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Comparative Evaluation of Transfer Accuracy and Surface Wear of Clear Aligner Attachments Fabricated with Different Composite Resin Viscosities: An In Vitro Study

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Abstract

Aim

This in vitro study evaluated the transfer accuracy and surface wear of clear aligner attachments fabricated using composite resins with different viscosities and two attachment designs.

Methods

Thirty-six extracted human teeth were assigned to six groups based on composite resin type (restorative, orthodontic, or flowable) and attachment design (conventional rectangular or optimized cylindrical). Attachments were digitally planned, transferred using 3D-printed templates, and scanned at baseline (T0) and after mounting (T1) to assess transfer accuracy. Samples then underwent simulated toothbrushing for 30,000 cycles at 2 N force before being rescanned (T2–T3). Three-dimensional deviations between scans were quantified using Geomagic Control X. Two-way ANOVA and Tukey HSD tests were used for statistical analysis (α=0.05).

Results

Composite viscosity and attachment design showed no significant influence on transfer accuracy ($P>0.05$). Surface wear differed significantly among groups ($P<0.001$). Restorative composite resin demonstrated the least wear (mean 0.12 mm), followed by orthodontic composite resin, while flowable composite resin exhibited the greatest wear (mean 0.31 mm). Cylindrical attachments generally showed lower wear than rectangular attachments.

Conclusion

Under the conditions of this study, composite resin viscosity did not affect attachment transfer accuracy. Surface wear following simulated toothbrushing was lower in high-filler restorative composites and in optimized cylindrical attachment designs.

Keywords: Orthodontics, Attachment, Surface wear, Clear aligner, Toothbrushing, Viscosity.

Background

Clear aligner therapy (CAT) is a recent and popular advancement in orthodontic appliances, attributed to the growing need for aesthetic orthodontic appliances (1). CAT, at its inception, addressed uncomplicated malocclusions, such as spacing and crowding. Significant advancements in CAT materials and technology have occurred over the last 10 years. Currently, CATs are employed to address complex malocclusions, including extraction cases, open bites, deep bites, sagittal

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corrections, and molar distalization (2-4). Auxiliary features, such as resin attachments, were incorporated to provide more predictable tooth movement, especially in complicated conditions (5). Composite resin attachments are secured to the tooth surface to facilitate tooth movement by augmenting the contact area between the aligner and the teeth, offering pushing surfaces, and enhancing aligner retention. Consequently, this leads to more predictable and effective tooth movement (6,7). Several attachment designs are available, each tailored to a specific tooth movement. Prior research has indicated that the interplay of form, size, and the quantity of attachments can considerably affect the effectiveness of CAT (8,9). The positioning and arrangement of composite attachments significantly influence the overall efficacy of CAT and the aligner (10,11). Another important factor influencing the efficacy of CAT is the type of composite resin used to fabricate aligner attachments. The ideal composite attachment material must possess sufficient optical and mechanical properties and maintain those properties throughout the duration of CAT. Also, it is crucial that it accurately replicates the active surface of the attachment while maintaining dimensional stability under intraoral conditions, since this directly influences the entire aligner force system (12,13). Due to repeated removal of aligners, the composite attachments must withstand mechanical stresses. Furthermore, composite attachments must withstand deterioration from harsh intraoral conditions and from regular oral hygiene activities such as toothbrushing (14).

The literature has documented prior research that evaluated the characteristics of different viscosities of light-cured composite resins used for attachment placement, with a focus on accuracy, bond strength, placement time, and wear (6,15-17). The wear resistance of composite resin is primarily determined by the quantity, dimensions, and morphology of resin fillers, the composition of the resin matrix, and the adhesion between the matrix and the fillers. Abrasive wear can be reduced by minimizing filler particle size and increasing filler loading (18-19). Presently, flowable and packable composite resins with diverse filler and matrix compositions are used to fabricate attachments. To increase clarity, Gazzani et al. (17) investigated the mechanical properties of flowable and non-flowable nanocomposite resins. The study simulated the effects of aligner removal and insertion and evaluated the performance of both composite resins. Nevertheless, research has not examined the impact of routine patient activities, such as brushing, on the surface morphology, specifically the wear resistance, of these composite resins. Therefore, the present study aimed to compare the accuracy of attachment placement and wear caused by toothbrushing of aligner attachments fabricated from three different composite resins. The primary objective was to compare the wear experienced by attachments fabricated from three different aligner materials after simulated toothbrushing. The secondary objective of the study was to compare the transfer accuracy of three different composite resin materials.

Methods

The current in vitro study was conducted after obtaining Institutional Ethics Committee clearance (SRB/SDC/ORTHO-2201/24/275). Written consent was obtained from the patients for the use of extracted teeth in the study.

Sample Preparation

Aligner attachments were fabricated on extracted human teeth. The tooth samples were obtained from patients who had undergone therapeutic extraction or extraction due to periodontal disease. Teeth with restorations, caries, fractures, or developmental defects were excluded from the study.

After extraction, all tooth samples were thoroughly cleaned with distilled water to remove debris, plaque, bone remnants, and soft tissue. The cleaned samples were then stored in a hydrogen peroxide solution in an airtight container until further processing.

Sample Size Calculation

The sample size was estimated using G* Power software (version 3.0.10; Heinrich-Heine-Universität, Dusseldorf, Germany) bases on an a priori F-test with an effect size calculted from a stdy by Chen et al (15). With the effect size *f*=0.588, alpha error probability =0.05 , statistical power(1-beta) =0.85, this resulted in a minimum total sample size of 36, achieving an power of 0.864. Samples were equally distributed among the six experimental groups, with six specimens per groups .

Attachment Design and Fabrication

Two different aligner attachment designs were evaluated in this study. The first design was a conventional rectangular attachment, while the second design was an optimized cylindrical

attachment (Figure 1). The attachments were bonded to the buccal surface of the teeth.

Three types of composite resin materials were used for attachment fabrication:

1. Restorative composite resin (Te-Econom Plus Restorative Composite, Ivoclar Vivadent, USA)
2. Orthodontic composite resin (Enlight Orthodontic Adhesive, Ormco, Glendora, CA, USA)
3. Flowable composite resin (Tetric N Flow Composite, Ivoclar Vivadent, USA)

Based on the attachment design and composite material used, the samples were divided into six experimental groups:

Group 1: Conventional rectangular attachment fabricated with restorative composite resin

Group 2: Optimized cylindrical attachment fabricated with restorative composite resin

Group 3: Conventional rectangular attachment fabricated with orthodontic composite resin

Group 4: Optimized cylindrical attachment fabricated with orthodontic composite resin

Group 5: Conventional rectangular attachment fabricated with flowable composite resin

Group 6: Optimized cylindrical attachment fabricated with flowable composite resin

Scanning and Time-Point Measurements

To evaluate surface changes in the composite attachments, the teeth were scanned at different time points using a three-dimensional scanning system (3 Shape Trios, Copenhagen, Denmark).

T0 (Baseline Scan):

Each tooth was scanned immediately after attachment fabrication to obtain the baseline morphology of the attachment and tooth surface before any mechanical wear.

T1 (Post-Mounting Scan):

After the baseline scan, each tooth specimen was mounted in die stone blocks to stabilize the samples for brushing simulation (Figure 2). A second scan was obtained to verify the accuracy of mounting and to serve as a reference prior to brushing.

T2 (Post-Brushing Simulation Scan):

The mounted specimens were then subjected to simulated toothbrushing using a brushing simulator (Toothbrush Simulator ZM-3.8 SD Mechatronik, GmbH, Feldkirchen-Westerham, Germany). The brushing simulation represented approximately six months of toothbrushing and consisted of 30,000 brushing cycles. The movements included linear motion along the x-axis (10,000 cycles) and y-axis (10,000 cycles), as well as circular motion (5,000 clockwise and 5,000 counterclockwise cycles). A standardized force of 2 N was applied, corresponding to the average brushing force used by adult patients. After completion of the brushing simulation, the teeth were rescanned to assess the resulting surface changes.

T3 (Superimposition):

The scans obtained at different time points were imported into Geomagic Control X software (Hexagone AB, Stockholm, Sweden) and superimposed to evaluate volumetric and surface wear of the attachments. Color-coded deviation maps were generated to visualize differences between the scans and to determine the accuracy and trueness of the attachment surfaces (Figure 3). Superimposition of the models scannedat T0 and T1 indicated the accuracy and trueness of the attachment realization from virtual design.

Surface wear of the composite attachments was assessed by comparing the three-dimensional scans obtained before and after brushing simulation. The superimposed models allowed quantitative and qualitative evaluation of surface deviations. Color maps illustrated the magnitude of surface loss or deformation, thereby enabling assessment of the wear resistance of each attachment type and composite material (Figure 4).

Table 1: Chemical compositions of composite resin materials used in the study

Composite	Brand	Resin	Total content of inorganic fillers	Mean particle size
Restorative	Te-Econom Plus Restorative Composite (Ivoclar, Vivadent, USA)	Dimethacrylate and TEGDMA (22 wt%).	76 wt%	850nm
Orthodontic	Enlight (Ormco, Glendora, Calif)	Dimethacrylate 20-30%	63.1 wt%	0.5-15 μm
Flowable	Tetric N flow (Ivoclar Vivadent USA)	Monomethacrylates and dimethacrylates (28 wt%)	68.2 wt%	5 μm

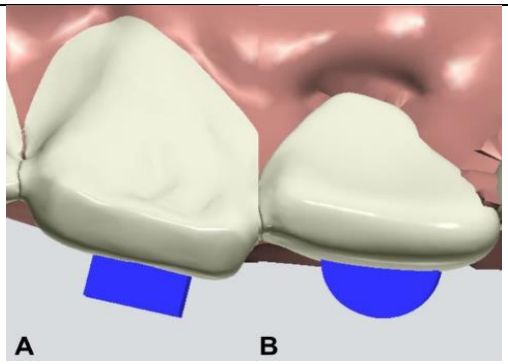

Figure 1: The conventional rectangular and optimized cylindrical attachments planned on the surfaces of the virtual model.

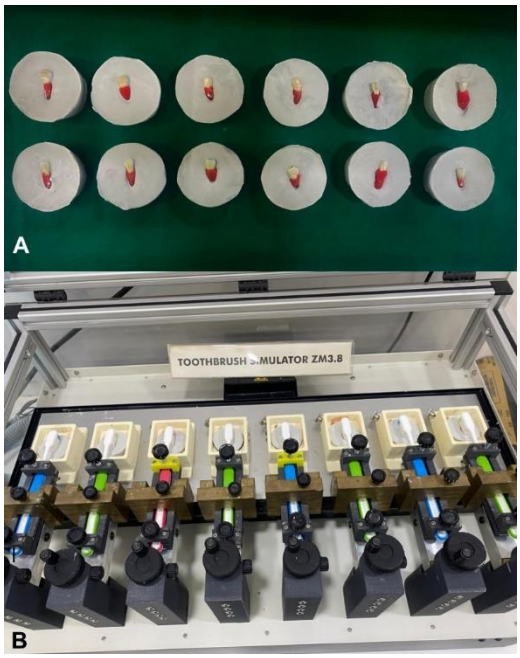

Figure 2: The prepared samples and the samples undergoing simulated brushing using a brushing simulator (ZM-3.8 SD Mechatronik, GmbH, Feldkirchen-Westerham, Germany).

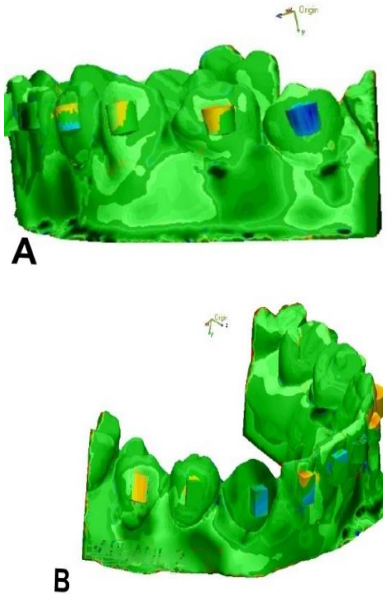

Figure 3: Superimposition of the models scanned at T0 and T1. The color maps indicate the level of accuracy and trueness between virtually planned and realized attachments.

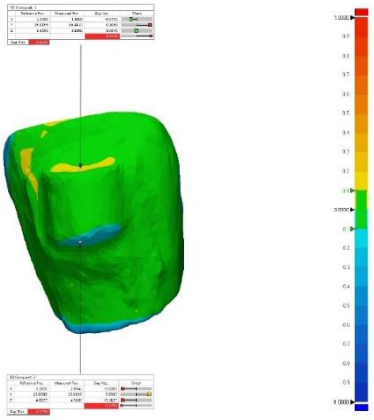

Figure 4: Superimposition of the individual tooth scanned at T2 and T3. The color maps indicate the surface wear due to simulated tooth brushing.

Statistical Analysis

The statistical analysis for this study was carried out using SPSS, version 29 (IBM Corp, Armonk, New York, USA) . The data was found to be normally distributed based on the Shapiro-Wilk test. Transfer accuracy and wear due to toothbrushing on the aligner attachments across six groups were compared using a two-way ANOVA. Pairwise comparisons were performed using the Tukey HSD test. Effect sizes were reported as eta-squared (η^2). P-values of ≤0.05 were considered statistically significant.

Results

Assessment of Transfer Accuracy

Table 2 presents the average transfer accuracy, as indicated by deviation errors for each group. The transfer accuracy was determined by superimposing the models at T0 and T1. The average values of all six groups were comparable. Two-way ANOVA revealed that neither attachment type nor composite resin type demonstrated a significant effect on transfer accuracy (Table 3).

Table 2: The means and SDs of the error values based on the superimposition of the models at T0-T1 and T2-T3 using Geomagic Control X software

Groups	Transfer accuracy (T0-T1) (mm)	Wear due to brushing (T2-T3) (mm)
	Mean ± SD	Mean ± SD
Group 1	0.0258±0.0024	0.1273±0.0152
Group 2	0.024±0.0033	0.1091±0.0089
Group 3	0.0258±0.0037	0.2276±0.0209
Group 4	0.0257±0.0039	0.1305±0.0197
Group 5	0.0247±0.0027	0.3105±0.0328
Group 6	0.025±0.0029	0.21±0.0177

Table 3: Two-way ANOVA was used to compare the groups

	F	P-value	η2
Transfer accuracy (T0-T1)			
Attachment type	0.1660	0.689	0.0087
Composite resin type	0.1887	0.830	0.0199
Attachment and composite resin type	0.2283	0.798	0.0240
Wear due to brushing (T2-T3)			
Attachment type	73.6653	<0.001*	0.2412
Composite resin type	96.5433	<0.001*	0.6322
Attachment and composite resin type	10.3248	<0.001*	0.0676

* indicates statistical significance (P≤0.05)

Assessment of Surface Wear

Upon superimposing the models at T2 and T3, changes in attachment dimensions were recorded and attributed to surface wear from toothbrush simulation. Table 2 details the mean error for each group. Two-way ANOVA revealed statistically significant main effects for both factors and their interaction (Table 3). Composite resin type demonstrated the largest effect on surface wear, accounting for 63.2% of the total variance. Attachment type also showed a significant main effect, with conventional rectangular attachments exhibiting significantly greater surface wear than optimized cylindrical attachments. A statistically significant interaction was observed between attachment type and composite resin type; also, composition of both (Table 3).

Pairwise comparisons using post hoc Tukey tests (Table 4) revealed statistically significant differences between most group pairs. Notably, within the same composite resin type, conventional rectangular attachments consistently showed greater surface wear than optimized cylindrical attachments, with the difference most pronounced for orthodontic composite resin (P<0.001) and flowable composite resin (P<0.001), but not statistically significant for restorative composite resin (P=0.808).

Table 4: Pairwise comparisons of the error values using the Tukey HSD depicting surface changes after simulated toothbrushing

Groups	Mean diff.	P-value
Group 1 - Group 2	0.0181	0.8082
Group 1 - Group 3	-0.1003	<0.001*
Group 1 - Group 4	-0.0033	0.9999
Group 1 - Group 5	-0.1833	<0.001*
Group 1 - Group 6	-0.0827	<0.001*
Group 2 - Group 3	-0.1184	<0.001*
Group 2 - Group 4	-0.0214	0.6853
Group 2 - Group 5	-0.2014	<0.001*
Group 2 - Group 6	-0.1008	<0.001*
Group 3 - Group 4	0.0971	<0.001*
Group 3 - Group 5	-0.0830	<0.001*
Group 3 - Group 6	0.0176	0.8266
Group 4 - Group 5	-0.1800	<0.001*
Group 4 - Group 6	-0.0795	<0.001*
Group 5 - Group 6	0.1005	<0.001*

* indicates $P \leq 0.05$

Discussion

Attachments used for CAT provide numerous functions, including enhancing aligner retention and facilitating intricate tooth movements such as rotation correction and extrusion (20,21). The accuracy of tooth movements has increased substantially up to 70–80% due to advancements in attachment designs (22). Therefore, the dimensional precision of the attachment is crucial to the therapeutic efficacy of the aligners. This study examined the effect of composite resin materials and attachment designs on the transfer accuracy and surface wear of aligner attachments during simulated toothbrushing. The present study used two aligner attachment designs for the analyses: a conventional rectangular design and an optimized cylindrical design. The rectangular or box-type attachment is a common attachment that can be used horizontally or vertically. It is used for aligner retention, buccal root torque, and correction of unilateral cross-bites, among other applications. Optimized attachments are uniquely designed to apply appropriate force and enable more predictable and complex tooth movements (23). As a representation of the optimized attachment, a cylindrical shape was randomly selected from the options available in the planning software. The current study employed Geomagic Control X software to measure changes in attachment positions using model superimposition. According to the study conducted by Adel et al. (21), Geomagic software exhibited the greatest accuracy in model superimposition.

The present investigation determined that neither the material nor the type of attachment exerted any substantial impact on the transfer accuracy of the aligner attachments from virtual models to the dental surface. D'Antò et al. (7) conducted a comparable study, analyzing three composite resins of differing viscosity to assess alterations in attachments from virtual models. The results indicated that varying viscosities of the composite did not affect the form or volume of attachments replicated using a template on extracted teeth; however, the orthodontic composite resin exhibited minor overflow, consistent with the current investigation. These findings were further supported by Bellocchio et al. (24), who compared two composite resins of different viscosities and found that material type did not significantly affect attachment transfer accuracy. Similarly, Erbas and Atik (25) evaluated four composite resins, including Filtek Z350 XT flowable and universal restorative, under different curing irradiances and found that while the flowable composite resin showed higher overflow values, no significant difference was found between composite resin groups in terms of

placement accuracy defects, consistent with the present findings.

Another investigation compared a flowable composite resin (TetricEvoflow, Ivoclar Vivadent) with an orthodontic composite resin (Transbond XT, Light Cure Paste Adhesive, 3M) and found that the flowable composite resin resulted in more errors than the more viscous alternative, contrary to the findings of the present study (26). Chen et al. (14) examined the properties of restorative (Filtek Z350XT), flowable (Filtek Z350XT flowable), and bulk-fill composite (Sonicfill) resins. The flowable composite resin exhibited a bigger volumetric variation from the planned and actual attachments than the other materials, contrary to the conclusions of the current investigation. These conflicting results can primarily be attributed to differences in composite resin filler composition and measurement methodology. Chen et al. (15) used Filtek Z350XT Flowable (65 wt% fillers), whereas the flowable composite resin used in the present study (Tetric N Flow, Ivoclar Vivadent) has a higher filler content of 68.2 wt%. The difference in filler loading between the flowable and restorative composite resins in the Chen et al. study (13.5 wt%) was considerably larger than in the current investigation (7.8 wt%), which may explain why the flowable composite resin performed comparably in the present study. Furthermore, Chen et al. (15) assessed three-dimensional deviation and volumetric change, which captures material overflow and polymerization shrinkage, whereas the present study measured error value from digital scan superimposition.

The current investigation revealed that both attachment type and composite resin type influenced attachment surface wear after simulated brushing, with composite resin type exhibiting the greatest effect. The flowable composite resin in the rectangular design exhibited the greatest change. Vas et al. (27) conducted a study assessing the impact of various toothbrush types on aligner attachment using scanning electron microscopy (SEM). Significant alterations in attachment morphology were observed with hard and medium toothbrushes, whereas soft and ultra-soft brushes resulted in fewer changes. However, the current study did not compare the various types of toothbrushes. Presently, little research is available on the impact of toothbrushing on the abrasion of aligner attachments. Prior studies evaluating attachment wear have employed alternative methodologies. Gazzani et al. (17) conducted a study using a tribometer to evaluate attachment wear. They found that the conventional nanocomposite resin exhibited superior mechanical capabilities and wear resistance compared to its flowable counterpart, rendering it optimal for aligner attachments. Roatkanjanaporn et al. (28) evaluated the wear volume of attachments during aligner insertion and removal fabricated from Tetric N-Flow, Beautifil Injectable X, and Filtek Z350 XT. They found no significant differences in wear volume between the three composite resins, despite all groups exhibiting measurable wear primarily in the gingival regions. Different wear measurement methods and experimental conditions could have led to this contrasting finding compared to the present study. The physical and mechanical characteristics of composite resins are primarily influenced by the filler content, particularly the filler ratio. An increased filler ratio often leads to elevated material viscosity (23). This characteristic of the restorative composite resins improves their wear resistance, as demonstrated in the current investigation. Akcan et al. (29), in a six-month clinical study comparing three composite resins, reported that filler properties significantly influenced wear, with the suprananofilled flowable (Tokuyama Estelite Universal Flow, 70 wt% fillers) showing the least surface wear. In contrast, the nanohybrid flowable composite resin (Gaenial Universal Injectable, 69 wt%) showed the greatest. Ocak et al. (30) assessed attachment wear after thermal cycling and toothbrushing. They found significant differences in volumetric wear between four composite resins using micro-CT analysis, with Gaenial Universal Flo demonstrating the highest wear resistance and Flow Tain (60 wt% fillers) exhibiting the greatest volume loss. These findings reinforce the current study's observation that filler content is a primary determinant of wear resistance, as the restorative composite resin with the highest filler loading (76 wt%) demonstrated superior wear resistance. However, in the present study, orthodontic composite resins showed lower surface changes compared to flowable composite resins despite having a lower percentage of fillers. This can be explained by Akcan et al. (29), who suggested that filler particle geometry, distribution, and resin matrix composition also play important roles, as composite resins with spherical nanofillers or those lacking TEGDMA diluent may exhibit enhanced wear resistance independent of total filler loading. In the present study, the orthodontic composite resin had a wider filler particle size range (0.5–15 μm) and tighter filler packing. Also, the flowable composite resin contained monomethacrylates in its resin matrix (28 wt%), which produced fewer cross-links during

polymerization compared to the dimethacrylate-based matrix of the orthodontic composite resin.

Regarding attachment type, flowable composite resins with rectangular attachments demonstrated the greatest surface changes compared to cylindrical attachments. This can be ascribed to the inadequate edge strength of flowable composite resins. Any design that exhibits fragile edges, such as the rectangular design, may render it susceptible to heightened deterioration (31).

Limitations

The present study had some limitations. The first limitation was the in vitro study design, which did not account for additional patient-related factors that contribute to transfer accuracy in vivo. Second, the current study examined just three commercially available materials. Due to the significant variability in the composition of resin-based materials, comparisons with newer materials are necessary. Additional clinical trials with larger sample sizes are necessary to evaluate alterations in the surface of the aligner attachment at various time points to improve generalizability.

Conclusion

The present investigation suggested that, under the conditions of this study, the viscosity of composite resins did not appear to influence the accuracy of transferring virtually planned attachments to the tooth surface. Regarding surface changes after brushing, composite resins with higher filler content (restorative composites) and cylindrical attachments showed slightly less wear after simulated toothbrushing.

Acknowledgments

None.

Conflicts of Interest

The authors do not have any competing interests to declare.

Data availability statements

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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