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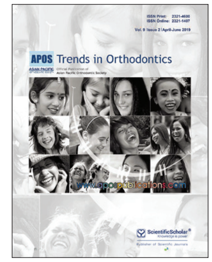

Clinical Article

Impact of resin composite type on enamel surface damage during rotary instrument removal in aligner therapy: An *in vitro* study

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Received: 10 June 2025
Accepted: 17 November 2025
EPub Ahead of Print: 07 March 2026
Published:

DOI
10.25259/APOS_138_2025

Quick Response Code:

APOS
ASIAN PACIFIC ORTHODONTIC SOCIETY

ABSTRACT

Objectives: Attachments are composite structures that help clear aligners (CAs) move teeth and must be removed at the end of treatment. Made from various composites, they are sometimes replaced during therapy. This study evaluates enamel damage after removing attachments made from three different composites, aiming to determine whether the type of resin affects the extent of damage caused by rotary instruments.

Material and Methods: This *in vitro* study used 30 extracted teeth, divided into three groups: A (packable composite), B (flowable composite), and C (orthodontic composite). Before bonding (T0), each tooth was duplicated in epoxy resin. Attachments were applied using a consistent protocol, then removed with a tungsten carbide bur. After removal (T1), teeth were finished with sandpaper discs and polished with pumice paste. Impressions were taken to create resin replicas. Enamel damage was assessed using scanning electron microscopy (SEM), and a modified enamel damage index (EDI) was applied. Data were analyzed with a Chi-square test ($P < 0.05$).

Results: Groups A (packable composite) and C (orthodontic composite) showed a significant difference in enamel damage ($P = 0.0235$) at T1. However, there were no significant differences between Group B (flowable composite) and the other groups ($P > 0.05$).

Conclusion: Attachment removal causes enamel damage, with greater damage observed in the packable composite group compared to the orthodontic composite group. Group A (packable composite) shows a heterogeneous distribution, with a prevalence of EDI 2 (60%) and lower proportions of EDI 1 and EDI 3 (20% each). In Group B (flowable composite), EDI 1 predominates (60%), followed by EDI 2 (40%). Finally, Group C (orthodontic composite) is characterized almost exclusively by EDI 1 values (80%), with a residual proportion of EDI 2 (20%). These results suggest that the type of composite used for attachments influences enamel surface integrity during removal.

Keywords: Aligner therapy, Enamel damage, Resin composite, Rotary instrument, Scanning electron microscopy

INTRODUCTION

Extensive literature has investigated the predictability, accuracy, and efficiency of clear aligner (CA) therapies.[1-8] The choice of materials for CAs and their attachments plays a crucial role in treatment success.[9,10] Attachments, typically made from resin composites, are bonded to the teeth to facilitate complex movements that CAs alone cannot achieve.

The effectiveness of attachments is inherently linked to the chemical and physical properties of the resins used, which vary based on factors such as monomer type, filler materials, particle size, and filler percentage. Previous studies have given priority to the evaluation of the wear and cutting resistance of materials used for attachments. These factors are essential; wear resistance safeguards the structural integrity of attachments during treatment, reducing the performance risks associated with degradation.[11-19] Similarly, shear bond strength is critical, as attachments must withstand chewing forces and the repeated application of CAs to ensure effective tooth movement and positive treatment outcomes.

Attachments may require replacement throughout the treatment process due to damage or design alterations necessitated by changing orthodontic needs. At the end of treatment, it is essential to remove attachments to restore the teeth's original esthetics. Rotary instruments are typically employed for this debonding process, but there are concerns regarding enamel damage during adhesive removal.[17] The use of attachments according to Eliades *et al*.[20] involves risks arising from the need to use acid etching and the procedures for its removal. The removal of these relatively large composite thicknesses, compared to that present between the bracket and the tooth, could be harmful due to inhalation of the resulting aerosol. Our research is based on the hypothesis that removal could be harmful to the dental enamel and that the risk could be related to the different types of composite used.

To mitigate enamel damage, established procedures have been developed for minimizing the removal of composite layers during debonding.[21-24] The most widely used study method for observing the damage suffered by dental enamel after the removal of orthodontic brackets is scanning electron microscopy (SEM). This tool allows good observation of small samples of hard surfaces. Much like computer tomography (CT), SEM is capable of producing images where grayscale levels show material density, and it is better suited for nanometer resolution. To analyze organic samples, it is necessary to cover them with a thin metal layer, which is not necessary with CT. Therefore, if you want to analyze the same object before and after having subjected it to experimental conditions, it is necessary to use replicas of the initial phase made of epoxy resin.

This study aims to evaluate the impact of three different resin composites on enamel surface integrity during attachment removal using SEM. The selected resins display significant differences in filler content. Each composite not only has a distinct filler composition but also varies in the percentage of inorganic components, which significantly affects its viscosity.

We hypothesize that the type of resin influences the extent of enamel damage caused by rotary instruments, leading to varying effects based on the material selected. The null hypothesis was that there is no significant difference in the extent of enamel damage caused by rotary instruments when removing attachments made from different resin composites.

MATERIAL AND METHODS

Study design and setting

This *in vitro* experimental study was conducted at the Institute of Dental Clinic and Maxillofacial Surgery and the Institute of Physics of the Università Cattolica del Sacro Cuore, Rome, Italy, from January to March 2023.

Sample calculation

The sample size was calculated for the enamel damage index (EDI) variable for independent groups (Alpha = 0.05; Power: 85%). Assuming a mean of 2.67 with a standard deviation of 0.516 and a difference between means of 1.00,[25] 10 samples are required for each group.

Operative procedures

The extracted teeth were selected according to these inclusion criteria:

- Molars and premolars from permanent dentition, removed for orthodontic, prosthetic, or periodontal reasons.[26-28]
- The clinical crowns were well-preserved with no visible surface damage and free of any hard or soft tissue residues. All specimens were stored in a physiological solution at 4°C after extraction.

The exclusion criteria include

- The presence of prosthetic crowns or filling materials, and enamel with carious lesions
- Congenital or acquired enamel anomalies or damage
- Teeth with any soft or hard tissue remnants

30 selected extracted teeth were evenly divided into 3 groups of 10, each treated with a different type of resin composite [Table 1]. Three composites from the same manufacturer (3M, St. Paul, Minnesota, USA) and similar formulations were chosen. This choice aimed to minimize variations due to material production, which could introduce bias into the study. Group A received a restorative packable composite (Filtek Supreme XTE), Group B received a restorative flowable composite (Filtek Supreme Flowable), and Group C was treated with an orthodontic composite (Transbond XT). Before the treatments, each specimen was polished using pumice prophylaxis paste (SuperPolish, Kerr, Bioggio, Switzerland) and water, then rinsed, and dried with a moisture-free air spray.

Replicas were utilized for SEM analysis at T0 to ensure the samples' surfaces remained uncontaminated by any coating.[29] This was essential for examining the surfaces both before the experimental procedures and after the attachments were removed [Figure 1], to assess the entity of the observed changes in enamel surface integrity. Impressions of each tooth were made using polyvinyl siloxane (Hydrorise Light Body, Zhermack, Rovigo, Italy) and cast in epoxy resin (EMbed 812, EMS, Washington, Pennsylvania, USA) to create a replica [Figure 2] of the surface before attachment bonding (T0). The epoxy resin was cured in an oven at 60°C for 48 h to ensure complete hardening. The samples analyzed after the experimental procedures were observed directly, without the use of replicas.

One attachment was placed on the buccal surface of each specimen using a 3 mm^2 template [Figure 3], which ensured a uniform shape for each resin structure. The procedure for placing the attachments proceeded as follows:

- Step 1: The buccal surface of the tooth, where the attachment was to be placed, was etched with 37% orthophosphoric acid (DentoEtch, Itena, Villepinte, France) for 30 s. It was then rinsed thoroughly with water and dried with a gentle air stream.
- Step 2: A thin layer of bonding agent (Adper Scotchbond Singlebond 2, 3M, St. Paul, Minnesota, USA) for restorative composites, along with a light-cured adhesive primer (Transbond XT) for the orthodontic composite, was applied and cured with a high-power lamp (Art-L3, Opticore N3, IDS, Savona, Italy) for 20 s.

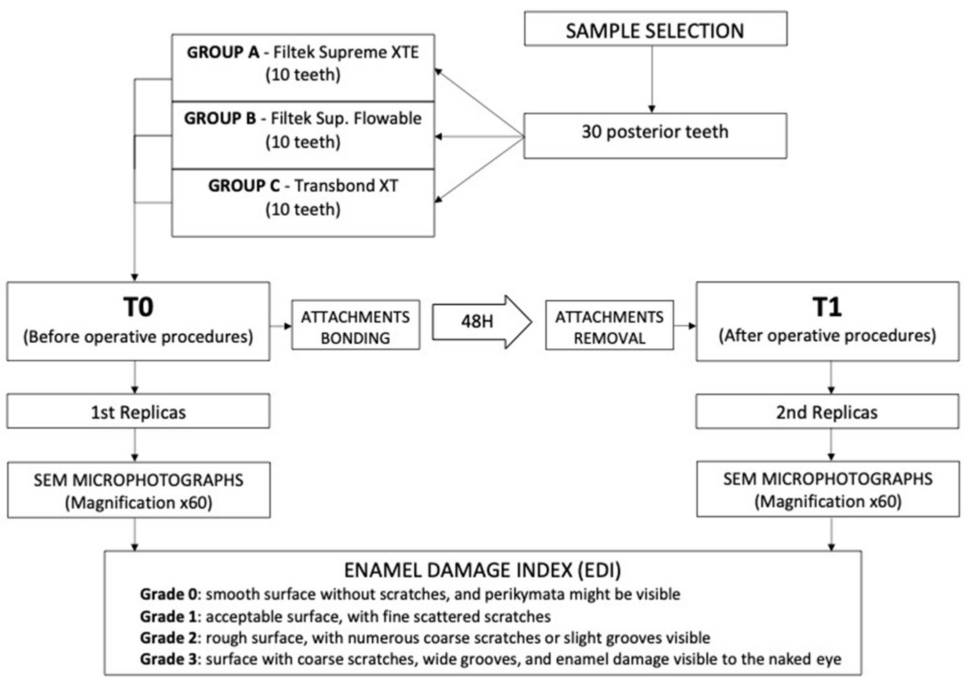

Figure 1: Flowchart of study groups and procedures of the study.

Table 1: Tested materials.

Material	Filler Content (by weight)	Detailed Filler Content	Monomer	Manufacturer
Filtek Supreme XTE	78.5%	Non agglomerate/non aggregate Silica filler (20 nm); Non agglomerate/non aggregate Zirconia filler (4-11 nm); Aggregated zirconia (20 nm)/silica (4-11 nm) cluster filler	Bis-GMA, UDMA, TEGDMA, Bis-EMA	3M, St. Paul, Minnesota, USA (3M)
Filtek Supreme Flowable	65%	Ytterbium trifluoride (0.1-5.0 μm); Non agglomerate/ non aggregate Silica filler (20 nm); Silica filler (75 nm); Surface modified aggregated zirconia (20 nm)/silica (4-11 nm) cluster filler	Bis-GMA, TEGDMA, Procrylate	3M, St. Paul, Minnesota, USA (3M)
Transbond XT	70.2%	Silicon dioxide (0.5-10 μm)	Bis-GMA, TEGDMA	3M, St. Paul, Minnesota, USA (3M)

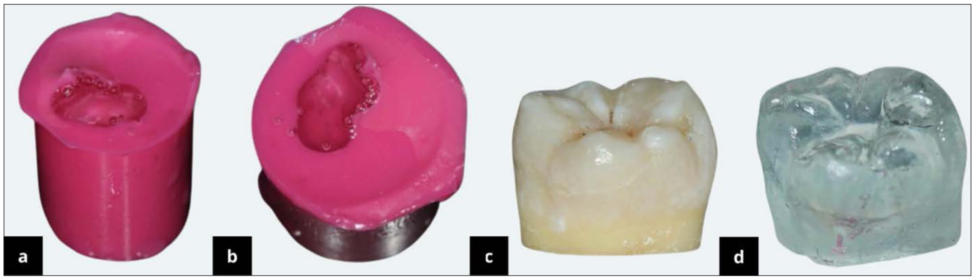

Figure 2: (a and b) Impression cast in epoxy resin, (c) original extracted tooth (d) versus his replica.

Figure 3: Template used to place attachments.

- Step 3: The resin composite was placed into the hollow of the template using a metal spatula for the restorative packable composite, while a thin-tip syringe was used for the restorative flowable and orthodontic composites. After loading each composite, it was properly positioned on the prepared tooth surface and cured according to the manufacturer's instructions, utilizing the optimal wavelength (400–500 nm). No polishing or finishing steps were performed after removing the attachment templates. The attachment covered an area of 3 mm^2.

The selection of the removal procedure was guided by best practices from the literature that are considered less traumatic for dental enamel.[21,30] After the resins had cured for 48 h, each attachment was removed using a new 12-blade tungsten carbide bur (C22AGK, Edenta, Schaanwald, Liechtenstein) attached to a low-speed handpiece operating at 20,000 rpm, without water cooling. Omitting water during bur use improved visibility of the composite remnants, allowing for a more precise and controlled removal. To prevent heat generation, the bur was operated intermittently, with short activation intervals rather than continuous use. The process included finishing the residual resin using sandpaper discs (Sof-Lex, 3M, St. Paul, Minnesota, USA) that ranged from medium to ultrafine grit. These discs were used with a low-speed handpiece running at 10,000 rpm. The sandpaper discs were changed for each sample analyzed. Polishing was then carried out using pumice prophylaxis paste (SuperPolish, Kerr, Bioggio, Switzerland) mixed with water.

To ensure consistency, all procedures were performed by the same operator, in the same environment, and on the same day. Before the attachment removal in the experimental groups, the operator practiced the procedure by removing attachments from 30 teeth that were not part of the study group.

SEM analysis

The dental replicas were attached to aluminum stubs, with the base of the stubs coated in silver conductive paint (Silver Paint, Agar Scientific, Stansted, Essex, United Kingdom). They were then covered with a 50 nm layer of gold to prepare the samples for analysis using a high vacuum SEM (Supra 25, Zeiss, Wetzlar, Germany).

SEM images were captured at ×60 magnification for both T0 and T1. The replicas for T0 and T1 from each sample were aligned in the same direction, with the surface of interest facing the beam, enabling accurate comparison between the two images.

The condition of the enamel at T0 and T1 was assessed using a modified EDI[31,32] that features four distinct grades: 0 – Smooth surface with no scratches, with possible visibility of perikymata, 1 – Acceptable surface with fine, scattered scratches; 2 – Rough surface showing numerous coarse scratches or slight grooves; and 3 – Surface exhibiting coarse scratches, wide grooves, and visible enamel damage.

The first operator was not blinded to the composite type during the removal and SEM evaluation. Later, another blind operator confirmed the assessments.

Statistical analysis

Data analysis was conducted using R software (version 3.1.3, R Development Core Team, R Foundation for Statistical Computing, Vienna, Austria) to calculate the frequencies of EDI scores across different groups. A Chi-square test was employed to assess differences among the tested materials, with P values less than 0.05 considered statistically significant.

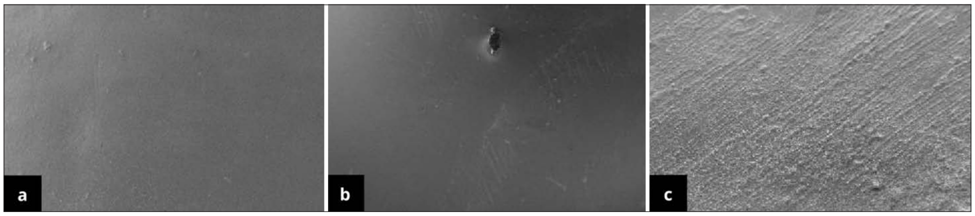

Figure 4: (a) SEM image of an enamel surface at T0 with an enamel damage index grade of 0 (b) SEM image of an enamel surface at T1 with an enamel damage index grade of 1, (c) SEM image of an enamel surface at T1 with an enamel damage index grade of 2.

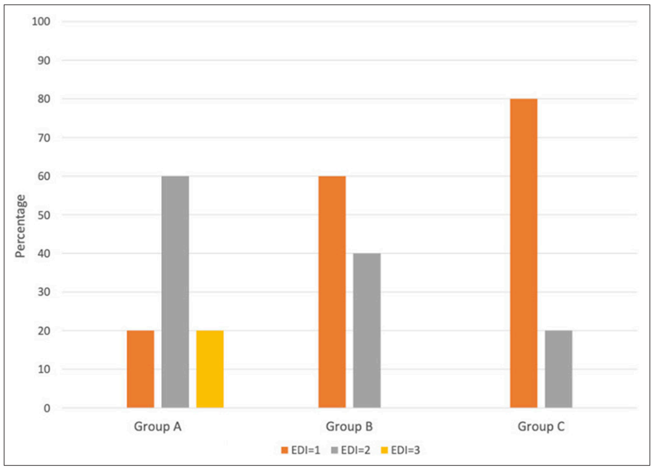

Figure 5: Frequency distribution.

To evaluate the reproducibility of the assessments, intra-examiner reliability was determined on 10 samples both before and after the operative procedures, with the same examiner conducting the evaluations during two separate sessions spaced by at least 1 week. In addition, another researcher independently assessed the same samples to evaluate inter-examiner reliability. The Kappa coefficient was used to measure the level of agreement.[33]

RESULTS

The Kappa values were 0.92 for intra-examiner agreement and 0.97 for inter-examiner agreement. SEM images were utilized to evaluate EDI scores at T0 and T1 [Figure 4]. [Figure 5] illustrates the frequencies of EDI scores at T1 across the different groups. The Chi-square test indicated a statistically significant difference ($P = 0.0235$) between Group A (Restorative Packable Composite) and Group C (Orthodontic Composite); however, neither of these groups exhibited significant differences ($P > 0.05$) when compared to Group B (Restorative Flowable Composite).

DISCUSSION

At the conclusion of clear aligner treatment (CAT), the removal of attachments is essential for restoring teeth to their original appearance.[21,34] Removing the composite used for orthodontic procedures is potentially harmful. The effects of removing the thin layer of composite at the interface between the bracket and teeth have been extensively studied. In contrast, there is no literature on the effects of removing attachments, which have been used more recently.

The variables that can influence the removal procedures of attachments depend on the materials used for their production and the removal method adopted. Although the effects produced on the enamel surface have been observed by most researchers using SEM, recent studies show that the results are observable with micro CT.[17,35] Micro CT offers the advantage of being able to study samples at different experimental stages without altering or replicating them, making the image acquisition procedure simpler and offering new observation perspectives.

During the attachments removal procedure, the risks of enamel damage are primarily due to the use of rotary instruments.[36-39] To mitigate these risks, many researchers advocate for tungsten carbide burs, citing their effectiveness in preserving enamel integrity. Although alternative methods, such as diamond and stainless-steel burs, are common, they tend to be too aggressive for delicate enamel structures, particularly when dealing with resin residues.[40]

The attachments used in CAT comprise a variety of composites, each with distinct physical properties and behavior during application.[12-16] Past studies have examined critical factors such as bond strength, color stability, and degree of cure, but the specific effects of these composites during removal remain largely unexplored.[41-44] Our investigation aimed to assess how the cleaning procedures affect enamel surfaces, particularly focusing on the composition and filler percentage of the composites used.

Despite all attachment samples beginning with an EDI score of 0, no group maintained this score at the initial time point (T1), highlighting significant enamel damage due to the rotary cleaning process. Previous research has shown that packable composites generally offer better wear resistance and retention. Still, our findings indicate that the specific packable composite used (Filtek Supreme XTE) caused more substantial enamel damage compared to the orthodontic composite (Transbond XT). This unexpected result suggests that while packable composites possess enhanced mechanical properties, these features may ironically contribute to greater difficulty during removal and, subsequently, increased enamel wear.

The implications of these findings are particularly significant when considering younger patients. As children's teeth undergo maturation, the enamel becomes harder and less porous, making them potentially more susceptible to damage during attachment placement and removal. Future research could study the effect of removing attachments on children's teeth.

This study does have limitations, chiefly its exclusion of *in vivo* complexities and the possible variability in operator skill, which can significantly affect treatment results. *In vitro* conditions inherently lack the presence of the salivary pellicle and patient-specific biological factors, which can significantly influence the behavior of resin removal and the subsequent surface response of the enamel. *In vivo*, the continuous interaction with saliva not only modifies the surface characteristics through the formation of the acquired pellicle but also contributes to the natural remineralization and repair processes of the enamel over time. Therefore, when composite removal procedures are performed correctly under clinical conditions, the saliva may play a beneficial role in promoting enamel recovery and maintaining surface integrity.[30]

By relying on a single brand of composites and following standard cleaning procedures as outlined in the existing literature, we aimed to minimize bias. However, the applicability of our findings may vary when different methodologies or composite brands are employed. Future studies should continue exploring these variables to establish broader conclusions regarding composite behavior during attachment removal. The integration of SEM observations with those made using micro CT could provide a more complete picture of the subject.

CONCLUSION

The removal procedures for orthodontic attachments significantly damage the enamel surface. The use of rotary instruments is particularly harmful to enamel in cases involving packable composite attachments compared to orthodontic composite attachments. Therefore, it is imperative to consider the behavior of composite materials during the removal phase when selecting composites for bonding attachments. This study underscores the necessity of cautious selection in the materials used for bonding attachments, particularly in light of their potential impact on enamel integrity during removal procedures. Future research is encouraged to enhance the safety and effectiveness of orthodontic treatments (OTs), with a focus on minimizing enamel damage.

Ethical approval: Institutional Review Board approval is not required.

Declaration of patient consent: Patient's consent is not required as there are no patients in this study.

Financial support and sponsorship: Nil.

Conflicts of interest: There are no conflicts of interest.

Use of artificial intelligence (AI)-assisted technology for manuscript preparation: The authors confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript, and no images were manipulated using AI.

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How to cite this article: Nucci L, Agostinacchio V, Sassatelli F, Scribante A, Grippaudo C, Vaid N. Impact of resin composite type on enamel surface damage during rotary instrument removal in aligner therapy: An *in vitro* study. APOS Trends Orthod. doi: 10.25259/APOS_138_2025