IN VITRO WEAR OF TEN UNIVERSAL COMPOSITES

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ABSTRACT

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Objectives: To test wear of 10 universal composites and the antagonist. Null hypothesis: there are no differences in the composite and antagonist wear.
Materials and Methods: Flat samples, light cured as of manufacturer's instructions and polished were made from Admira Fusion (AF), Filtek Supreme Ultra (FS), G-aenial Sculpt (GS), Harmonize (HR), Herculite Ultra (HU), Tetric Evoceram (TE), TPH Spectra (SP) and three Ultradent experimental materials (UPI Exp 1-3) (n = 8), and stored in water for 3 weeks. They were subjected to wear in a chewing simulator (1.2 x 105 cycles, 49 N, 0.7 mm lateral movement, 1 Hz, steatite antagonists (Ø 6 mm), simultaneously thermocycled (5/55°C) every 90 s). The volumetric wear of the composite was measured with a 3D laser scanner) after 5,000, 10,000 then every 10,000, up to 120,000 cycles. The wear of antagonists was measured after 120,000 cycles.
Results: From 5,000 – 120,000 load cycles wear was linear. The total volumetric wear of composites was: GS 0.428 ± 0.083 mm^3, UPI Exp 3 0.51 ± 0.042 mm^3, HU 0.576 ± 0.072 mm^3, SP 0.609 ± 0.088 mm^3, FS 0.635 ± 0.077 mm^3, HR 0.658 ± 0.116 mm^3, TE 0.714 ± 0.097 mm^3, Ultradent UPI Exp2 0.725 ± 0.132 mm^3, UPI Exp 1 0.894 ± 0.278 mm^3 and AF 1.578 ± 0.37 mm^3. The wear of AF was significantly the largest ($p < 0.0001$). GS showed the lowest wear, but shared this position with UPI Exp 3, HU, SP, FS and HR. The total wear of UPI Exp3 was the lowest.
Conclusion: The null hypothesis was rejected.
Clinical Relevance: Except for AF, wear should be within acceptable limits.
Keywords: Dental materials; In vitro; Wear; Composite; Thermocycling.

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1. Introduction

Since their invention in the 1950s [1-3], composites have been continuously improved, however without abandoning their basic concepts. Over the years it became very obvious that the fillers used had the greatest influence on their physical and mechanical properties [4]. The fillers determine the mechanical properties, they reduce the polymerization shrinkage, the filler selection may optimize wear behavior, they influence the optical properties (translucency) and may enhance the radiopacity. Furthermore, the surface characteristics and thus the polishability depend on the fillers, with consequences for the handling properties and finally the aesthetic appearance of a composite restoration [5]. Historically quartz was first replaced by a variety of different glasses, followed by so-called microfillers (Aerosil, fumed silica), which were first introduced into a resin matrix, which was polymerized and ground into powder. This filler was also referred to as prepolymerized particles [6-8] which were incorporated into a matrix filled with fumed silica. Optimal X-ray contrast was achieved by ytterbium trifluoride filler [9]. In parallel with the improvement in glass milling technology, it was also recognized that optimal "intelligent" filler particle size distribution reduced the resin content, which had a positive effect on polymerization shrinkage [8]. Using flame spray pyrolysis [10] silica based nanoparticles over a wide range of size could be produced. Furthermore, it was possible to create spherical mixed oxide (ytterbium oxide and silica) nanoparticles that matched the refractive index of the resin mix (1.53) resulting in radiopaque composites with high translucency [11]. Finally, composites based solely on nanoparticle technology were introduced. However, the true single particle nanofillers are dispersed in a matrix, which is filled with so-called nanoclusters, with dimensions far away from the nano range [12]. Being aggregated nanoparticles, the clusters lost many advantages of the nanotechnology. The changes outlined above are reflected in a multitude of composite classifications based on their fillers [4,6,7,13-17].
Clinical Studies of early composites placed in posterior teeth have revealed substantial wear [18]. With the improvement of the filler technology as described above, the longevity of posterior composite restorations can be excellent. The survival behavior of restorations is shown best with Kaplan-

Table 1. Materials used incl. filler composition.

Name	Color	Type	Filler	Manufacturer	Batch #
Admira Fusion (AF)	A2	Universal Nanohybrid-Ormocer	84% w/w inorganic fillers: SiO_2 glass and nanoparticles	Voco GmbH, Cuxhaven, Germany	1638273
Filtek Supreme Ultra (FS)	A2 Enamel	Ultra Universal	Agglomerated zirconia/silica cluster, average cluster size 0.6 – 20 µm. Non agglomerated/non aggregated silica filler 20 nm, and zirconia filler 4 – 11 nm. Total filler 72.5 % w/w	3M Espe St. Paul, MN, USA	N808359
G-aenial Sculpt (GS)	Adult Enamel	Universal Nanohybrid Compactable	Uniform nano-filler dispersion technology Barium glass 300 nm	GC Corp, Tokyo, Japan	1506111
Harmonize (HR)	A2 E Enamel	Nanohybrid Universal	Barium glass 400 nm, Silica and zirconia nanoparticles > 5nm. Average particle size 50 nm Total filler 81 % w/w	Kerr Co., Orange, CA, USA	6173894
Herculite Ultra (HU)	A2 Enamel	Nanohybrid	Ba-glass filler 0.4µm, Prepolymerized Filler, Silica nanofiller, 20 – 50 nm Total filler 78 % w/w	Kerr Co., Orange, CA	6037221
Tetric EvoCeram (TE)	A2 Enamel	Universal Composite	Ba-Al-Silicate glass 0.4 and 0.7 µm, Yterbuimfluoride, Mixed Oxyde 160 nm, Isofiller (Prepolymerized Filler), SiO_2 40 nm	Ivoclar Vivadent, Schaan Liechtenstein	V27337
TPH Spectra (SP)	A2 HV	Universal Composite	Ba-Al-borosilicate glass, Ba-B-F-al-silicate glass, SiO_2. Total filler 77.2% w/w	Dentsply Caulk, Milford, DE, USA	160401
Ultradent UPI Exp 1	A2 Dentin	Universal Composite	Total filler: 68% v/v zirconia-silica glass ceramic and 20 nanometer silica	Ultradent Products Inc., South Jordan, UT, USA	RT00E00A
Ultradent UPI Exp 2	Enamel	Universal Composite	Total filler: 56% v/v zirconia-silica glass ceramic and 20 nanometer silica	Ultradent Products Inc., South Jordan, UT, USA	SW20E15B
Ultradent UPI Exp 3	Enamel	Nano-hybrid Composite	Total filler: 80.9% w/w barium borosilicate glass filler. Average particle size is 0.89 micrometers	Ultradent Products Inc., South Jordan, UT, USA	20E15B

Meier survival statistics. However, with those the comparison of different studies is difficult. Therefore, most authors report the % survival of restorations after a given time (e.g. 5 or 10 years). For direct comparisons these can be converted into %-annual failure rates (AFR). On the one side, clinical long-term studies show annual failure rates (AFR) between 0.1% and 0.67% after 10 years [19], 1.1% after 30 years [20], and 1.5/2.2% after 22 years [21]. On the other hand, higher AFRs have been reported. In a systematic review Opdam et al [22] reported AFRs of 1.8% (5 years) and 2.4% (10 years). However, when discriminating between high caries risk and low caries risk, the respective numbers were 3.2% and 4.6% for high caries risk and 1.2% and 1.6% for low caries risk respectively. A significant material effect could be found as well. In another review article, Demarco et al [23] reported AFRs between 0% and 8.6%, which may allow the question that the dentist may be a significant cofactor. Hickel and Manhart [24] found similar results. They reported AFRs between 0% and 9%. Only 3 out of 24 studies reported wear. The authors concluded that the factors influencing longevity of restorations were the patient, the dentist and the material. In an extensive review about the longevity of restorations Manhart et al [25] found that over time composites have significantly improved. For direct restorations they found in publications before 1990 an AFR of 4.2, while in papers published after 1990 the AFR was 2.0. In the past, composites were specifically developed for a specific indication (anterior or posterior restorations), based on their aesthetic or wear behavior. Contemporary composite materials that have reached a high degree of maturity, are complex constructs [26], and well accepted by the profession. They are designed as universal composites suitable for the application in the anterior and posterior segment. Furthermore, with the improved knowledge of application techniques composites are used for larger restorations as in the past, which brings back the question if composites are sufficiently wear resistant to carry occlusal load. Composite restorations should have similar wear to enamel so restorations behave similarly to teeth. This is important, especially when the indication of

Table 2. Light curing parameters according to manufacturers' instructions for use.

Material	Curing time (s)	Exitance irradiation (mW/cm²)	Radiant exposure (J/cm²)
Admira Fusion	20	1170	23.40
Filtek Supreme Ultra	10	1170	11.70
G-aenial Sculpt	10	1170	11.70
Harmonize	10	1170	11.70
Herculite Ultra	10	1170	11.70
Tetric EvoCeram	10	1170	11.70
TPH Spectra	10	1170	11.70
UPI Exp 1	20	1170	23.40
UPI EXP 2	20	1170	23.40
UPI EXP 3	20	1170	23.40

direct composite restorations includes the buildup of missing cusps. Then the occlusion cannot be supported by natural tooth structure (enamel). Therefore, the aim of this study was to test the wear characteristics of three experimental universal composites as compared to seven commercially available contemporary composites with different filler-compositions. The null hypothesis was that there are no differences in the composite wear as well as in the wear of the antagonists.

2. Materials and Methods

The Universal composite materials used are described in Table 1.

Eighty aluminum sample holders (inner Ø 8 mm depth 1.5 mm) were modified to have mechanical retention, then one coat of universal bond (Monobond Plus, Ivoclar Vivadent, Liechtenstein) was added and left for 60 s, followed by air blasting to evaporate the solvent. Then one coat of adhesive (Optibond FL 2, Kerr, CA, USA) was applied and light cured according to the manufacturers' instructions using a Valo Grand (Ultradent Products, South Jordan, UT, USA) at standard mode delivering 1170 mW/cm², measured with a Bluephase Meter II (Ivoclar Vivadent, Liechtenstein). The composites were filled into the sample holders in one increment, then the top surface was flattened with a Mylar® matrix band and the composites were light cured with a Valo Grand in contact with the matrix band according to the composites manufacturers' instructions (Table 2).

The composite surfaces where finished and polished by using (Sof-Lex Disks, 3M, MN, USA), light orange disc for finishing and yellow disc for polishing for 10-15 s, and the final gloss was obtained with Astropl silicon polishers (Ivoclar Vivadent, Liechtenstein). All samples were stored in distilled water for 3 weeks at 37°C. Steatite balls (Ø 6 mm) mounted into aluminum

Table 3. Settings of Chewing Simulator.

Load	5 kg
Upstroke	2 mm
Downstroke	1 mm
Horizontal movement	0.7 mm
Upward speed	60 mm/s
Downward speed	60 mm/s
Horizontal speed	40 mm/s
Frequency	1 Hz
Thermocycling	5°C-55°C 30 s holding time, transfer time 15 s, total cycle 90 s
Direction	Back and forth

holders with composite were used as antagonists. One antagonist per sample (n = 64) was used and discarded after finishing all cycles.

The chewing simulator was run according to the parameters listed in Table 3. The specimens were simultaneously thermocycled (5/55°C) every 90 s. This resulted in 120,000 mechanical cycles and 1333 thermal cycles as a total. After 5,000, 10,000, 20,000, 40,000, 60,000, 80,000, 100,000, and 120,000 load cycles, Polyvinylsiloxane impressions (Virtual Extra light body, Fast set Wash material, Ivoclar Vivadent, Liechtenstein) using small cylindrical PVC trays were taken from the samples. From the antagonists, impressions were taken before the experiment and after 120,000 cycles (end point of the experiment). All impressions were cast using a dental stone (Micro stone, Whip Mix Co, Louisville, KY, USA).

The stone models were then scanned with a 3D laser scanner, Laserscanner LAS-20 (SD Mechatronik GmbH, Feldkirchen-Westerham, Germany). By using geometric software Geomagic control 2014 (3D Systems, Inc, USA), the scanned data were used to measure the wear of the samples after each round. The flat surface of the sample was used as a reference plain and the wear was calculated as the volume of the wear facet relative to the reference plane. The wear of the steatite antagonists was measured as well in volume loss comparing the initial with the final model. Data were analyzed using ANOVA, linear regression and the Tukey test.

From every group selected samples were dried in ambient air, sputtered with AuPd, and SEM, MIRA3 (TESCAN, PA, USA) pictures at magnifications up to 3200 were taken from the worn surfaces (composite and antagonist) in order to see the wear patterns and possible breakdowns in the surfaces.

3. Results

As expected, from 10,000 – 120,000 load cycles we found a statistically significant linear correlation of wear with chewing cycle (Fig. 1) The ANOVA showed significant differences ($p < 0.0001$). After 120,000 cycles, the total wear of composite in volume varied from 0.428 mm³ to 1.578 mm³.

The volumetric wear for every material after 120,000

Table 4. Wear of composites in mm³ after 120K cycles. Same letter = same statistical group ($p < 0.05$).

Material	Mean ± SD	Statistical group
Admira Fusion	1.578 ± 0.369 mm³	A
UPI Exp 1	0.894 ± 0.278 mm³	B
UPI Exp 2	0.725 ± 0.132 mm³	BC
Tetric EvoCeram	0.714 ± 0.097 mm³	BC
Harmonize	0.658 ± 0.116 mm³	BCD
Filtek Supreme Ultra	0.635 ± 0.077 mm³	BCD
TPH Spectra	0.609 ± 0.088 mm³	CD
Herculite Ultra	0.576 ± 0.072 mm³	CD
UPI Exp 3	0.510 ± 0.042 mm³	CD
G-aenial Sculpt	0.428 ± 0.083 mm³	D

Table 5. Wear of antagonists in mm³ generated by the different composites tested after 120K cycles. Same letter = same statistical group ($p < 0.05$).

Material	mean ± SD	Statistical group
G-aenial Sculpt	0.290 ± 0.023 mm³	A
Herculite Ultra	0.231 ± 0.024 mm³	B
UPI Exp 2	0.210 ± 0.024 mm³	BC
Harmonize	0.206 ± 0.025 mm³	BC
TPH Spectra	0.175 ± 0.018 mm³	C
UPI Exp 3	0.130 ± 0.037 mm3	D
Tetric EvoCeram	0.129 ± 0.028 mm³	D
UPI Exp 1	0.121 ± 0.026 mm³	D
Filtek Supreme Ultra	0.113 ± 0.017 mm³	D
Admira Fusion	0.100 ± 0.017 mm³	D

load cycles is shown in Table 4. The different composites created significantly different wear of the steatite antagonists ($p < 0.05$) (Table 5 and Fig. 2). Note that AF had significantly more wear than all other materials tested. GS showed the least wear; however, it shared this position with UPI Exp3, HU, SP, FS and HR. Since most composites wear in a similar way, there is a lot of overlap between 0.6 mm³ and 0.9 mm³ volume loss.

In general, the antagonist wear was a fraction of the composite wear and as a trend, materials which were worn a lot, produced the least antagonist wear, as seen with AF. On the other side, the material that showed the least wear (GS), was the most aggressive against the antagonist. When looking at wear as a system, then the total wear (∑composite wear + antagonist wear) is of interest Fig. 3). Here the ranking was similar to the one of composite wear. However, UPI Exp 3 due to its very low antagonist wear ended up having the least total wear.

Some selected SEMs are shown in Figs 5-11. The composites mostly revealed the filler structure at high magnification (Figs 4–9), while the antagonists were either smooth or showed various degrees of

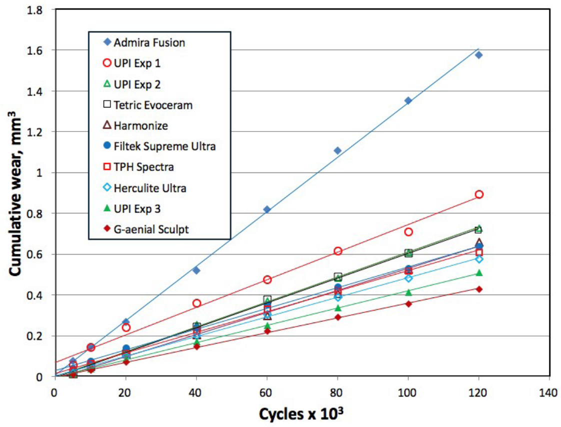

Figure 1. Cumulative wear of ten composites up to 120,000 load cycles. ($p < 0.0001$).

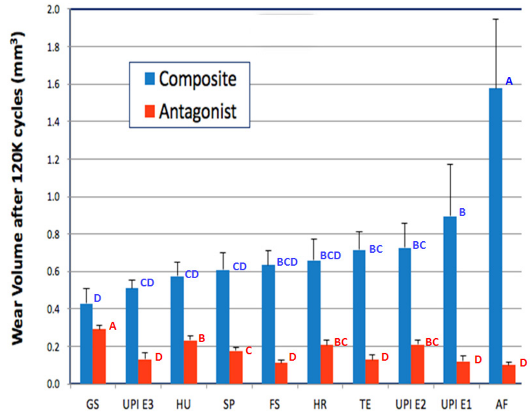

Figure 2. Wear volume of ten composites and the corresponding antagonists after 120,000 load cycles. Blue letters show same statistical group for composites, red letter for antagonists ($p < 0.05$). AF = Admira Fusion, FS = Filtek Supreme, GS = G-aenial Sculpt, HR = Harmonize, HU = Herculite Ultra, TE = Tetric Evoceram, SP = TPH Spectra, UPI Exp 1-3 = Ultradent experimental composites.

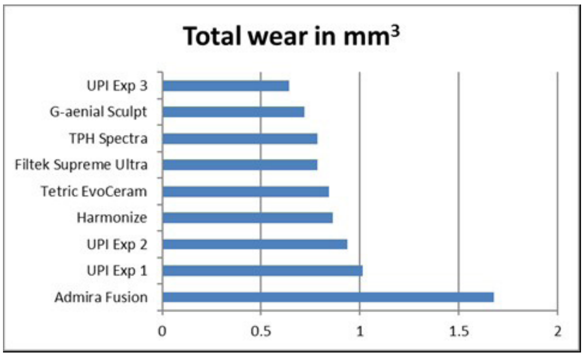

Figure 3. Total wear (∑ of composite + antagonist wear) in mm³..

scratches. Furthermore, pores were visible as well (Figs. 10 and 11).

4. Discussion

The seven commercial universal composites represent a selection of widely used materials. The three experimental materials were formulations of composites to be placed in the same market segment. All composites were light cured according to manufacturer's recommendations which reflects the condition of their clinical use. As can be seen in Table 2 the radiant exposure was

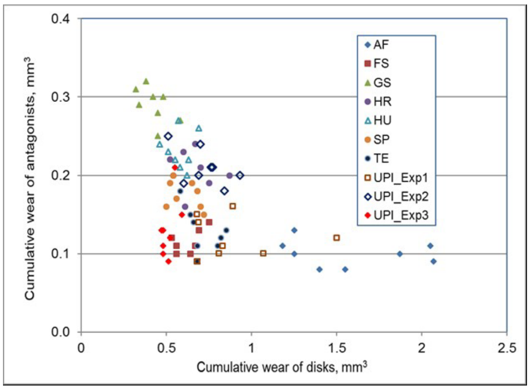

Figure 4. Cumulative wear of composites vs cumulative wear of Antagonists. AF = Admira Fusion, FS = Filtek Supreme, GS = G-aenial Sculpt, HR = Harmonize, HU = Herculite Ultra, TE = Tetric Evoceram, SP = TPH Spectra, UPI Exp 1-3 = Ultradent experimental composites.

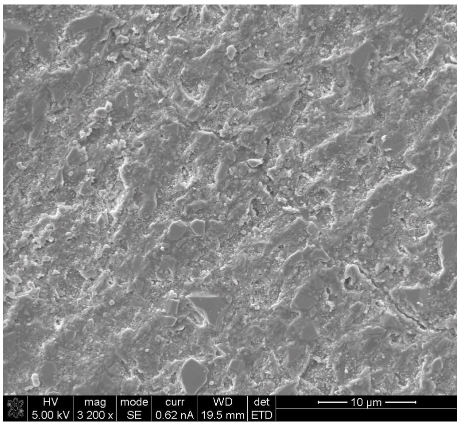

Figure 5. Worn surface of AF. Note the sharp filler particles and the fracture line. SEM 3200 (AF1 011).

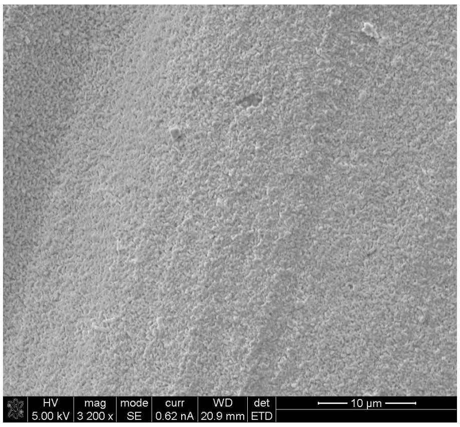

Figure 6. Worn surface of GS. Note the fine granular surface. SEM 3200x (GS2-016).

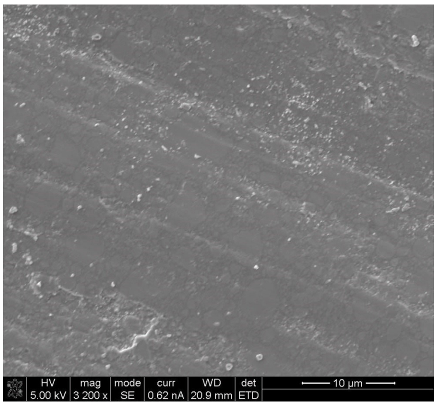

Figure 7 Worn surface of UPI Exp 1 Note the filler particles that are well integrated SEM 3200x (MO1-014).

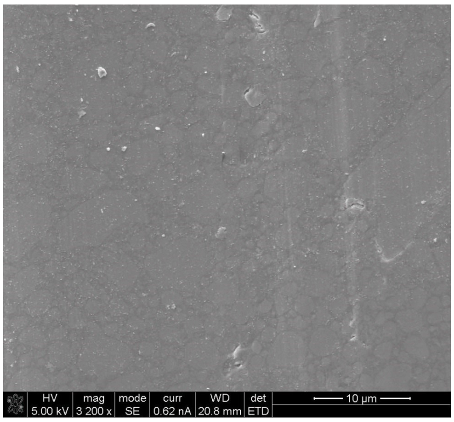

Figure 8. Worn surface of UPI Exp2. Note the larger particles as compared to the ones in Fig 6 (M006).

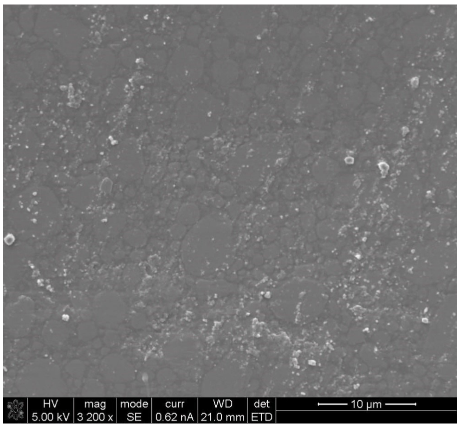

Figure 9. Worn surface of UPI Exp 3. Note the densly packed spherical particles of various sizes. (Mu2-15).

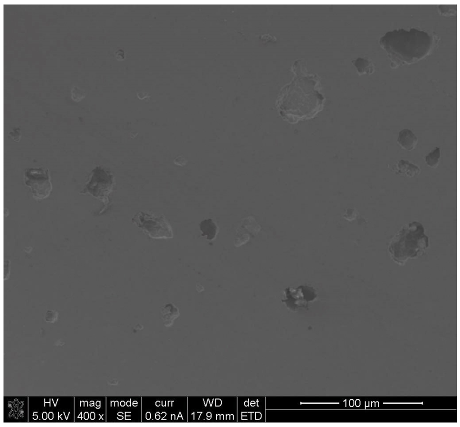

Figure 10. Antagonist worn by AF. Note the smooth surface and the pores SEM 400x. (Af Ant 004).

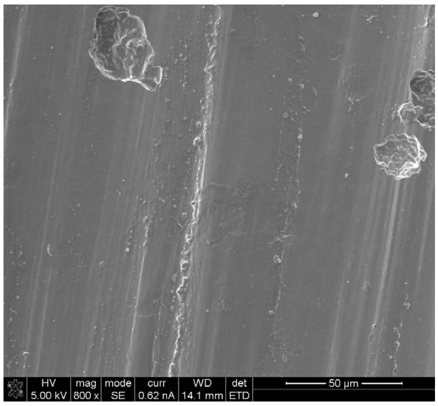

Figure 11. Antagonist surface worn by GS. Note the pores and the scratches. (GS 2 Ant 004).

between 11.7 and 23.4 J/cm², which is within the recommendations found in the literature to cure 2 mm depth of composite [27,28].

Wear is a complex process. Therefore, there is no specific standard for testing wear of dental restorative materials. Especially in vitro, it is difficult to completely mimic the clinical situation. The various in vitro wear simulating machines use different approaches; recently, however, two-body wear machines with a sliding component and preferably computer-controlled forces and movements have been preferred [29]. Since every wear tester uses a different theoretical model [29], different antagonists are used in terms of material, shape and dimensions [30-35]. In the present work, spherical steatite antagonists (ø 6 mm) were used because of their hardness, reproducibility, the standard shape similar to a molar cusp, and the easy availability. It was deliberately decided not to use enamel as antagonists, due to variability in mechanical properties and shape. Attempts to grind natural cusp tips into a standard shape have revealed additional defects which would contribute to the variability of the expected results. In addition, most Mechatronics chewing simulator users use steatite antagonists, allowing comparisons with other studies. For the operation of the chewing simulator standard parameters as recommended by the manufacturer were used [36]. Therefore, our data are comparable to those of the Ivoclar Vivadent group in Schaan [26]. The Ivoclar protocol uses standardized Empress (leucite ceramics) antagonists that are in the shape of a molar cusp, while in the present experiment spherical steatite antagonists were used, which may explain the slightly different findings.

The wear values obtained with similar composite materials in a previous experiment [37] were approximately twice that of those in the present study using the same chewing simulator. This difference can be explained by the different chewing force [37]. In the present experiment, a load of 49 N was used, while in the previous experiment the load was 59 N, which seems to be too much since fractures of the same samples had occurred. It is difficult to determine the actual chewing force in vivo under function. Literature data show a large variation (20-120 N). The decision to use 49 N was based on a publication by Gibbs et al. [38], where 49 N were found to be the average chewing force under normal function.

A laser scanner was used to measure wear facets. Heintze et al. [39] have shown that there is no significant difference between a mechanical or optical profilometer and a laser scanner.

For the present study, almost the same method was used as in previous studies [36,37]. The difference was that in the Matias study, the composite samples and the antagonists were directly scanned, while in the present study we chose to use hard plaster replicas. The reason for this was that when we scanned directly facets in polished, flat composite or ceramic surfaces and analyzed them with the Geomagic software, we found distortions in the flat surface at the transition to the facet [40]. In addition,

Table 6. Wear rate in x 10^{-6} mm³/cycle of the tested materials. Same letter = means same statistical group ($p < 0.05$).

Material	mean ± SD	Statistical group
Admira Fusion	13.33 ± 3.24	A
UPI Exp 1	6.77 ± 1.83	B
UPI Exp 2	6.11 ± 1.15	BC
Tetric EvoCeram	6.09 ± 0.95	BC
Harmonize	5.40 ±1.00	BCD
Filtek Supreme Ultra	5.1 ± 0.72	BCD
TPH Spectra	5.04 ± 0.74	CD
Herculite Ultra	5.40 ± 0.54	CD
UPI Exp 3	4.26 ± 0.49	CD
G-aenial Sculpt	3.26 ± 0.73	D

we had two evaluators who outlined the wear facets and measured the volume as an expression of wear based on the LAS 20 scans, which obtained identical data. All in all, this resulted in small standard deviations so that we could differentiate the material wear of the different materials at an early stage.

As in earlier experiments [36,37], the wear behavior was inconsistent in the first 5,000 - 10,000 cycles and had a higher variability. This is a well-known effect called "running in". Therefore, the analysis of the data began at 10,000 cycles. From this point on the wear development was linear with an excellent correlation with the number of cycles ($R^2 > 0.98$, see Fig. 2), reflecting the results of Heintze et al. [31,39], Wang et al. [41] and Matias et al [37].

When comparing the wear volume, the tested composites had approximately the same values as Tetric N Ceram Bulkfil, as tested in an earlier study [36], where at 120,000 load cycles, Tetric Ceram Bulkfil showed 0.66 ± 0.27 mm³ whereas in the present study Tetric Ceram had 0.714 ± 0.097 mm³ wear. The wear data of the present study are also comparable to those presented by Lendenmann and Wanner [26] for a large group of composites. The slight differences can be explained by the fact that different antagonists were used. In the present work, steatite spheres with a diameter of 6 mm were used, while the Ivoclar-Vivadent method used Empress antagonists in the shape of a molar cusp [26].

The linear wear development over time confirms the results of previous studies and allows formulating a wear rate for each material (Table 6). Considering that there are 4 statistical groups for the wear and the wear rate of the composites (Table 4 and 6, Fig. 2) the null hypothesis is rejected. The same is true for the antagonist wear (Table 5, Fig. 2).

To better understand the wear behavior of the tested composites, a plot of wear of composite vs wear of antagonists was created (Fig. 4). Some trends became visible. On the one side there is GS which forms a quite well-defined cluster with low wear and high antagonist wear. On the other side, namely the other extreme, it seems that AF forms its own group with very low antagonist wear but high composite wear. There we notice as well that for the composite wear there is a wide spread of the data points especially towards high wear. All other composites, with the exception of UPI Exp1 that has two "outlieres" they all form a big cluster which explains the overlap with statistical groups. Using the SEM pictures one can speculate about different wear mechanisms. AF (Fig. 5) seems to contain sharp edged filler particles up to 3 µm, which seem to be dislocating from the surface. In Fig. 4 even a fracture line is visible. These may explain the high wear of the material. Furthermore, AF is the only material under test that contains an ormocere as matrix, which may as well be the reason for the higher wear. On the other side, GS showed itself a scratch pattern, but "grooves" and "mountains" showed the same very small granular structure (Fig. 6). It seems that very small and hard filler particles, which are well retained to the matrix are responsible for the high wear of the antagonists as well as for the low wear of the material itself.

The UPI Exp1 and UPI Exp2 are the "Dentin" and the "Enamel" version of the same material. Regarding wear, they are in the same statistical group, which they share with TE, HR and FS. However, their structure as seen in Figs. 7 and 8 is slightly different. Both have spheroid/spherical fillers which seem to be perfectly integrated into the matrix. However, the size seems to vary slightly. The "dentin" version (UPI Exp 1) contains particles which have sizes below 4 µm, while the "enamel" version has not only filler particles of about the same dimension, but there are also definitely larger particles (8-10 µm and larger).This makes sense, since the light is scattered at the resin filler interface, which means that with larger filler particle less scattering and thus more translucency may be expected. UPI EXP3 (Fig. 9) seems to be based on a different approach. Most of the particles seem to be spherical, but there is a wide range of sizes. Thus, they may have been produced with spray flame pyrolysis [10] and the manufacturer has attempted to reach a maximum filler load by using different ranges of particle distributions [8]. This may be an explanation for its good wear behavior.

The different scratch patterns seen on the antagonists should correlate to the measured wear. This was only partly conclusive. The antagonists of AF seem polished (Fig. 10) while the antagonists of UPI EXP3 seem almost untouched. On the other side severe scratches could be observed on the antagonists of GS (Fig. 11) and SP. The other materials have more or less similar scratch patterns of median expression. Basically, one could expect that fillers with lower hardness would produce less scratches.

Every known wear testing device has a different approach on how to simulate wear [31]. Therefore, direct comparisons of numeric values, e.g. volumetric or vertical wear are impossible. Thus, only studies done with Willitec/Mechatronik wear testing machines can be used to perform direct comparisons with the present study. However, this is difficult as well, since there are only a few studies available which have tested the same composite materials. Lazaridou et al [33] have tested among others G-aenial Posterior, Tetric Evo Ceram and Filtek Supreme XTE. From these 3 materials only Tetric EvoCeram is the same material as the one tested in the present study. The other two are predecessors with a less developed technology as the comparable ones in the present study. For Tetric EvoCeram they report 0.33 ± 0.052 mm^3, while in the present study the same material showed 0.714 ± 0.097 mm^3 volumetric wear. This is substantially higher. The comparison between Filtek Suprem XTE and Filtec Supreme Ultra is about the same (0.374 ± 0.05 mm^3 vs 0.635 ± 0.077 mm^3) with the incertitude about the slight material difference. The discrepancy can be explained with a slight difference in the methods. Lazaridou et al were loading the samples in water at 37°C, while in the present study the samples were thermocycled, which represents an additional stress. On the other hand, the difference between G-aenial Posterior and GS (0.342 ± 0.07 mm^3 vs 0.427 ± 0.083 mm^3) is only minimal, which leads to the assumption that this material has been significantly improved over the years.

In the present study the wear of TE was determined to be 0.7 mm^3. Heintze et al [39] have used almost the same approach as used in this study and measured for Tetric Ceram, approx. 0.6 mm^3; Tetric N Ceram's wear was determined with the same method being approximately 0.5 mm^3 and the one of Tetric EvoCeram was approximately 0.4 mm^3 [42]. These data compare well with the values of D'Arcangelo et al. [30] which reported mean wear values for different direct composites between 0.529 ± 0.139 mm^3 and 1.425 ± 0.245 mm^3. This is almost the same range as was found in the present study despite the fact that they used a different antagonist (3 mm ø zirkonium oxide).

Early composites showed definitely more wear than enamel [18], but during the continuous improvement of composite resins, the materials characteristics, especially the physical and mechanical data got improved much [5] and the wear characteristics improved as well. With this fact, other characteristics have become more important for the clinicians in the selection process for the favorite material to use. Aesthetic considerations (shade, chameleon effect), ease of application (bulk fil, thixotropy, low stickiness) or good short-term outcome (no postoperative pain) got more into the focus in the last years. Never the less wear of the tested composites is still higher than the wear of enamel [36]. Therefore, the wear behavior should, among other parameters, still be part of the evaluation process of resin composites.

5. Conclusions

The majority of the tested composites showed a similar wear behavior with slight differences of the measured volumetric wear. Some materials were either positioned on the high side (AF with significantly higher wear) and GS with the lowest wear. If one considers total wear, then UPI EXP 3 showed the most favorable outcome with low wear and the lowest antagonist wear.

Since these results were produced with an in vitro wear simulation, the transposition of the outcome into the clinical situation should be done with much caution.

Authors contributions

JFR: idea, experimental design, wrote manuscript. HH: performed experiment, measured wear. NA: performed experiment, measured wear. CS: did statistical analysis, contributed substantially to discussion.

Conflict of Interest

All authors declare that they have no conflict of interest.

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Questions

1. An universal composite is:

❑a. A composite with a universal, standard filler;
❑b. A composite which allows restorations with all cavity classes;
❑c. A composite for high esthetic indications;
❑d. A composite with high wear resistance.

2. The materials were stressed as follows:

❑a. Mechanical stress static 100 N for 50 h;
❑b. Thermocycling for 1333 cycles from 5°C to 55°C;
❑c. 120,000 mechanical cycles with 50 N maximum force and lateral movement under load;
❑d. 120,000 mechanical cycles with 50 N maximum force and lateral movement under load and thermocycling for 1333 cycles from 5°C to 55°C.

3. Composite wear results:

❑a. There were significant differences between the materials with G-aenial Sculpt having the least wear and UPI Exp1 and 2, Tetric EvoCeram, Filtec Supreme Ultra, and Admira Fusion being in the group with the highest wear;
❑b. There were no statistical differences in the wear rate of the different composites tested;
❑c. The measured wear varied between 0.05 mm^3 and 0.4 mm^3;
❑d. The standard deviation was more than 50%.

4. The antagonist wear was:

❑a. Larger than the composite wear;
❑b. Equal to the composite wear;
❑c. Strongly correlated to the composite wear;
❑d. Much smaller than the composite wear with the exception of G-aenial Sculpt.