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ORIGINAL ARTICLE

Are resin composites suitable replacements for amalgam? A study of two-body wear

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Abstract
Objectives Wear resistance is an important property of the dental materials, particularly for large restorations in the posterior regions and for the patients suffering from parafunctional activities. Additionally, the wear resistance of flowable composite resin materials is a clinical concern, although they are popular among dentists because of their easy handling. The aims of the present study were to evaluate the wear resistance of nine composite resins both condensable (G-aenial posterior, Venus, GrandioSO, Tetric EvoCeram, Ceram X duo, Filtek Supreme XTE) and new-generation flowable resin composites (G-aenial Universal Flo, GrandioSO Flow and GrandioSO Heavy Flow) and to compare these results with amalgam.
Materials and method Eight specimens of each material were subjected to two-body wear tests, using a chewing simulator. The wear region of each material was examined under profilometer, measuring the vertical loss (μm) and the volume loss (mm^3) of the materials. Additionally, SEM analysis was performed to assess surfaces irregularities.
Results The results showed significant difference of the vertical loss and the volume loss of the examined materials ($p<0.001$). Although amalgam had the best wear resistance, two condensable resin composites (GrandioSO, Ceram X duo) and all flowable materials had no significant difference with amalgam. GrandioSO had the highest wear resistance and Filtek Supreme XTE the lowest wear resistance.
Conclusion The majority of resin composites had good wear resistance and similar to amalgam.
Clinical relevance Based on the in vitro measurements of two-body wear resistance, the new resin composites could replace amalgam for restorations placed in occlusal stress-bearing regions. New-generation flowable resin materials may also be used in occlusal contact restorations.

Keywords Wear · Amalgam · Resin composite · Chewing simulator

Introduction

Wear can be defined as the progressive loss of materials or tooth substances, because of the interaction of two surfaces, which are moving in contact. It can be classified into four basic types, attrition or two-body abrasion, three-body abrasion, fatigue, and corrosive wear. Attrition is related to the material or tooth surface loss, when the surfaces are in direct contact, without the presence of another body. Three-body abrasion is caused by the presence of an abrasive third body, which acts between two antagonistic surfaces. One characteristic reason for abrasion wear is the presence of food, acting as a third body between the two surfaces during the mastication cycle. Fatigue wear is caused by subsurface cracks of the material because of repeating load cycling. Chemical reasons, such as acids can cause corrosive wear that can produce a surface layer, which can easily be removed though contact with the antagonist [1–3]. These types of wear may occur in combination with others or alone [4]. The main clinical mechanism that is thought to cause wear of dental materials is the combination of attrition and abrasion [5]. The attrition wear occurs in the occlusal contact area and the three-body abrasion wear in the occlusal free area. In vivo measurements showed

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that wear is most likely to be observed at the occlusal contact areas, on the cuspal inclines or the central fossae [4].

Wear is a process that depends on multiple factors. The restorative material, the oral environment, and the structure of the enamel can play an important role. The composition and the properties of the material, the abrasive nature of the food, the enamel's characteristics, and the chewing behavior can positively or negatively influence wear resistance [4, 6, 7].

It is widely accepted that patients' demands for tooth-colored restorations have increased. For this reason, resin composites (RCs) have replaced other non-aesthetic restorations such amalgam. In the past years, one of the most common failures of resin-based material restorations was the low wear resistance, which led to loss of anatomical form. Nowadays, efforts have been made in order to minimize this problem. Fillers size, volume, and shape have been modified. Although these efforts are proved to be successful, low wear resistance is still considered to be a concern especially in large direct restorations or in patients with oral habits [8–11].

Wear resistance of dental materials is difficult to evaluate, although there are many in vitro and in vivo studies. Neither of them can be characterized as the most relevant method. In vivo studies are time consuming and difficult to be carried out with a sufficient number of dental patients [2]. To overcome the problem of time needing and the possibly cost of the indirect in vivo methods for the estimation of wear, researchers try to simulate oral environment in laboratory procedures. Because of difficulties to mimic oral environment, no general agreement on the most suitable wear simulator device exists. Several simulator devices, using different methods of actuation, had been produced. Two-body wear simulator devices, such as SD Mechatronik (for attrition), three-body wear simulator devices (for abrasion), such as ACTA or two- and three-body wear devices (for both attrition and abrasion measurements), such as OHSU, are the most used in literature [10–23]. The type of antagonist is of equally importance, but there is no agreement in the literature on the most suitable material, which can act as antagonist in wear simulation devices. Enamel, porcelain, stainless steel, and steatite ball had been proposed. Shortall et al. showed that porcelain is a good alternative option, because of the close similarity with dental enamel [21]. Additionally, some researchers denied that steatite can be a good substitute [3], but it is acceptable for others [7, 13, 24]. The shape of the antagonists is no more questionable. Ball shape antagonists develop a greater contact area, which lead to decreased fatigue [9].

The aims of the present in vitro study were to evaluate the wear resistance of nine commercial and representative RCs depending on the chemical composition and filler configuration and to compare the results with the reference material, amalgam, using a two-body wear simulator device (SD Mechatronik). The null hypothesis tested was that there was no significant difference regarding the mean vertical loss and the mean volume loss between the differently filled RCs materials and the reference material, amalgam, using an in vitro two-body wear simulator protocol.

Method

Nine modern commercially available RCs (six condensable and three flowable) were used in the present study. Amalgam was used as a reference material. Table 1 shows the type and the composition of each material provided by manufacturers' data.

Eight specimens for each direct restorative material were fabricated using aluminum holders ($d=10$ mm, depth=3 mm) (SD Mechatronik, Feldkirchen, Germany). The RCs were directly placed in the holders in layering technique. Each layer was cured according to manufacturer's instructions using a conventional QTH polymerization device (Elipar TriLight, 3M ESPE, 750 mW/cm^2). The top layer was condensed with a clear strip to remove excess material. Then, the flat specimens were polished with SiC papers up to 1000 grit, until they were homogenously finished. Steatite balls, a multi-component semi-porous crystalline ceramic material ($d=$ 6 mm), were used as antagonists. The specimens were placed in distilled water at 37 °C for 24 h before used.

To simulate oral mastication function, a chewing simulator (CS8, SD Mechatronik, Feldkirchen, Germany) was used. The specimens and the antagonists were mounted in the mastication simulator. A weight of 5 kg (corresponding to 50 N) was used in each chamber, and a lateral sliding component was set to 0.7 mm. The frequency of the antagonist movement was 1.7 Hz, and each mastication cycle was repeated 120,000 times. During the in vitro mastication process, water at 37 °C was used for two basic reasons, first, to simulate oral environment and second, to remove worn particles from the material's surface.

The evaluation of wear was conducted using a high-resolution non-contact profilometer equipped with white light sensors (CyberSCAN CT 100, Cyber Technologies GmbH, Ingolstadt, Germany) that ensure a z-resolution of up to 3 nm. Using a software (CHRocodile S 600, Cyber Technologies, Germany) and a high-resolution camera connected to the light sensor, the mean volume loss (mm^3) and the mean vertical loss (μm) of the original samples were measured. The non-attrition regions of the materials were taken as reference surfaces. Line scans ($n=3$) were taken using the optical profilometer (CT100, Cyber Technologies, Ingolstadt, Germany) in order to measure the mean surface roughness Ra of the tested materials before and after the two-body abrasion procedure. The roughness after the two-body wear test was measured in the deepest area of the wear facet. Figure 1a, b shows the vertical loss and the volume loss of the same specimen.

Table 1 Type and composition of the materials according to manufacturers' information

Material	Type	Resin matrix	Filler	Filler size	Filler weight (%)	Filler volume (%)
G-aenial posterior (GC)	Microhybrid	UDMA Dimethacrylate-comonomers Bis-GMA free	Pre-polymerilized Silica/lanthanoid fluoride fluoroaluminosilicate/silica Fumed silica	16–17 μm >100 nm <100 nm	77	65
G-aenial Universal Flo (GC)	Nanohybrid	UDMA, Bis-MEPP TEGDMA	Silicon dioxide Strontium glass	16 nm 200 nm	69	50
Venus (Heraeus Kulzer Inc.)	Microhybrid	Bis-GMA TEGDMA	Barium aluminum Fluoride glass Silicon dioxide	0.7–2 μm 0.01–0.04 μm	78	61
GrandioSO (VOCO)	Nanohybrid	Bis-GMA, BisEMA, TEGDMA	Glass ceramic Silicon dioxide	1 μm 20–40 nm	89	73
GrandioSO Flow (VOCO)	Nanohybrid	HEDMA, Bis-GMA TEGDMA	Glass ceramic Silicon dioxide	1 μm 20–40 nm	80.2	Not available
GrandioSO Heavy Flow (VOCO)	Nanohybrid	HEDMA, Bis-GMA, TEGDMA	Glass ceramic Silicon dioxide	1 μm 20–40 nm	83	Not available
Tetric EvoCeram (Ivoclar Vivadent NA)	Nanohybrid	Bis-GMA, Bis-EMA, UDMA	Barium glasses, ytterbiumtrifluoride, mixed oxide, prepolymers	550 nm (40–3000 nm)	80	68
Ceram X duo (Dentsply)	Nanohybrid	Methacrylate-modified polysiloxane Bis-GMA, TEGDMA	Barium-aluminum-borosilicate glass Nanofiller Nano ceramic particle	1.1–1.5 μm 10 nm 2.3 nm	76	57
Filtek Supreme XTE (3M ESPE)	Nanofilled	Bis-GMA, UDMA TEGDMA, BisEMA PEGMA	Non-agglomerated/non-aggregated silica Non-agglomerated/non-aggregated zirconia Aggregated zirconia/silica cluster (comprised of 20 nm silica and 4 to 11 nm zirconia particles).	20 nm 4–11 nm	78.5	63.3
Amalgam (Dispersalloy, Dentsply)		Silver, tin, copper, zinc admixture of lathe-cut rods, silver-copper spheres				

After the wear measurements, the attrition surfaces were examined under a digital light microscope (Stemi SV6, Zeiss, Germany) in order to determine the surface texture and the surface irregularities of the representative wear patterns. For SEM (Leitz ISI 50, Akashi, Tokyo, Japan), the specimens were mounted on aluminum stubs, sputter-coated with gold, and examined at ×250 magnification.

For the statistical analysis, the PASW 20.0 (SPSS, IBM, Chicago) package was used. Means and standard deviations were measured with descriptive statistics and analyzing using one-way ANOVA. Regression analyses were carried out to estimate the correlation between vertical loss and filler weight and size. Pearson's correlation was used in order to evaluate the relationship between the vertical and the volume loss.

Results

Table 2 shows the mean vertical loss, mean volume loss of the materials, and the mean surface roughness before and after the two-body wear test. One-way ANOVA shows significant differences among the vertical loss and also among the volume loss of the examined materials. The surface roughness of the materials did not differ significantly before the procedure. After the wear process, the surface roughness ranged from 1.49 to 3.8 μm.

New flowable materials were found to have comparably good wear resistance. G-aenial Universal Flo had better wear resistance than G-aenial posterior ($p<0.001$) and had the least volume loss among all the materials. No significant difference in vertical depths was found between GrandioSO and GrandioSO Flow ($p=0.637$) or GrandioSO and GrandioSO Heavy Flow ($p=0.818$). Among the conventional RC materials, GrandioSO had the best wear resistance. The mean vertical loss of Ceram X duo showed no significant difference with GrandioSO ($p=0.233$). The greatest mean vertical loss was determined for Filtek Supreme XTE. Mean vertical loss of G-aenial posterior and of Tetric EvoCeram had no significant difference with Filtek Supreme XTE ($p=0.992$, $p=0.574$, respectively). No significant difference was found also for

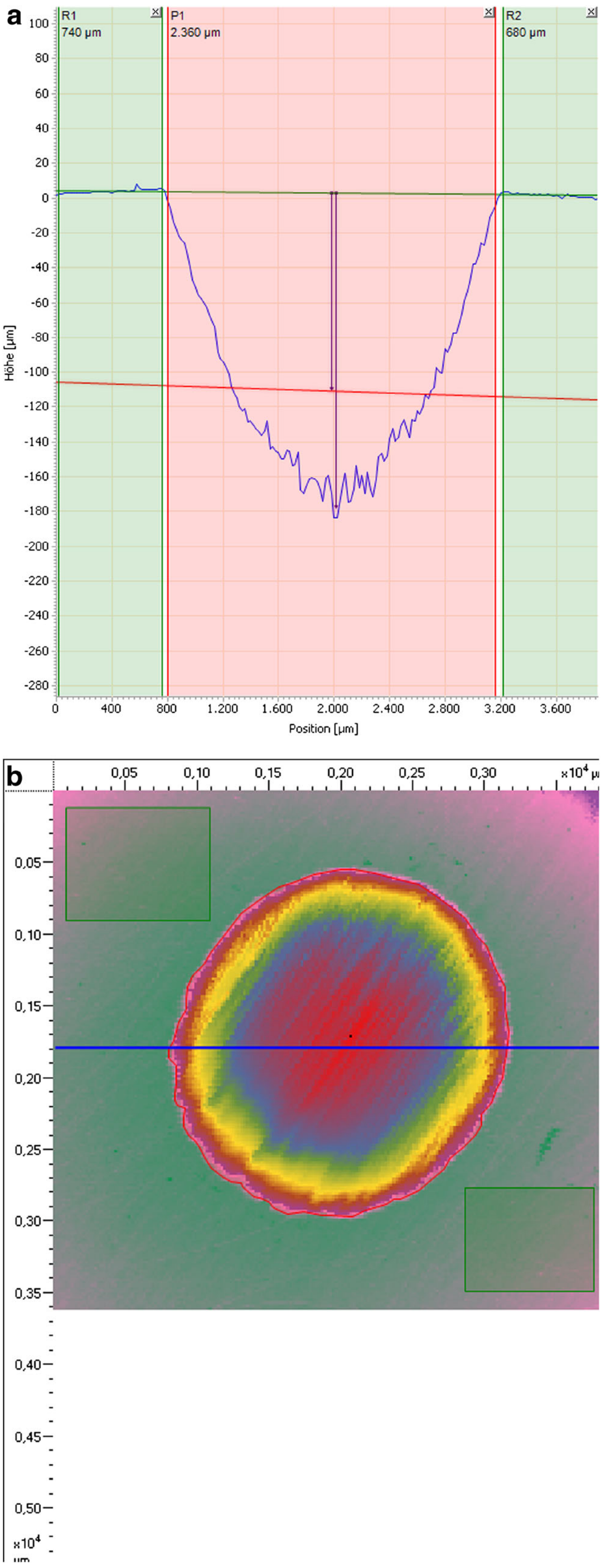

Fig. 1 **a** Vertical loss and **b** volume loss of Filtek Supreme XTE. The grooves in the deepest part are also obvious

G-aenial Universal Flo, GrandioSO, GrandioSO Flow, GrandioSO Heavy Flow, Ceram X duo, and the reference material, amalgam (p=0.172). The correlation between vertical loss and volume loss was high (r=0.829, p=0.001). No linear correlation coefficient was found between filler weight and filler size and vertical loss (r^2=0.039 and r^2=0.040, respectively).

Figure 2 shows the attrition region of each material at ×250 magnification. In all groups, the wear region was rough with grooves along the sliding direction. The attrition region of GrandioSO Flow (Fig. 2d), GrandioSO Heavy Flow (Fig. 2e), and Filtek Supreme XTE (Fig. 2h) appeared scratched and rougher than the surfaces of the other materials. Filler exfoliations and cracks, mainly perpendicular to the sliding direction, were obvious. GrandioSO Flow (Fig. 2d) was locally damaged. G-aenial posterior (Fig. 2a) presented a smoother surface with minimal scratches and grooves. Larger prepolymerized filler particles were mostly well attached to the resin matrix. The surface of G-aenial Universal Flo (Fig. 2b) was smoother than the surface of GrandioSO Flow (Fig. 2d), GrandioSO Heavy Flow (Fig. 2e), and Filtek Supreme XTE (Fig. 2h) (supported by the low standard deviation), but evidence of microcracks exists. GrandioSO (Fig. 2c) presented relatively smooth surface with small number of shallow pits because of dislodgment of small filler particles. Tetric EvoCeram (Fig. 2f) showed a comparably rough surface. Occasionally, surface voids after exfoliation of filler particles were determined. Ceram X duo (Fig. 2g) presents a more uniformly attrition surface; only small pits were detected. Venus (Fig. 2i) had more pitting in the attrition area than the other materials.

Discussion

Within the limitation of the current study, the null hypothesis that there was no significant difference of the tested materials regarding the wear resistance was rejected.

In the present study, SD Mechatronik (Willytec) oral simulator device was used. The Willytec simulator, which is considered as a device, that satisfied the requirements for laboratory devices expressed by the FDA reproduces two-body wear (attrition). In order to be reliable, this device followed several prerequisites. The force produced with the oral simulator must be similar to the mastication forces produced in the oral environment. Studies had shown that the normal forces produced during mastication range from 20 to 12ON [9]. A force of 50 N used in this study seems to be acceptable, because it simulates the normal mastication forces [25]. Additionally, the contact time (400–600 ms), sliding movement (in order to test the fatigue strength of the material), the frequency of load cycle, and the number of cycles are equally important factors [9]. The number of cycles used in wear simulators reporting in the literature varies between

Table 2 Mean and max vertical loss (μm), volume loss (mm^3), and roughness (μm) of the examined materials

Table 2	Type	Mean (SD) vertical loss (μm)	Mean (SD) volume loss (mm^3)	Mean (SD) roughness (μm) Before	Mean (SD) roughness (μm) After
G-aenial Posterior	MH	110.3 (10.07)^{D}	0.3422 (0.07)^{d,e}	0.17 (0.03)*	1.54 (0.47)^{1}
G-aenial Universal Flo	NH	79.44 (5.71)^{A,B}	0.1631 (0.015)^{a}	0.22 (0.05)*,**	1.49 (0.25)^{1}
GrandioSO	NH	67.93 (25.78)^{A}	0.2617 (0.127)^{b,c,d}	0.22 (0.03)*,**	2.49 (0.69)^{2,3}
GrandioSO Flow	NH	81.02 (11.7)^{A,B}	0.2339 (0.045)^{b}	0.22 (0.04)*,**	3.31 (0.50)^{4,5}
GrandioSO Heavy Flow	NH	79.28 (16.3)^{A,B}	0.2423 (0.063)^{b,c}	0.23 (0.04)*,**	2.9 (0.78)^{3,4}
Tetric EvoCeram	NH	103.34 (11.79)^{C,D}	0.3297 (0.052)^{c,d,e}	0.19 (0.02)*	2.1 (0.7)^{1,2}
Ceram X duo	NH	85.75 (11.83)^{A,B}	0.2670 (0.065)^{b,c,e}	0.17 (0.03)*	1.77 (0.58)^{1,2}
Filtek Supreme XTE	NF	116.62 (12.29)^{D}	0.3738 (0.047)^{e}	0.22 (0.05)*,**	3.8 (0.89)^{5}
Venus	MH	91.84 (9.35)^{B,C}	0.3102 (0.04)^{b,c,d,e}	0.21 (0.03)*,**	1.51 (0.42)^{1}
Amalgam		70.55 (15.27)^{A}	0.1046 (0.041)^{a}	0.25 (0.02)**	1.70 (0.70)^{1,2}

The same superscripted letters in the mean vertical loss (upper-case letters) and in the mean volume loss (lower-case letters), the same numbers of superscripted asterisks in the roughness before, and the same superscripted numbers in the roughness after the procedure indicate statistically homogenous subsets ($p>0.05$)

MH microhybrid, *NH* nanohybrid, *NF* nanofilled

50,000 and 1,200,000. The number of occlusal contacts per day at medium chewing forces was estimated to range between 300 to 700 cycles. In the current study, 120,000 mastication cycles were produced corresponding approximately from 6 months to 1 year in vivo [4, 9]. Lateral movement was set to 0.7 mm and the frequency of load cycles at 1.7 Hz. Steatite, a multicomponent semi-porous crystalline ceramic material, was used as antagonist. It has been found that steatite antagonists with a diameter of 6 mm could mimic the human molar cusps and have similar wear rates on composite materials with enamel [13, 24, 26]. Amalgam was used as a reference material, as it is a material with high wear resistance and a long-standing clinical success [9].

The present study found that the wear resistance between amalgam and some RCs have no significant difference. For example G-aenial Universal Flo, GrandioSO, GrandioSO

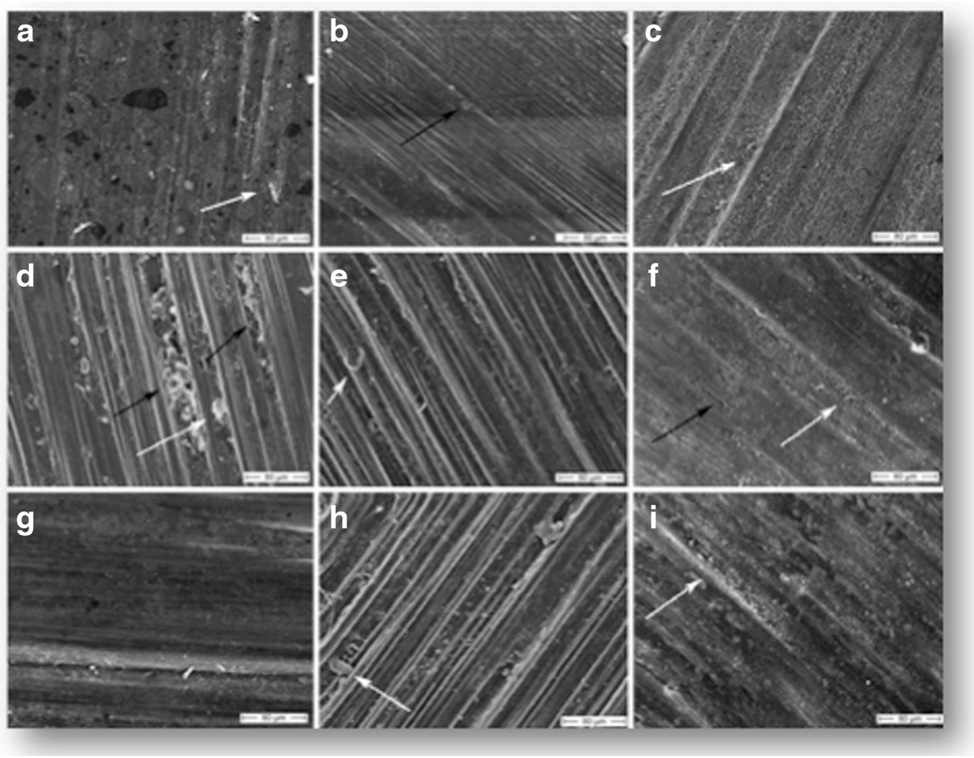

Fig. 2 SEM microphotographs at ×250 of representative resin specimens tested after 120,000 cycles (*scale bar* 80 μm). From left to right: **a** G-aenial posterior, **b** G-aenial Universal Flo, **c** GrandioSO, **d** GrandioSO Flow, **e** GrandioSO Heavy Flow, **f** Tetric EvoCeram, **g** Ceram X duo, **h** Filtek Supreme XTE, and **i** Venus. *Black arrows* indicate examples of cracks on the materials' surface and *white arrows* indicate examples of exposed fillers

Flow, GrandioSO Heavy Flow, and Ceram X duo had good wear resistance similar to the amalgam. Amalgam had been used for over 150 years due to high wear resistance and the minimal wear produced to the opposite teeth [27].

Flowable RCs are very popular among dentists. To reach their fluidity, they contain higher amount of resin matrix and lower amount of fillers [16]. The most flowable resins are filled with 41–53 % by volume and 56–70 % by weight, depending on the filler particle that they contain. Because of their composition, their use is limited to the restorations of preventive cavities, pit, and fissure sealants and as liners or bases. In order to enhance the wear resistance and strength properties of these materials, new flowable RCs with higher filler weight have been produced. For example, GrandioSO Flow and GrandioSO Heavy Flow are filled with 80.2 and 83 % by weight, respectively. In contrast with other studies showing that flowable materials exhibited more wear than their condensable materials [16], in the current study, flowable materials showed similar or better wear resistance than the condensable. Microhybrid (MH) G-aenial posterior RC showed significantly higher vertical loss than G-aenial Universal Flo. This result could be probably not expected, because the filler weight of G-aenial Universal Flo is less than G-aenial posterior. One possible explanation is that G-aenial Universal Flo contains smaller filler particles than G-aenial posterior. The study of Beun et al. showed that it is possible to produce flowable materials with similar properties to conventional MH composites by adding nanoparticles [28]. The present results give an indication that new generation flowable RC materials could be used now in a wider range of clinical application.

It is well known that the decreased filler size and increased filler volume can positively influence the wear resistance of the RC materials. The small inter-particle space produced by the decreased filler size and the increased filler volume protect the softer resin matrix from wear. Otherwise, it is easier for the soft resin matrix to be removed by a third body leaving unsupported filler particles. If this process continues, the wear of the material will be obvious [20, 29]. Studies that compared conventional or macrofilled (MaF) resin materials with microfilled (MiF) or hybrid demonstrated that MaF composites had lower wear resistance [7, 18]. The use of conventional RCs (MaF) was abandoned, because the large size of the fillers led to minimal mechanical properties included wear resistance.

The results from the newer types of RC materials remain controversial. There are several in vitro studies that try to verify which type of RC materials acting better against wear, especially in the loaded posterior regions. Cha et al. (2004) tried to estimate wear process in nine different types of resin, MH, and nanofilled (NF) types. The results have shown different wear rates between the materials, but there was only poor correlation between wear rate and the size of fillers, supposing that also the resin matrix and resin coupling can affect wear [19]. Turssi et al. showed that NF composites have improved wear resistance in comparison to the MiF [17]. On the contrary, Yesil et al. found that nanofillers of the RCs did not significantly increase the wear resistance of the material compared to the MiF materials [10]. In a recent study, Hahnel et al. showed that MH and NF composite materials have similar behavior in the wear resistance [7]. Comparing MiF and MH materials, the study of Clelland et al. showed that MH had greater wear resistance than MiF [16]. The present study also revealed that wear resistance was completely material dependent. The majority of nanohybrid (NH) RC materials (GrandioSO, GrandioSO Flow and GrandioSO Heavy Flow, G-aenial Universal Flo and Ceram X duo, expect of Tetric EvoCeram) had good wear resistance similar to amalgam. Venus (MH) had no significant difference with some NH materials used in this study. Finally, G-aenial posterior (MH) and Filtek Supreme XTE (NF) did not significantly differ.

The present study found that there was no correlation between the filler volume and size and wear resistance. Recent studies did not find any statistically significant correlation between the filler volume or filler size and wear resistance [7, 19, 30, 31]. One possible explanation for these results is that the filler weight of the RCs could be sometimes overestimated. Studies found differences between the filler weight stated by the manufacturers and that measured using thermal gravimetry [7, 32]. It is suggested that the aggregates of prepolymerized organic resin could be estimated as filler particles and measured by the manufacturers, but cannot be measured with thermogravimetry. In addition, even the MH composite materials include nanoparticles in their composition [7]. From all the above results, it could be concluded that wear resistance of the RCs is a mechanical property that can be influenced not only by the fillers size and volume, but also by the composition of the resin matrix and by the silane coupling agent which improve the bond of fillers and resin matrix [19]. The correlation between vertical loss and volume loss was high, as it was expected. Due to their close relationship, only one variable could be measured in order to estimate the wear resistance of dental materials [9].

From Table 2, it can be seen that the results for G-aenial Universal Flo in comparison with the three GrandioSO products are inconsistent between the two wear measurement approaches. For the mean vertical loss, all four materials showed no statistical difference, presenting the best standard deviation for G-aenial Universal Flo. However, only in terms of volume loss, G-aenial Universal Flo produced statistical improved wear resistance. One possible explanation is that the scatter in volume loss as well as in vertical depth for GrandioSO was found extremely high; thus, the ranking changed. Additionally, G-aenial Universal Flo with its fine filler distribution showed improved wear resistance over the whole area, resulting in a lower attrition volume loss. G-aenial Universal

Flo (Fig. 2b) produced a much smoother attrition surface compared to, e.g., GrandioSO Heavy Flow (Fig. 2e).

Surface roughness of dental materials depends on the material composition—especially on filler size and morphology, porosity, and the procedures used for polishing. Roughness is also related to the mechanical properties of each material. The increased roughness can further result in more plaque accumulation, which can increase the possibility of gingival problems and dental caries [33]. In this study, the surface roughness of the materials before the two-body test (expect of amalgam) did not differ significantly. Its values ranged from 0.17 to 0.25 μm, being closed to the value of 0.2 μm, which has been suggested to be clinically acceptable [33]. As it was expected, after the procedure, all the surface roughness of the examined materials was found increased. Wear can lead to greater roughness because of the disintegration of the filler particles from the surface [34]. In this study, G-aenial Universal Flo had the least roughness after wear and Filtek Supreme XTE had the greatest. As SEM analysis verified, GrandioSO Heavy Flow (Fig. 2e), GrandioSO Flow (Fig. 2d), and Filtek Supreme XTE (Fig. 2h) showed the roughest surfaces (highest Ra values) among all the examined materials.

From the present study, it can be concluded that composite resins can replace amalgam. Some RCs have similar wear rates with amalgam; thus, they can be used in occlusal-contact restorations. Of course, there are other physical and mechanical properties that must be included in order to be a material suitable for restorations. There are in vivo studies that measured the survival rate of amalgam versus RC restorations. Although all studies found that both materials had good longevity, some of them concluded that amalgam had better longevity [35, 36] and other that there was no difference between the examined materials [37]. Only one study found that RCs were more suitable restorative materials than amalgam [38]. The above studies generally concerned restorations that they have been done more than a decade ago. The dental materials used today are being modified in order the mechanical and physical properties to be enhanced. For these reasons, nowadays, the conclusion of these results must be cautious. Another clinical concern is if RC materials perform well in extensive restorations including cusps. The study of Van Nieuwenhuysen et al. showed that extensive amalgam restorations had better results than RCs; thus, only amalgam can be considered as appropriate alternatives to crowns [39]. Shenoy referred that while amalgam can be used for large restoration and cusp capping, the use of RCs for this kind of restorations is still controversial [40]. There is a need of well-designed studies to conclude if newly types of RC materials are sufficient for extensive restorations.

Conclusion

Within the limits of this study, it can be concluded that the majority of NH resin composite materials (GrandioSO, GrandioSO Flow and Heavy Flow, G-aenial Universal Flo and Ceram X duo, expect of Tetric EvoCeram) had good wear resistance similar to amalgam. Additionally, new flowable materials with increased filler volume have better wear resistance than some conventional composites, showing best results for G- aenial Universal Flo. Therefore, they may be adequate not only for small non-contact, but also for occlusal contact restorations. SEM analysis shows the formation of microcracks and pits on the materials' surfaces. Microcracks can be indicative of fatigue wear.

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

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