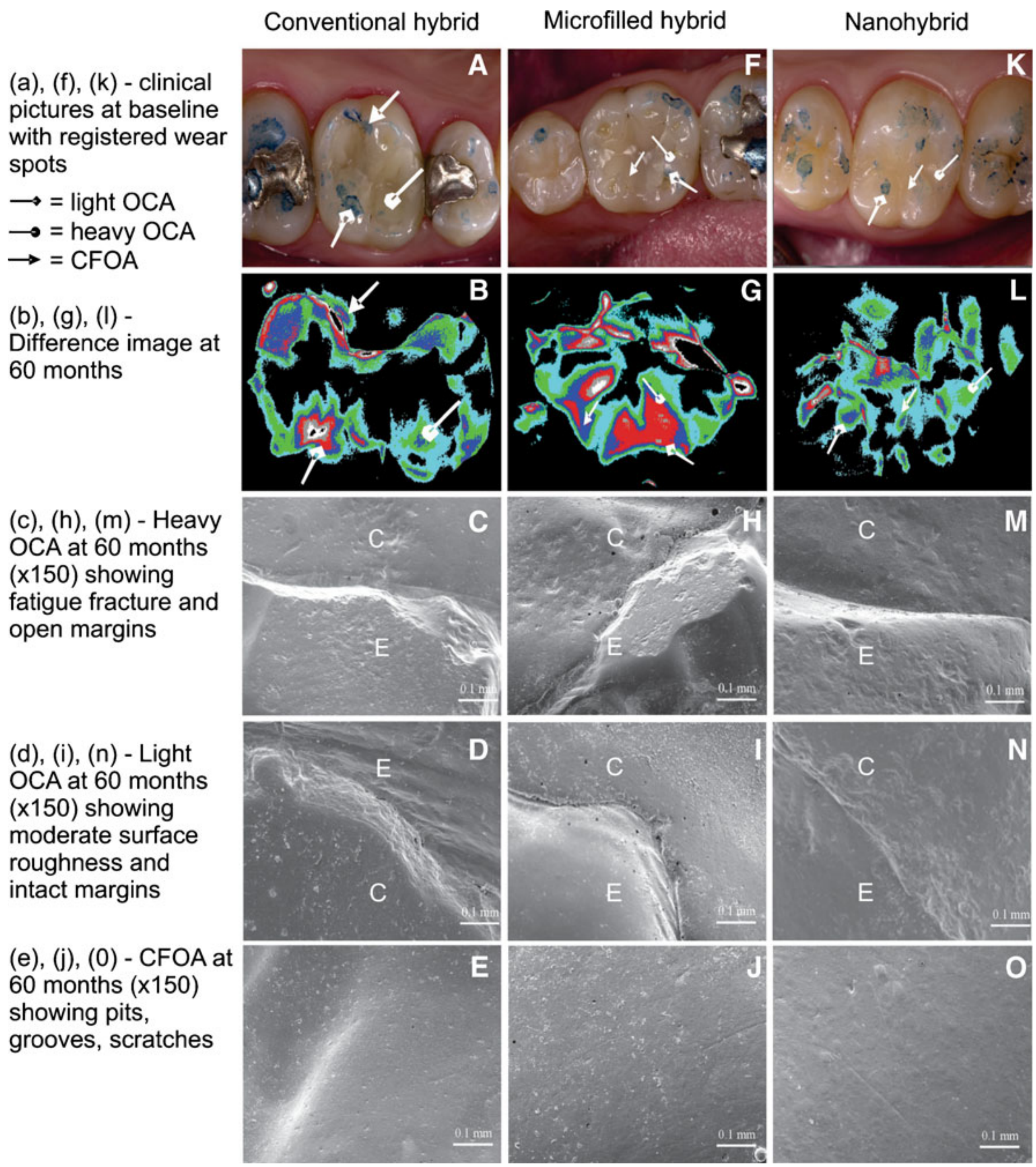

Fig. 3 A representative conventional, microfilled, and nanohybrid composite restoration at 60 months recall

nonlinearity with time similar to several clinical [12, 22] and in vitro studies [30]. The non-linear wear curves and the decrease in the mean wear rate (vertical and volume wear) of the three restorative materials from the running-in wear period of initial 6 months to the successive steady-state period thereafter could be related to the progressive increase of OCA wear facet with the accompanying reduction in chewing pressure [31] and the chipping of overhangs from the grooves and localized marginal fractures in and around the bevels within 6 months of clinical service [15].

Volume loss of restorative material is directly proportional to the product of the area of wear and the mean vertical loss in that area [32]. Irrespective to the type of restorative material evaluated in this study, the volume wear had a strong relationship to surface area in agreement with a previous study, in which the wear of composites increased with the size of restoration [14] as class II restorations presented a large surface area to masticatory forces. Since the linear mixed model applied in this study assumed normality of the outcome variables, it was not necessary to log transform the volume loss and surface area data set to adjust the volume loss for the surface area as proposed by [33].

One of the major limitations of this study is the patient selection bias resulting from the predominant inclusion of female dental student participants with a narrow age range of 26–32 years. The selection bias was however accommodated by including the patient as a random effect in the models. Other limitations include the small sample size, existing controversy over cavosurface bevels [34, 35] and errors inherent to replication procedures, and wear quantification technique. Quadrant type did not seem to influence the wear rates as demonstrated in a previous study [13], indicating a lack of effect of chewing-side preferences on wear rate.

A previous study [12] with more than one operator reported that significant differences in wear rates of restorations placed by two different operators were caused by differences in handpieces used for cavity preparation, restoration finishing techniques and occlusal anatomy carving style. Although the armamentarium for cavity preparation, restoration technique, and curing protocol were standardized in this study, a significant interaction between the variables operator and cavity type could not be eliminated. A possible explanation for this interaction could be that operator A predominantly restored conservative cavities of small caries lesions and placed short cavosurface bevels, while operator B performed majority of amalgam replacements and placed long bevels. While more conservative outline forms of operator A could have lead to less exposure of resin restoration to functional stress and eventually less volume wear, modified cavity preparations of operator B performed opposite.

Although wear resistance of composites remained within ADA guidelines, SEM analysis showed surface disintegrations caused by fatigue at occlusal contact areas. Irrespective of the type of the hybrid composite, the predominant wear mechanism seen on heavy OCA facets is fatigue crack formation, probably resulting from Hertzian sliding-contact stresses. Exponents of wear in these wear facets (3D laser scanning) were in the range of 10^{-8} to 10^{-9}, consistent with moderate wear via a micro-crack mechanism. Additionally, pitting due to erosion around filler particles was a damage mechanism on some light OCA wear facets with corresponding exponents of wear in the range of 10^{-7}. Dental microwear [36–38] was evident along the food escape pathways of CFOA. These surface damages, although evident within the 3 years of clinical service, did not seem to worsen until 5-year recall.

Conclusions

Overall, the wear resistance of three hybrids complies with ADA specification minimum requirements for posterior composite restorations: vertical wear (<50 μm/year). While quadrant type did not seem to influence the wear rates, operator cavity type interaction and surface area of restorations did significantly influence the volume wear rates. The micromorphological surface degradation patterns observed in majority of restorations within the first 5 years of clinical service, do not seem to contribute to any increased functional risk of fracture or a harmful effect on pulp and periodontal biocompatibility.

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Hickel R, Manhart J (2001) Longevity of restorations in posterior teeth and reasons for failure. J Adhes Dent 3:45–64
2. Lambrechts P, Debels E, Van Landuyt K, Peumans M, Van Meerbeek B (2006) How to simulate wear? Overview of existing methods. Dent Mater 22:693–701
3. Lambrechts P, Vuylsteke M, Vanherle G, Davidson CL (1984) Quantitative evaluation of the wear resistance of posterior dental restorations: a new three-dimensional measuring technique. J Dent 12:252–267
4. Lambrechts P, Braem M, Vuylsteke-Wauters M, Vanherle G (1989) Quantitative in vivo wear of human enamel. J Dent Res 68:1752–1754
5. Palaniappan S, Elsen L, Lijnen I, Peumans M, Van Meerbeek B, Lambrechts P (2009) Three-year randomised clinical trial to evaluate the clinical performance, quantitative and qualitative wear patterns of hybrid composite restorations. Clin Oral Investig 14:441–458
6. American Dental Association (2001) ADA acceptance program guidelines: resin based composites for posterior restorations. ADA Council on Scientific Affairs, Chicago
7. Ryge G, Snyder MA (1972) Evaluating the clinical quality of restorations. JADA 87:369–377
8. Mehl A, Gloger W, Kunzelmann KH, Hickel R (1997) A new optical 3-D device for the detection of wear. J Dent Res 76:1799–1807
9. Chung KH (1990) The relationship between composition and properties of posterior resin composites. J Dent Res 69:852–856
10. Jaarda MJ, Wang R, Lang BR (1996) A regression analysis of filler particle content to predict composite wear. J Prosthet Dent 77:57–67
11. Condon JR, Ferracane JL (1997) In vitro wear of composite with varied cure, filler level, and filler treatment. J Dent Res 76:1405–1411
12. Söderholm KJ, Lambrechts P, Sarrett D, Abe Y, Yang MC, Labella R et al (2001) Clinical wear performance of eight experimental dental composites over three years determined by two measuring methods. Eur J Oral Sci 109:273–281
13. Lobbezoo F, Naeije M (2001) A reliability study of clinical tooth wear measurements. J Prosthet Dent 86:597–602
14. Wilson NH, Norman RD (1991) Five-year findings of a multiclinical trial for a posterior composite. J Dent 19:153–159
15. Palaniappan S, Bharadwaj D, Mattar D, Peumans M, Van Meerbeek B, Lambrechts P (2009) Three-year randomized clinical trial to evaluate the clinical performance and wear of a nanocomposite versus a hybrid composite. Dent Mater 25:1302–1314

16. Okeson J (2003) Management of temporomandibular disorders and occlusion, 5th ed. CV Mosby and Co, St. Louis, MO pp. 416,418,605
17. Kleinberg I (1991) Occlusion practice and assessment. Knight Publishing, Oxford, p 28
18. Smukler H (1991) Equilibration in the natural and restored dentition. Quintessence Publishing, Chicago, p 110
19. Bayne SC, Taylor DF, Heymann HO (1992) Protection hypothesis for composite wear. Dent Mater 8:305–309
20. Willems GLP, Braem M, Vanherle G (1993) Three-year follow-up of five posterior composites: in vivo wear. J Dent 21:74–78
21. Wendell JJ, Vann WF (1988) Wear of composite resin restorations in primary versus permanent molar teeth. J Dent Res 67:71–74
22. Wilder AD, May KN, Bayne SC, Taylor DF, Leinfelder KF (1999) Seventeen-year clinical study of ultraviolet-cured posterior composite Class I and II restorations. J Esthet Dent 11:135–142
23. Blalock JS, Chan DC, Browning WD, Callan R, Hackman S (2006) Measurement of clinical wear of two packable composites after 6 months in service. J Oral Rehabil 33:59–63
24. Ferracane JL (2006) Is the wear of dental composites still a clinical concern? Is there still a need for in vitro wear simulating devices? Dent Mater 22:689–692
25. Johansson A (1992) A cross-cultural study of occlusal tooth wear. Swed Dent J 86:1–59
26. Bakke M, Holm B, Jensen BL, Michler L, Moller E (1990) Unilateral, isometric bite force in 8-68-year-old women and men related to occlusal factors. Scand J Dent Res 98:149–158
27. Kim SK, Kim KN, Chang IT, Heo SJ (2001) A study of the effects of chewing patterns on occlusal wear. J Oral Rehabil 28:1048–1055
28. Dahl BL, Carlsson GE, Ekfeldt A (1993) Occlusal wear of teeth and restorative materials. A review of classification, etiology, mechanisms of wear, and some aspects of restorative procedures. Acta Odontol Scand 51:299–311
29. DeLong R (2006) Intra-oral restorative materials wear: rethinking the current approaches: how to measure wear. Dent Mater 22: 702–711
30. Winkler MM, Greener EH, Lautenschlager EP (1991) Non-linear in vitro wear of posterior composites with time. Dent Mater 7:258–262
31. Krejci I, Lutz F, Zedler C (1992) Effect of contact area size on enamel and composite wear. J Dent Res 71:1413–1416
32. Pintado MR, Anderson GC, DeLong R, Douglas WH (1997) Variation in tooth wear in young adults over a two-year period. J Prosthet Dent 77:313–320
33. Schmid-Schwap M, Rousson V, Vornwagner K, Heintze SD (2009) Wear of two artificial tooth materials in vivo: a 12-month pilot study. J Prosthet Dent 102:104–114
34. Isenberg BP, Leinfelder KF (1990) Efficacy of beveling posterior composite resin preparations. J Esthet Dent 2:70–73
35. Baratieri LN, Canabarro S, Lopes GC, Ritter AV (2003) Effect of resin viscosity and enamel beveling on the clinical performance of Class V composite restorations: three-year results. Oper Dent 28:482–487
36. Patrick M (2006) Brief communication: intertooth and intrafacet dental microwear variation in an archaeological sample of modern humans from the Jordan Valley. Am J Phys Anthropol 129:39–44
37. Ryan AS (1979) Wear striation direction on primate teeth: a scanning electron microscope examination. Am J Phys Anthropol 50:155–168
38. Kaidonis JA (2008) Tooth wear: the view of the anthropologist. Clin Oral Investig 12:S21–S26