Original Article

DOI: 10.14235/bas.galenos.2026.64497
Bezmialem Science

Factors Affecting Attachment Loss in Clear Aligner Treatment: A Prospective Clinical Study

Şeffaf Plak Tedavisinde Ataçman Kaybını Etkileyen Faktörler: Prospektif Klinik Çalışma

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ABSTRACT

Objective: This study aimed to evaluate the incidence of composite attachment loss in patients undergoing clear aligner treatment and to identify patient-, tooth-, and treatment-related factors associated with attachment debonding.

Methods: Twenty-one patients (17 females, 4 males; mean age 23.86±8.21 years) receiving clear aligner therapy were included. Attachments were bonded according to the manufacturer's protocol using high-viscosity composite. Patients were followed for 6 months and attachment loss was recorded at routine appointments. Statistical analyses were performed using Fisher's exact test, Yates' correction, and Pearson chi-square test, with p≤0.05 considered significant.

Results: Among 427 attachments, 21 were lost. Attachment loss was significantly associated with attachment type (conventional vs. optimized, p=0.009), with conventional attachments exhibiting higher loss rates. No significant associations were observed between attachment loss and attachment size, dental arch, tooth type, patient sex, chewing habits, daily aligner wear time, aligner removal frequency, or removal direction.

Conclusion: Attachment loss in clear aligner treatment is related to the attachment type, with optimized attachments showing improved retention. Tooth location appears to have minimal effect.

Keywords: Clear aligner therapy, orthodontic attachments, attachment loss

ÖZ

Amaç: Bu çalışmanın amacı, şeffaf plak tedavisi gören hastalarda kompozit ataçman kaybı insidansını değerlendirmek ve ataçman debondingi ile ilişkili hasta, diş ve tedaviye bağlı faktörleri belirlemektir.

Yöntemler: Şeffaf plak tedavisi gören 21 hasta (17 kadın, 4 erkek; ortalama yaş 23,86±8,21 yıl) çalışmaya dahil edildi. Ataçmanlar, üretici firmanın protokolüne uygun olarak yüksek viskoziteli kompozit kullanılarak yapıştırıldı. Hastalar 6 ay boyunca takip edildi ve rutin randevularda ataçman kayıpları kaydedildi. İstatistiksel analizler Fisher'ın kesin testi, Yates düzeltmesi ve Pearson ki-kare testi kullanılarak yapıldı; p≤0,05 değeri istatistiksel olarak anlamlı kabul edildi.

Bulgular: Toplam 427 ataçmandan 21'i kaybedildi. Ataçman kaybı, ataçman tipi (konvansiyonel ile optimize, p=0,009) ile anlamlı şekilde ilişkili bulundu ve konvansiyonel ataçmanlarda daha yüksek kayıp oranları gözlendi. Ataçman boyutu, dental ark, diş tipi, hastanın cinsiyeti, çiğneme alışkanlıkları, günlük plak kullanım süresi, plak çıkarma sıklığı veya çıkarma yönü ile ataçman kaybı arasında anlamlı bir ilişki saptanmadı.

Sonuç: Şeffaf plak tedavisinde ataçman kaybı, ataçmanın tipi ile anlamlı olarak ilişkilidir; optimize ataçmanlar daha iyi retansiyon göstermektedir. Dişin ark içindeki konumunun ise minimal etkisi olduğu görülmektedir.

Anahtar Kelimeler: Şeffaf plak tedavisi, ortodontik ataçmanlar, ataçman kaybı

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Received: 05.01.2026
Accepted: 20.02.2026
Epub: 06.07.2026

Cite this article as: Şahin Ş, Ünsal H, Kurt G. Factors affecting attachment loss in clear aligner treatment: a prospective clinical study. Bezmialem Science. [Epub Ahead of Print]

Introduction

Clear aligner therapy has gained widespread popularity as an alternative to conventional fixed appliances, largely due to increasing aesthetic concerns and a greater emphasis on patient comfort. Compared with traditional bracket systems, clear aligners provide superior aesthetics, improved comfort, easier maintenance of oral hygiene, reduced soft tissue irritation, and enhanced invisibility during social interactions, all of which contribute to their growing acceptance among patients and clinicians alike (1-4).

Composite attachments are bonded to tooth surfaces using templates to enhance the efficiency of tooth movement in aligner systems, making them an integral component of aligner therapy. They can be designed to aid in controlling specific tooth movements or serve as anchorage units, playing a critical role in enhancing force delivery for challenging movements such as rotation, intrusion, and extrusion, while also improving aligner retention (5). In systems such as Invisalign, attachments are generally categorized as conventional or optimized. Conventional attachments are standardized in shape, typically rectangular, whereas optimized attachments are irregular and individually designed according to tooth morphology (3). These attachments are virtually planned and bonded using dedicated templates, with different shapes serving distinct biomechanical purposes. Clinicians prescribe attachments for teeth requiring greater control to enhance the predictability of complex movements (6). Initially, ellipsoid-shaped attachments were used, but they were later replaced by bulkier conventional forms—horizontal, vertical, and beveled—to improve biomechanical control. In 2009, Align Technology introduced optimized (SmartForce®) attachments, which are automatically applied by the software under predefined criteria and are claimed to improve the efficiency of orthodontic force application for certain movements (7).

Attachment loss remains a common clinical challenge in clear aligner therapy. Although the biomechanical importance of attachments is well recognized, limited evidence exists regarding the incidence of attachment loss, the factors influencing it, and the differences among attachment types. Understanding the underlying causes of attachment loss is clinically relevant, as it directly affects treatment predictability, efficiency, and patient satisfaction. Loss of attachments during therapy can compromise outcomes by reducing movement predictability, increasing the need for additional appointments, and prolonging overall treatment duration. This highlights the need for prospective clinical studies to clarify risk factors and optimize attachment design and placement.

Therefore, the aim of this study was to evaluate the incidence of composite attachment loss in patients undergoing clear aligner treatment, to identify potential risk factors, and to contribute to the development of clinical strategies to minimize attachment loss and enhance treatment efficiency.

We hypothesize that attachment type, patient-related factors, tooth position, and treatment variables do not significantly affect attachment loss in clear aligner therapy. This hypothesis assumes that patients maintain high compliance with aligner wear and that attachments are bonded according to the recommended protocol.

Methods

Ethical Approval

The study protocol and informed consent process were conducted in accordance with the Declaration of Helsinki and approved by the Research Ethics Committee of Bezmialem Vakıf University (approval no: 2022/19, date: 18.01.2022). Written informed consent was obtained from all participants prior to enrollment. This study was retrospectively registered at ClinicalTrials.gov (NCT07352644).

Study Design and Participants

A total of 21 patients were included. Based on a previous study (8), a sample size of 20 participants was calculated to achieve 80% power with a significance level of $\alpha=0.05$ and a 95% confidence interval (CI). The participants were recruited among orthodontic patients scheduled to begin clear aligner treatment (Invisalign®, Align Technology, San Jose, CA, USA) at Bezmialem Vakıf University Department of Orthodontics between January and June 2022.

Inclusion Criteria

Permanent dentition (a), mild to moderate crowding (b), no history of previous orthodontic treatment with fixed appliances or aligners (c).

Exclusion Criteria

Poor oral health (a), bruxism (b), crown restorations (c), dental fluorosis (d), enamel hypoplasia or structural abnormalities affecting attachment bonding (e).

Patients with bruxism, identified via both self-report and clinical intra-extra oral examination, were excluded.

All patients were scanned with an intraoral scanner, and complete orthodontic documentation was obtained. Virtual treatment planning was performed using ClinCheck® software (Invisalign®), and aligners with corresponding attachment templates were fabricated (Figure 1).

Attachment Bonding Protocol

All attachments were produced with the initial template. The teeth were etched with 35% phosphoric acid (DMG Etching Jumbo Gel) for 30 seconds, rinsed with water for 30 seconds, and air-dried. A light cured bonding agent (TRULOCK® Light Activated Bonding Resin, Rocky Mountain Orthodontics, Denver, Colorado, USA) was applied and polymerized with an LED curing unit (VALO® Cordless, Ultradent Products, Inc., South Jordan, Utah, USA). Every attachment reservoir was filled with composite in accordance with the clinical guidelines presented by Invisalign®. Each attachment reservoirs in the templates were filled with a high-viscosity composite resin (TruLock® Light Activated Adhesive). The template was seated intraorally with finger pressure, and additional pressure was applied near the attachments to ensure proper adaptation. The composite was light cured for 10 s (5 s each from the mesial and distal sides) using the same curing unit. Excess resin was removed and polished with a high-speed handpiece and white stone burs. All procedures were performed by the same department clinicians in accordance with the manufacturers' guidelines.

Patient Instructions and Follow-up

Patients were instructed to wear their aligners for 20-22 hours per day, replacing them every 10 days and to remove them before eating and drinking. Oral hygiene instructions were provided. Patients attended follow-up visits approximately every 4 weeks. Attachment loss was defined as detachment or the presence of irregular residual composite. Each patient was monitored for 6 months and data on attachment loss were documented, including the number, location, size, and type of attachment (optimized/conventional) lost (Figure 1). For each attachment, data regarding type (optimized/conventional), size, tooth type, and position in the dental arch were documented.

Additional patient-related factors such as unilateral chewing habits, type of malocclusion, number and type of attachments, use of intermaxillary elastics, frequency of aligner removal, duration of daily wear and direction of aligner removal were recorded.

Attachment Placement and Assessment

Attachments were placed following standard treatment planning protocols, with no customized designs or force-specific positioning applied. Attachment integrity was evaluated at each follow-up visit through direct intraoral examination under dental unit illumination, complemented by tactile verification using a dental explorer. An attachment was considered lost when complete or partial debonding, indicated by irregular residual composite, was observed (Figure 2).

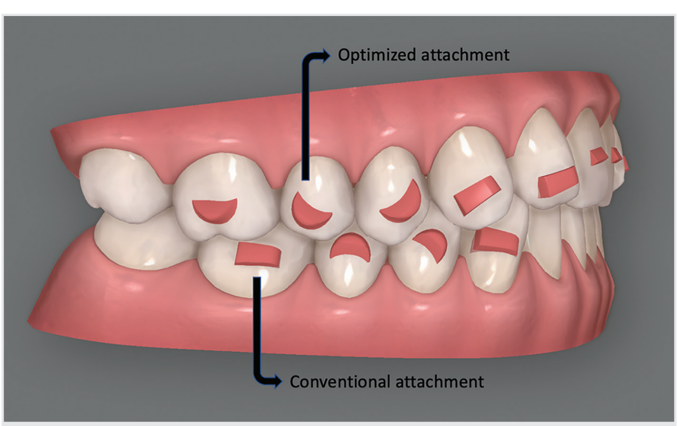

Figure 1. Optimized and conventional attachments on ClinCheck® software

All attachment loss assessments were performed by a single experienced orthodontist, minimizing inter-examiner variability. To further ensure accuracy, all recorded attachment loss events were reviewed and confirmed by the clinical director, a senior orthodontist, at each follow-up visit before any corrective procedures. No formal intra-rater reliability analysis was conducted.

Statistical Analysis

Data were analyzed using IBM SPSS Statistics for Windows, version 25.0 (IBM Corp., Armonk, NY, USA). Categorical variables were analyzed with Fisher's exact test when expected frequencies were <5, Yates' correction when expected values were 5-25, and Pearson's chi-square test when expected values were >25. For tables larger than 2×2, Pearson's chi-square test was applied. A p-value ≤0.05 was considered statistically significant.

Results

Twenty-six patients were initially enrolled; five were excluded due to incomplete cooperation, leaving 21 patients for analysis. The final study sample consisted of 21 patients (17 females, mean age: 23.59±8.64 years; 4 males, mean age: 25.00±6.98 years; overall mean age: 23.86±8.21 years). Attachment loss occurred in 10 patients (47.6%), with 21 of 427 attachments (4.9%) failing. The incidence of attachment loss according to patient-related factors are presented in Table 1. Attachment loss was not significantly associated with sex, daily aligner wear, removal direction or frequency, or unilateral chewing (p>0.05; Table 1).

The incidence of attachment loss according to treatment position factors are presented in Table 2. Attachment loss was not associated with the number of attachments (p=1.00), use of intermaxillary elastics (p=0.361), or size of conventional attachments (p=0.453). Attachment type was significantly associated with loss, with conventional attachments showing higher attachment loss rates than optimized attachments (p=0.009; Table 2). Attachment type was significantly associated with attachment loss in the logistic regression model, with conventional attachments exhibiting a higher risk of attachment loss than optimized attachments (odds ratio=3.73; 95% CI: 1.40-9.93; p=0.008).

The incidence of attachment loss according to tooth position are presented in Table 3. No statistically significant differences were observed between attachment loss and the dental arch, arch side or tooth type (p>0.05).

Discussion

Attachments used in the clear aligner treatments increase the retention of the aligners and provide better control over tooth movement (9). Attachments are crucial mechanical components; and their damage may sometimes cause the tooth to not track properly, which may affect treatment results. Attachment loss may prolong treatment duration and alter treatment prognosis, leading to significant clinical challenges. Limited data exist regarding attachment loss, and this study aimed to identify potential risk factors associated with it.

In our study 21 out of 427 attachments were lost. Previous studies report varying rates of attachment loss during clear aligner treatment. Fausto et al. (10) observed a considerable frequency of surface wear (53%) and failure (24%), while Yaosen et al. (11) reported an average attachment loss rate of 6.7%. Lin et al. (12) reported a 1-year attachment damage rate of 14.79% for first-class and 9.70% for posterior-class attachments (overall 12.22%). Weckmann at al. (13) analyzed 125 samples and 24% were lost. The attachment loss rate observed in the present study (4.9%) was lower than those reported in previous investigations, which ranged from 6.7% to 24% (10-13). Factors that may explain the lower loss rate include the use of high-viscosity composite with increased filler content, which improves adaptation and reduces polymerization shrinkage. Strict adherence to the manufacturer's bonding protocol minimized errors and contamination. The patients were instructed to wear aligners 20-22 hours daily and trained in proper insertion and removal, reducing mechanical stress on attachments. Additionally, the incorporation of optimized attachments

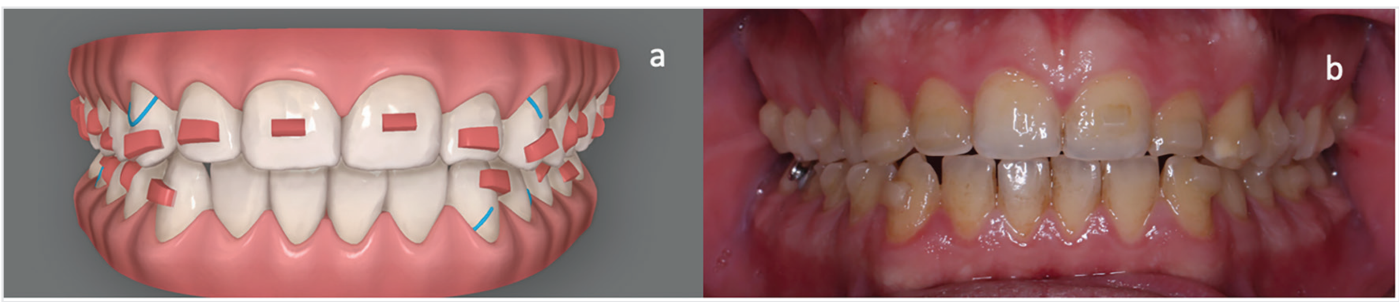

Figure 2. a) Conventional attachment planned on the maxillary right central incisor (tooth #11), b) intraoral photograph showing attachment loss on the same tooth

Table 1. Incidence of attachment loss according to patient-related factors

Factors	Outcome*		Total	p-value
	Loss	Retained		
Sex				
Female	8 (47.1)	9 (52.9)	17 (81)	1.000[c]
Male	2 (50)	2 (50)	4 (19)	
Daily aligner wear				
≤18 hour	0 (0)	1 (100)	1 (4.8)	1.000[c]
>18 hour	10 (50)	10 (50)	20 (95.2)	
Removal direction				
Buccal	1 (100)	0 (0)	1 (4.8)	0.476[c]
Lingual	9 (45)	11 (55)	20 (95.2)	
Unilateral chewing				
Right	1 (33.3)	2 (66.7)	3 (14.3)	0.754[a]
Left	2 (40)	3 (60)	5 (23.8)	
None	7 (53.8)	6 (46.2)	13 (61.9)	
Aligner removal frequency (per day)				
≤5	4 (50)	4 (50)	8 (38.1)	1.000[c]
<5	6 (46.2)	7 (53.8)	13 (61.9)	

[a]: Pearson chi-square, [c]: Fisher's exact test, *: n (%)

in our sample, which showed superior retention compared to conventional designs, likely contributed to the reduced attachment loss. Finally, variations in study design, patient characteristics, attachment type distribution, and follow-up protocols across studies may also explain differences in reported rates of attachment loss.

Attachment loss did not differ significantly by dental arch (p=0.355), side of placement (p=0.105), or tooth type (p=1.000). The highest loss was observed in molars (10.6%), but this was not statistically significant. This finding is consistent with Lin et al. (12), who reported that tooth type did not significantly influence attachment loss. Yaosen et al. (11) suggested that molars were subject to greater mechanical and functional stress during mastication, which might increase the likelihood of attachment loss. Moreover, posterior teeth may be more susceptible to contamination during bonding procedures and exposed to greater mechanical forces during aligner removal, potentially contributing to higher loss rates.

Table 2. Incidence of attachment loss according to treatment plan-related factors

Factors	Outcome*		Total	p-value
	Loss	Retained		
Number of attachments				
>15	9 (45)	11 (55)	20 (90.9)	1.000[c]
≤15	1 (50)	1 (50)	2 (9.1)	
Use of elastics				
Yes	6 (40)	9 (60)	15 (71.4)	0.361[c]
No	4 (66.7)	2 (33.3)	6 (28.6)	
Attachment type				
Conventional	15 (8.4)	163 (91.6)	178 (41.7)	0.009[b]
Optimized	6 (2.4)	243 (97.6)	249 (58.3)	
Size of conventional attachments				
3 mm	11 (7.6)	134 (92.4)	145 (81.5)	0.453[a]
4 mm	4 (13.8)	25 (86.2)	29 (16.3)	
5 mm	0 (0)	4 (100)	4 (2.2)	

[a]: Pearson chi-square, [b]: Yates correction, [c]: Fisher's exact test, *: n (%)

Table 3. Incidence of attachment loss according to tooth related factors

Factors	Outcome* n (%)			
	Loss, n (%)	Retained, n(%)	Total, n (%)	p-value
Arch				
Maxilla	9 (3.8)	226 (96.2)	235 (55)	0.355[b]
Mandible	12 (6.3)	180 (93.8)	192 (45)	
Side				
Right	14 (7)	187 (93)	201 (47.1)	0.105[b]
Left	7 (3.1)	219 (96.9)	226 (52.9)	
Tooth type				
Incisor/canine	1 (0.7)	152 (99.3)	153 (35.8)	1.000[a]
Premolar	6 (4.2)	136 (95.8)	142 (33.3)	
Molar	14 (10.6)	118 (89.4)	132 (30.9)	

[a]: Pearson chi-square, [b]: Yates correction, *: n (%)

The type and properties of the composite used for attachment bonding play a crucial role in attachment retention (13). In our study, a high-viscosity composite was used which provides good adaptation to the attachment template and minimizes void formation. In line with this, Lopez et al. (14) demonstrated that dental composites with higher filler content exhibited lower polymerization shrinkage, resulting in stronger bonding to the tooth surface. This finding emphasizes that composite selection is an important factor in clinical practice, as materials with higher filler content may enhance attachment stability and reduce the risk of early attachment loss. While low-viscosity (flowable) composites may facilitate easier handling, they are more prone to surface irregularities and potential bonding failure. Thus, careful consideration of composite type, along with proper bonding technique, is essential for optimizing attachment longevity and treatment predictability.

No significant differences were observed between patients with and without attachment loss regarding gender, chewing habits, daily aligner wear time, removal frequency, or removal direction. Yaosen et al. (11) reported that frequent removal and reinsertion of aligners increased stress on attachments, and while less than five removals per day did not affect attachment loss, more frequent removal increased risk of attachment loss. In our clinic, patients were instructed to wear aligners at least 20-22 hours per day, in accordance with manufacturer recommendations, which might explain why daily wear time did not affect attachment loss incidence.

Previous studies did not evaluate the effect of elastic use, attachment type, or conventional attachment size on attachment loss (10-12). In this study, no significant differences were observed in attachment loss between patients using elastics and those not using them, nor regarding total attachment number or conventional attachment size ($p>0.05$). However, a significant difference was found regarding attachment type ($p=0.009$), with conventional attachments exhibiting higher loss than optimized attachments. Optimized attachments are individualized to tooth morphology, which may improve adaptation and reduce occlusal interference, potentially explaining the lower loss rates. Conventional attachments, having standard shapes and sizes, may adapt less effectively, leading to higher rates of attachment loss. Manual placement of conventional attachments during treatment planning may also fail to eliminate occlusal conflicts, further increasing the risk of loss. Fausto et al. (10) reported more surface wear in conventional attachments, particularly on mandibular and anterior teeth, with adhesive failure observed in 10% of samples, mostly in conventional attachments.

The results of this study underline the clinical relevance of attachment selection in clear aligner therapy. The significantly lower loss rate observed with optimized attachments suggests that careful consideration of attachment type during digital treatment planning may help minimize loss, particularly during the early stages of treatment when it occurs most frequently. These findings suggest that clinicians may consider prioritizing optimized attachment designs in certain cases, though further studies are needed.

Study Limitations

The limitations of this study include the relatively small sample size and the six-month follow-up period. Although the early phase of clear aligner therapy is clinically relevant, as attachment loss is most likely to occur during the initial stages of treatment, longer follow-up periods are necessary to evaluate long-term attachment survival. The limited sample size may reduce statistical power, particularly for subgroup analyses, and may restrict the generalizability of the findings. In addition, the absence of standardized intraoral photographic documentation and formal intra-rater reliability assessment should be taken into account evaluating the study outcomes. Overall, these limitations should be considered when interpreting the findings, particularly regarding their generalizability and long-term clinical applicability.

Conclusion

This prospective clinical study suggests that optimized, digitally planned attachments exhibit superior clinical survival compared with conventional attachments during the initial phase of clear aligner treatment. These findings support the role of digital treatment planning in improving attachment performance. However, the effects of different tooth movements, staging protocols, and biomechanical demands on attachment stability remain unclear. Further large-scale, long-term prospective studies are needed to confirm these findings and to establish evidence-based guidelines for attachment selection in aligner therapy.

Ethics

Ethics Committee Approval: The study protocol and informed consent process were conducted in accordance with the Declaration of Helsinki and approved by the Research Ethics Committee of Bezmialem Vakıf University (approval no: 2022/19, date: 18.01.2022).

Informed Consent: Written informed consent was obtained from all participants prior to enrollment.

Acknowledgments

The authors thank the clinical staff of the Department of Orthodontics, Bezmialem Vakıf University and Dt. Ecenur Kaplan for their assistance during patient follow-up.

Footnotes

Authorship Contributions

Surgical and Medical Practices: Ş.Ş., H.Ü., Concept: Ş.Ş., G.K., Design: Ş.Ş., G.K., Data Collection or Processing: H.Ü., Analysis

or Interpretation: Ş.Ş., G.K., Literature Search: Ş.Ş., H.Ü., Writing: Ş.Ş.

Conflict of Interest: No conflict of interest was declared by the authors.

Financial Disclosure: The authors declared that this study received no financial support.

References

1. Weir T. Clear aligners in orthodontic treatment. Aust Dent J. 2017;62(Suppl 1):58-62.
2. White DW, Julien KC, Jacob H, Campbell PM, Buschang PH. Discomfort associated with Invisalign and traditional brackets: a randomized, prospective trial. Angle Orthod. 2017;87:801-8.
3. Tai S. Clear aligner technique. Chicago: Quintessence Publishing Co. 2018.
4. Rosvall MD, Fields HW, Ziuchkovski J, Rosenstiel SF, Johnston WM. Attractiveness, acceptability, and value of orthodontic appliances. Am J Orthod Dentofacial Orthop. 2009;135:276.e1-12; discussion 276-7.
5. Dasy H, Dasy A, Asatrian G, Rózsa N, Lee HF, Kwak JH. Effects of variable attachment shapes and aligner material on aligner retention. Angle Orthod. 2015;85:934-40.
6. Gomez JP, Peña FM, Martínez V, Giraldo DC, Cardona CI. Initial force systems during bodily tooth movement with plastic aligners and composite attachments: a three-dimensional finite element analysis. Angle Orthod. 2015;85:454-60.
7. Karras T, Singh M, Karkazis E, Liu D, Nimeri G, Ahuja B. Efficacy of invisalign attachments: a retrospective study. Am J Orthod Dentofacial Orthop. 2021;160:250-8.
8. Azeem M, Hamid WU. Incidence of white spot lesions during orthodontic clear aligner therapy. J World Fed Orthod. 2017;6:127-30.
9. Rossini G, Parrini S, Castroflorio T, Deregibus A, Debernardi CL. Efficacy of clear aligners in controlling orthodontic tooth movement: a systematic review. Angle Orthod. 2015;85:881-9.
10. Fausto da Veiga Jardim A, Curado de Freitas J, Estrela C. Surface wear and adhesive failure of resin attachments used in clear aligner orthodontic treatment. J Orofac Orthop. 2024;85:52-62.
11. Yaosen C, Mohamed AM, Jinbo W, Ziwei Z, Al-Balaa M, Yan Y. Risk factors of composite attachment loss in orthodontic patients during orthodontic clear aligner therapy: a prospective study. Biomed Res Int. 2021;2021:6620377.
12. Lin S, Huang L, Li J, Wen J, Mei L, Xu H, et al. Assessment of preparation time and 1-year Invisalign aligner attachment survival using flowable and packable composites. Angle Orthod. 2021;91:583-9.
13. Weckmann J, Scharf S, Graf I, Schwarze J, Keilig L, Bourauel C, et al. Influence of attachment bonding protocol on precision of the attachment in aligner treatments. J Orofac Orthop. 2020;81:30-40.
14. Lopez C, Nizami B, Robles A, Gummadi S, Lawson NC. Correlation between dental composite filler percentage and strength, modulus, shrinkage stress, translucency, depth of cure and radiopacity. Materials (Basel). 2024;17:3901.