Original Article

Evaluation of wear amounts of different composite resin attachments used in clear aligner treatment over a 6-month period: a retrospective study

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ABSTRACT

Objectives: To compare surface wear among three different attachment composite resins over a 6-month follow-up period.

Materials and Methods: Intraoral scanning was performed on 28 participants immediately after initial bonding of attachments (T0), and at 1 (T1), 3 (T2), and 6 months (T3) after starting aligner treatment. In Group 1 (N = 154 attachments), Tokuyama Estelite Universal Flow; in Group 2 (N = 166 attachments), Filtek Z350 XT Universal Restorative; and in Group 3 (N = 161 attachments), G-ænial Universal Injectable resins were used for bonding the attachments. The surface wear depth on attachments was measured using superimposed digitized models. Kruskal-Wallis and Friedman tests were used with a significance set at 5%.

Results: As treatment progressed, surface wear increased significantly in all groups ($P < .001$). The wear amount for Group 3 was significantly greater than that for Groups 1 and 2 at the 3-month period ($P < .001$). Regarding T0–T3 surface wear, Group 2 (0.03 mm) and Group 3 (0.0609 mm) exhibited significantly greater wear than Group 1 (0.0243 mm; $P = .024$ and $P < .001$). Surface wear was also significantly greater in Group 3 than in Group 2 ($P < .001$). No significant difference was observed in T3–T0 wear values between conventional and optimized attachments within each group.

Conclusions: The wear of orthodontic attachments was greatly influenced by the type of composite resin. During the third and sixth months of the clinical period, G-ænial Universal Injectable resin demonstrated significantly greater surface wear than other resins. After 6 months, Tokuyama Estelite Universal Flow displayed the least surface wear. (*Angle Orthod*. 0000;00:000–000.)

KEY WORDS: Aligner; Attachment; Composite resin; Wear

INTRODUCTION

Clear aligner orthodontic treatment has grown in popularity and provides several benefits, including comfort, esthetics, and greater convenience for maintaining oral hygiene and periodontal health.[1,2] Attachments for aligner therapy are crucial components that are bonded to the labial or lingual surfaces of the teeth to improve aligner retention and aid in tooth movement.[3,4]

Attachments are primarily distinguished by their shape: While conventional attachments are mostly rectangular, optimized attachments have varied and irregular shapes. During clear aligner therapy, it is essential to maintain the integrity of the attachments consistently. Surface wear can occur on the attachments due to factors like brushing, eating, removing, and reseating the appliance. The attachments should resist mechanical stresses caused by the repeated removal and insertion of aligners.[5] Active surfaces of the attachments play a crucial role in transmitting forces to the tooth surfaces. The wear of attachment surfaces may affect the efficiency of clear aligner therapy, as demonstrated in a recent finite element study by Li et al.[6] In that study, the authors emphasized that, as wear of the attachments increased, the efficiency of distalization of the maxillary canines decreased. Additionally, stress resulting from the force during placement

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and removal of aligners could release resin monomers, which could impact cell viability, oxidative stress, and estrogenicity.[7,8]

Flowable or packable nanocomposites, which differ in filler volume and viscosity, are usually preferred by clinicians for preparing aligner attachments.[9,10] The wear of attachments can be influenced by the amount, shape, and size of the fillers as well as the formulation of the resin matrix. Authors of studies have reported that reducing the size of filler particles and increasing the filler loading can improve abrasive wear.[11,12] Authors of several studies[5,13–15] have investigated the surface wear of attachments used in clear aligner therapy. In a recent study[15] in which authors evaluated the surface wear of attachments at periods of 2, 4, 6, and 8 months using Filtek Z350 XT, it was concluded that the attachment wear volume increased gradually with time.

No previous authors have compared different types of composite resins regarding the surface wear values of aligner attachments. Additionally, no authors have compared contemporary universal flowable adhesives with enhanced mechanical properties to universal restorative packable composites. In the present study, the aim was to compare three different composite resins with high esthetic and mechanical characteristics (suprananofilled flowable: Tokuyama Estelite Universal Flow; high-viscosity universal restorative: Filtek Z350 XT Universal Restorative; and nanohybrid flowable: G-ænial Universal Injectable) with the goal of finding the most ideal material related to wear resistance in aligner treatment. The null hypothesis was that no significant difference would be found among the three composite resin types in terms of surface wear amount at follow-up periods of 1, 3, and 6 months.

MATERIALS AND METHODS

Participants in this retrospective study were recruited from patients who received aligner orthodontic therapy between October 2022 and 2024 at the Department of Orthodontics, Faculty of Dentistry, University of Hacettepe. The study protocol was approved by the Ethics Review Committee of Hacettepe University (SBA 24/358).

Sample size was calculated using G*Power version 3.1.9.7 (Düsseldorf, Germany). A minimum of seven samples per group was required (effect size: 1.985; power: 95%; $\alpha = .05$) based on expected volume loss differences (0.59 ± 0.07 mm^3 vs 0.75 ± 0.09 mm^3).[13] To increase power and account for potential losses, a minimum of 150 attachments per group was included.

Twenty-eight consecutive patients treated with aligners in the orthodontic department were selected. The inclusion criteria were (1) data from patients treated with Invisalign (Align Technology, Inc., Tempe, AZ, USA); (2) patients aged between 11 and 35 years old with permanent dentition at the beginning of the treatment; (3) patients who had aligner attachments bonded to tooth surfaces using one of three different composite materials (Tokuyama Estelite Universal Flow, Filtek Z350 XT Universal Restorative, and G-ænial Universal Injectable); (4) patients who had three-dimensional (3D) digital models taken at the beginning of treatment (T0) and 1 (T1), 3 (T2), and 6 months (T3) after. Exclusion criteria were (1) teeth with surface changes due to enamel anomalies, (2) resin or crown restorations on tooth surfaces, and (3) patients who demonstrated poor compliance with the aligner protocol.

Chewies to improve aligner seating and intermaxillary elastics were not used for the first 6 months of the period. Interproximal Reduction (IPR) was performed as described in each patient's virtual treatment plan. Control appointments were fixed at 4-week intervals. Patients were instructed to wear their aligners for at least 20 hours daily and to change them every 7 days. The attachments on the upper and lower arches were bonded with Invisalign attachment templates produced for each patient using one of three different composite resins by the same investigator (G.A.; Table 1). In all groups, the buccal tooth surface was etched with 37% phosphoric acid gel (3M Unitek, Monrovia, Calif) for 30 seconds, thoroughly rinsed with water, and then dried with gentle air. Each bonding protocol was performed according to the manufacturer's instructions.

Group 1 (9 patients, N = 154 attachments): Tokuyama Bond Force II (Tokuyama Dental, Tokyo, Japan) was applied for 10 seconds, thoroughly dried for 5 seconds, and light-cured. Tokuyama Estelite Universal Flow resin (Tokuyama Dental) was used to bond the attachments.

Group 2 (10 patients, N = 166 attachments): Adper Single Bond 2 (3M Unitek, Monrovia, Calif) was applied to the roughened enamel surface for 15 seconds, air-dried for 5 seconds, and light cured. Filtek Z350 XT Universal Restorative resin (3M Unitek) was used to bond the attachments.

Group 3 (9 patients, N = 161 attachments): A thin G-Premio bond (GC Corp, Tokyo, Japan) was applied to the enamel surfaces for 10 seconds. It was then thoroughly dried for 5 seconds and light-cured. G-ænial Universal Injectable resin (GC Corp) was used for bonding the attachments.

In Groups 1 and 3, the flowable resins were injected into the attachment gaps, while in Group 2, the composite resin was placed in the attachment gaps with a spatula. Each attachment was light-cured for 10 seconds using a VALO LED curing unit (Ultradent Products, Inc., South Jordan, Utah) with 1200 mW/cm^2 intensity.

Patients underwent intraoral scanning using an iTero Element 2 scanner (Align Technology) four

Table 1. Materials Used for Composite Attachment Bonding[a]

Composite	Chemical Composition	Filler % by Weight (Volume)	Manufacturer
Estelite Universal Flow (superlow flow; supranano filled flowable composite)	Bis-GMA, bis-MPEPP, TEGDMA, UDMA, spherical silica-zirconia filler, camphorquinone, radical amplifying agent	70% (56%)	Tokuyama Dental, Tokyo, Japan
Filtek Z350 XT (high-viscosity universal restorative)	Silica, zirconia, aggregated zirconia/silica, bis-GMA, UDMA, TEGDMA, dimethacrylate	78.5% (59.5%)	3M Unitek, Monrovia, Calif
G-ænial Universal Injectable (nanohybrid flowable)	Bis-EMA, dimethacrylate comonomers, UDMA, silica, barium glass (filler content: 69 wt%/50 vol%)	69% (50%)	GC Corporation, Tokyo, Japan

[a] EMA indicates, A ethoxylated dimethacrylate; GMA, A glycol dimethacrylate; MPEPP, A polyethoxy dimethacrylate; TEGDMA, triethylene glycol dimethacrylate; UDMA, urethane dimethacrylate.

times: immediately after initial bonding (T0), and at 1 (T1), 3 (T2), and 6 months (T3) after starting treatment. All 3D models were exported in stereolithography (.stl) format for analysis. Clinical information regarding the attachments (composite, attachment, tooth, and dental arch) was noted. If lost attachments were observed during regular appointments, these attachments were excluded from the analysis.

All digitized models were imported into Geomagic Control X software (3D Systems, Rock Hill, SC) for superimposition, and all teeth with single-bonded attachments were analyzed. Lingual and occlusal surfaces were chosen for the superimposition of the models since no attachments were bonded on them. The model at time T0 was defined as a Computer-Aided Design (CAD) (reference) model; the models at time T1, T2, and T3 were defined as MESH models. To perform "Best Fit Alignment," the reference model was divided into segments using the "Resegment" command of the program. The teeth with attachments were converted into separate segments. With this command, the superimposition process was performed on a per-tooth basis using the Best Fit Alignment command of the program (Figure 1). The superimposition accuracy between the reference values was examined with the "3D Compare" command (Figure 2). The deviation on the outermost buccal surfaces of the tooth was controlled with the "deviation" option of the superimposed tooth. The average surface wear depth from the most convex area of the buccal surface of the attachment to the reference was revealed for both attachment types (Figures 3A and 3B).

To ensure consistency across all steps, a single engineer performed the segmentation and alignment procedures. All measurements were taken twice by the same operator with a 2-week interval, and the average values were calculated.

Figure 1. Using the "Best Fit Alignment" command.

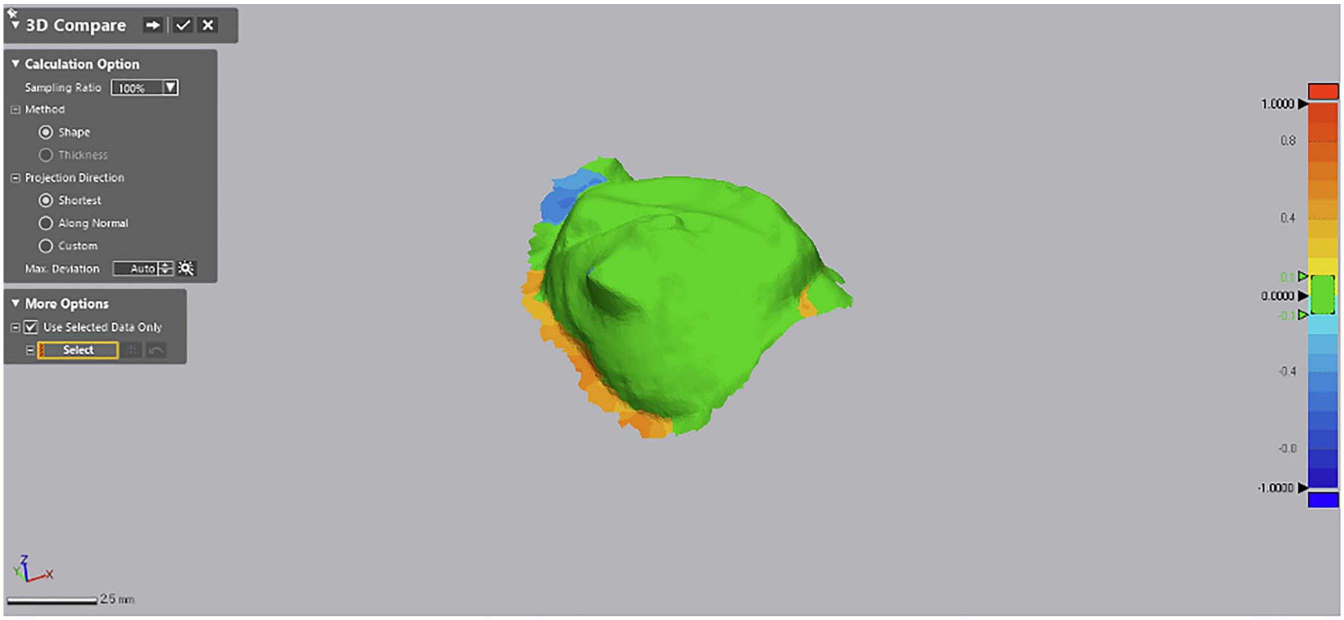

Figure 2. Using the “3D Compare” command.

Statistical Analysis

IBM SPSS 27.0 (IBM Corp., Armonk, NY, USA Release 2017) was used to conduct the analyses. Data were presented as number (percentage), mean ± standard deviation, and median (interquartile range). Normality and homogeneity were assessed with Shapiro-Wilk and Levene’s tests, respectively. The Kruskal-Wallis test was used to compare three independent groups that did not have a normal distribution. The Friedman test was used to examine the differences among three dependent groups. Post hoc corrected Bonferroni tests were employed to identify the group that created the difference. The Pearson χ^2 test was used in cases where the sample size assumption (expected value > 5) was met in testing the relationship between categorical variables. The significance level was set at $P < .05$.

RESULTS

Table 2 presents the clinical characteristics of the participants and attachments. No significant group differences were found in gender, malocclusion, growth pattern, tooth group, or dental arch. However, attachment type distribution differed significantly, with more optimized attachments in Group 1 and more conventional types in Groups 2 and 3 ($P < .001$).

Table 3 and Figure 4 show the comparison of wear measurements between different composite groups for each observation time. Measurements of T1–T0 surface wear were greater in Group 1 than in Group 2 ($P = .002$) and Group 3 ($P = .001$). For T2–T0 surface wear, the measurements for Group 3 were significantly greater than those for Groups 1 and 2 at the third month ($P < .001$). For T3–T0 surface wear measurements, Groups 2 and 3 showed significantly higher values than Group 1 ($P = .024$ and $P < .001$). The surface wear amount was also significantly higher in Group 3 than in Group 2 ($P < .001$). Surface wear differed significantly over time in all groups ($P < .001$; Table 3).

No significant T3–T0 wear difference was found between conventional and optimized attachments within each group (Table 4).

DISCUSSION

The purpose of this study was to assess and compare the wear resistance of universal flowable and conventional composite resins with different filler characteristics. In the present study, the outermost buccal surface edge ridges were evaluated for 3D deviation analyses, as it was stated in a recent study[15] that the deepest wear regions were located at the corners of the edges. In the present study, the null hypothesis was rejected, showing a significant difference in surface wear among three types of attachment composite resins during the follow-up periods.

It is known that the wear resistance of composite resins can be affected by the filler content, characteristics of the matrix, and the bond between the filler and the matrix.[16,17] Also, the filler size, quantity, geometry, and distribution affect the composite material wear properties.[17] In the present study, two highly filled universal flowable resins with different filler properties were chosen (Tokuyama Estelite Universal Flow resin

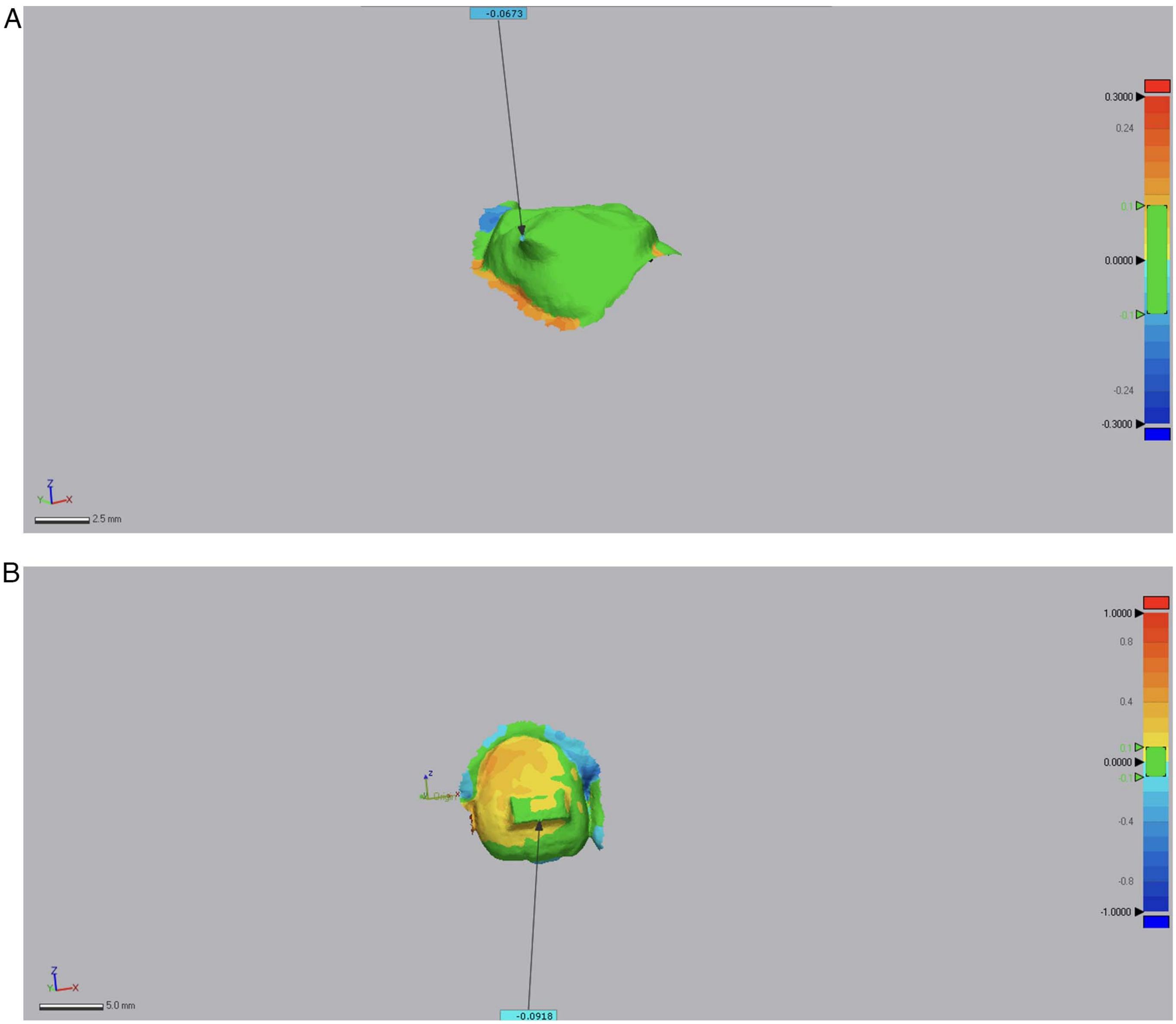

Figure 3. The average wear depth on the attachments. (A) Optimized; (B) conventional attachment.

and G-ænial Universal Injectable) to be compared with a universal packable composite because these materials have a lower modulus of elasticity along with improved mechanical properties and wear resistance.[18,19] According to the results of this study, during the third and sixth months of the clinical period, G-ænial Universal Injectable resin demonstrated significantly greater surface wear compared with the Tokuyama Estelite Universal Flow and Filtek XT Universal Restorative resins. The primary reason for the increased wear of G-ænial Universal Injectable resin may have been due to its lower filler loading than other resin materials. Chen et al.[13] also demonstrated that the wear volume loss of Filtek Z350XT Flowable resin with low filler loading was significantly greater than Filtek Z350XT and SonicFill with higher filler loadings.

Barreda et al.[5] used scanning electron microscopy to identify changes in the surface texture of attachments after 6 months of clinical use. According to their findings, significantly more surface wear was observed with a microfilled composite (Amelogen Plus TW) containing 76% filler compared with a nanofilled composite (Filtek Z350 XT), which had 72.5% filler content. Upon reviewing the 6-month results in the current study, Filtek Z350 XT Universal Restorative resin showed significantly less wear than the G-ænial Universal Injectable group; however, it displayed notably more wear value than the Tokuyama Estelite

Table 2. Clinical Characteristics of Included Participants and Attachments

	Group 1 (Tokuyama Estelite Universal Flow)	Group 2 (Filtek Z350 XT Universal Restorative)	Group 3 (G-ænial Universal Injectable)	Test Statistics	*P* Value
Age, mean ± SD	20.1 ± 8.65	23.66 ± 8.08	22.1 ± 8.16	12.840	.002*
Gender, No. (%)					
Female	7 (70%)	5 (55.6%)	5 (55.6%)	0.671[a]	.794
Male	3 (30%)	4 (44.4%)	4 (44.4%)		
Malocclusion, No. (%)					
Class I	3 (30%)	4 (44.4%)	3 (33.3%)	1.996[a]	.868
Class II	6 (60%)	4 (44.4%)	6 (66.7%)		
Class III	1 (10%)	1 (11.1%)	0 (0%)		
Growth pattern, No. (%)					
Brachiofacial	5 (50%)	2 (22.2%)	3 (33.3%)	3.122[a]	.588
Mesofacial	5 (50%)	5 (55.6%)	5 (55.6%)		
Doligofacial	0 (0%)	2 (22.2%)	1 (11.1%)		
Group of teeth (for attachments), No. (%)					
Molar	40 (24.1%)	40 (24.8%)	45 (29.2%)	3.972[b]	.410
Premolar	66 (39.8%)	51 (31.7%)	50 (32.5%)		
Anterior	60 (36.1%)	70 (43.5%)	59 (38.3%)		
Dental arch (for attachments), No. (%)					
Upper	99 (59.6%)	81 (54.7%)	85 (55.2%)	0.958[b]	.619
Lower	67 (40.4%)	67 (45.3%)	69 (44.8%)		
Attachment type (for attachments), No. (%)					
Optimized	125 (75.3%)	83 (51.6%)	93 (60.4%)	20.147[b]	< .001*
Convenional	41 (24.7%)	78 (48.4%)	61 (39.6%)		

[a] Fisher's exact test.
[b] Pearson χ^2 test was applied.
* $P < .05$ statistically significant.

Universal Flow group. Additionally, the least wear depth was observed for Tokuyama Estelite Universal Flow. The filler types of Tokuyama were quite different, containing small spherical fillers with an average particle size of 200 nm (supranano). The smaller filler particles are more closely packed, and the resin between the fillers is shielded from further abrasion.[20,21] This could have been the main reason for the least wear depth observed in Group 1.

Li and Yang[15] assessed the volume and average depth of attachment wear in three commonly used attachment types (3-mm rectangular, optimized rotating, and optimized root control) at various follow-up intervals. Like the current findings, the amount of wear of the attachments increased significantly as treatment time increased. In the study by Li and Yang,[15] only one type of composite (Filtek Z350 XT) was used, and after a 6-month period, an average wear depth value of nearly 0.04 mm was observed. This value was almost comparable with the value found for Group 2 (median value: 0.03 mm), for which Filtek Z350 XT was used in the current study.

Table 3. Comparison of Surface Wear Measurements According to Study Groups[a]

	Group 1 (Tokuyama Estelite Universal Flow)	Group 2 (Filtek Z350 XT Universal Restorative)	Group 3 (G-ænial Universal Injectable)	Test Statistics	*P* Between Groups
T1–T0 wear (mm)	0.0082 (0.0126, 0.0044)	0.0058 (0.011, 0.002)	0.0048 (0.0095, 0.0017)	16.958[b]	< .001* (1–2, $P = .002$; 1–3, $P = .001$)
T2–T0 wear (mm)	0.0152 (0.0235, 0.0101)	0.0153 (0.033, 0.0075)	0.0281 (0.055, 0.0124)	28.573[b]	< .001* (1–3, $P < .001$; 2–3, $P < .001$)
T3–T0 wear (mm)	0.0243 (0.0434, 0.0157)	0.03 (0.0546, 0.017)	0.0609 (0.0955, 0.032)	68.419[b]	< .001* (1–2, $P = .024$; 1–3, $P < .001$; 2–3, $P < .001$)
Test statistics	261.651[c]	304.261[c]	308.00[c]		
P within groups	< .001*	< .001*	< .001*		

[a] Values are medians (interquartile ranges). The post hoc corrected Bonferroni test revealed the group or groups that caused the difference.
[b] The Kruskal-Wallis test was applied.
[c] The Friedman test was applied.
* $P < .05$ statistically significant.

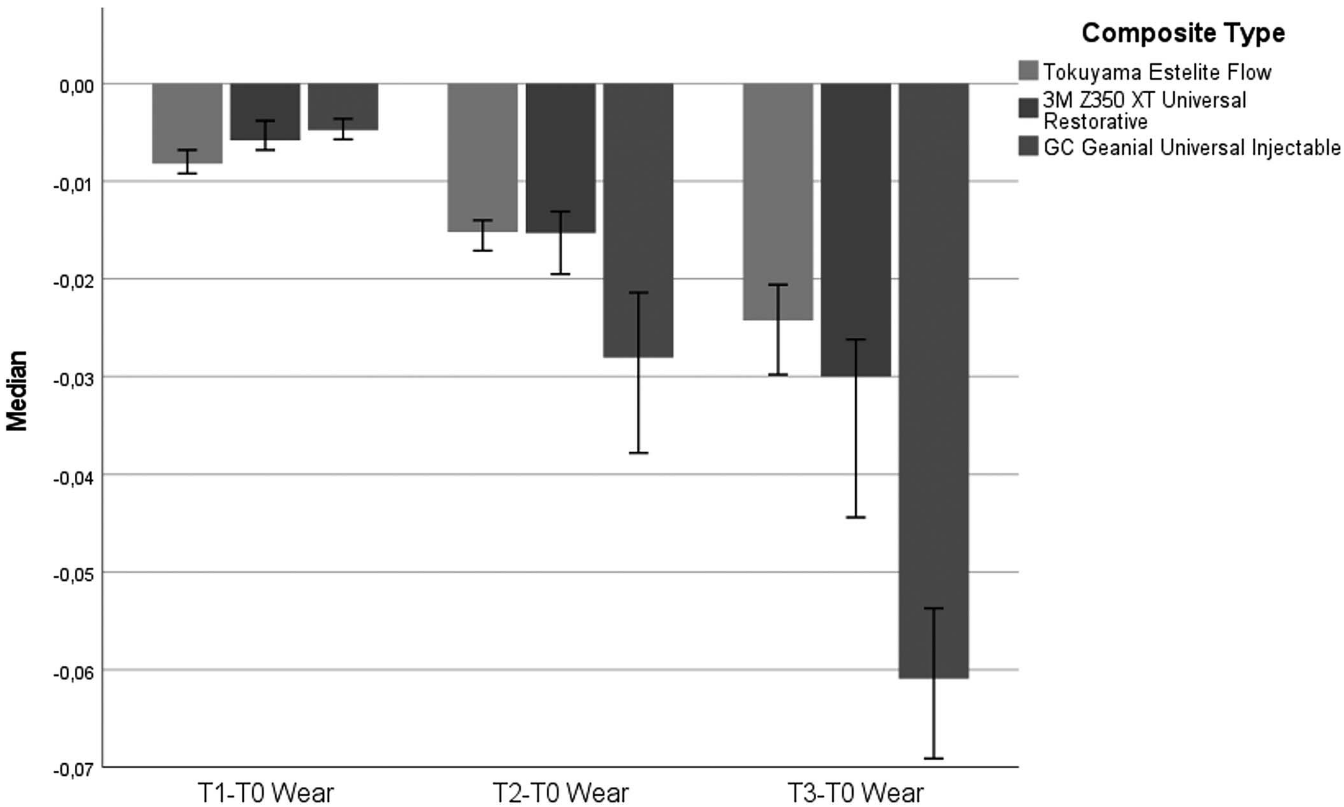

Figure 4. Box plot comparing wear measurements among the different composite groups.

According to the results of this study, the amount of surface wear in all composite resin groups was generally low (below 0.1 mm). It may not be considered clinically significant regarding aligner tracking, retention, or the predictability of tooth movement since the exact impact of attachment wear on tooth movement has rarely been studied.[5] On the other hand, although biochemical parameters were not evaluated in this study, even a small amount of composite wear can lead to undesirable effects in the oral environment, as the grinding of the resin adhesives may exhibit estrogenic action.[22] Authors of a recent study[23] emphasized that 1 week of simulated use of aligners influenced the surface characteristics and degradation rate of composite attachments by releasing monomers. Considering the release of active compounds from composites, selecting materials with lower wear may offer potential clinical benefits for patients.

In the study by Li and Yang,[15] 4 months after treatment, optimized root control attachments demonstrated more relative wear than 3-mm rectangular attachments. According to Fausto da Veiga Jardim et al.,[14] optimized attachments exhibited less surface wear than conventional attachments. However, contrary to these findings, optimized and conventional attachments showed no difference in wear values for the three composite types in the current study. The differences between the studies may be related to variations in composite resin types, specific mechanical forces applied during treatment, analysis of wear patterns on distinct attachment surfaces, scanner precision, methods for superimposition and measurement, and aligner usage instructions.

Table 4. Comparison of T3–T0 Wear Measurements Between Optimized and Conventional Attachments for Each Composite Group[a]

Groups	Variable	Conventional Attachment	Optimized Attachment	Test Statistics	*P* Value
Group 1 (Tokuyama Estelite Universal Flow)	T3–T0 wear (mm)	0.020 (0.037, 0.012)	0.024 (0.044, 0.017)	−1.397[b]	.163
Group 2 (Filtek Z350 XT Universal Restorative)	T3–T0 wear (mm)	0.031 (0.059, 0.018)	0.028 (0.054, 0.016)	−0.731[b]	.465
Group 3 (G-ænial Universal Injectable)	T3–T0 wear (mm)	0.054 (0.084, 0.028)	0.063 (0.096, 0.041)	−1.252[b]	.210

[a] Values are medians (interquartile ranges).
[b] Mann-Whitney *U*-test was applied.
* $P < .05$ statistically significant.

The cumulative damage from repeated stress influences the wear resistance of composite materials.[24] Potential factors that could not be controlled and may have affected the amount of wear in the current study, include tooth brushing, eating habits, occlusal forces, and the number of aligner removals per day. Unequal distribution of optimized vs conventional attachments among the groups could also have served as a confounding factor. Also, the retrospective design may have introduced selection bias. Additionally, the lack of strict standardization of aligner wear time and variability in patient-specific factors could have affected the outcomes. These issues may limit the generalizability of the findings, and future prospective studies are needed to confirm these results.

CONCLUSIONS

- The wear of orthodontic attachments was greatly influenced by the type of composite resin used.
- During the third and sixth months of the clinical period, G-ænial Universal Injectable resin demonstrated significantly greater surface wear than Tokuyama Estelite Universal Flow and Filtek XT Universal Restorative resins.
- Six months posttreatment, Tokuyama Estelite Universal Flow displayed the least surface wear.

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