Time-Dependent Fit Adaptation of Two Aligner Materials: A Scanning Electron Microscopy Study

Abstract

Background: The goal of the study is to analyze and differentiatethe changes in adaptation of aligner at attachment along with time of two different aligner materials after intra-oral usage: Polyethylene terephthalate-Glycol andCo-polyester.

Materials and methods:A total of 20 aligner appliances(N=20)were studied, comprising OF 10 Polyethylene Terephthalate Glycol (PET-G) aligners and 10 Co-polyester aligners . These aligners were evaluated at two time points: just before use (T_0) and after 15 days (T_{15}) of intraoral usage.Each aligner was used for a 15-day period and then adapted to its corresponding 3D-printed resin model. The aligners were sectioned bucco-lingually at the ellipsoid attachment area, and five samples per material per time point (n = 5) were analyzed. Scanning Electron Microscopy (SEM) was employed to measure gap width changes at five distinct levels within the attachment region. The mean values of gap width changes were statistically analyzed to compare the fit between PET-G and Co-polyester aligners.

Results: Statistically significant differences ($P < 0.005$) in fit of aligner were observed at given time points: co-polyester exhibited the smallest gap at T0, while PET-G showed the largest. Likewise, at various attachment levels, significant differences were found at T15 with the smallest gaps occurring at all the levels except at incisal and gingival end of ellipsoid attachment.

Conclusion: Co-polyester showed superior properties in the initial and final fit of the aligner than that of PET-G. More dimensional changes were observed in PET-Gwhen compared to Co-polyester due to which non uniform change in gap width is seen after intra-oral usage.

Keywords:

Attachment, adaptational fit, co-polyester,gap width,polyethylene terephthalate-glycol.

INTRODUCTION

Clear aligner therapy (CAT) is increasingly recognized as a key treatment option in orthodontics, particularly for adult patients[1]. These aligners are crafted from thermoplastic materials, such as polyurethane, polyurethane terephthalate-glucol, polyethelene terephthalate copolyester etcand involves a series of personalized, removable set of aligners designed to gradually shift the teeth based on a precise treatment plan created using advanced 3D imaging software. Recent advancements in attachment designs, materials, and auxiliary devices have greatly improved the biomechanics and reliability of treatment outcomes[2,3,4]. Research shows that clear aligners can effectively manage various orthodontic issues, including crowding[5], proclination[6], distalization[7],open bite and deep bite[8]. However, more complex cases involving deep bites, rotations, and torque adjustments require careful planning and effective anchorage for successfultreatment.Thematerial composition of clear aligners is a critical factor in assessing their effectiveness for predictable outcomes. Clear aligners are primarily made from materials, which may exhibit aging changes within the oral environment. Furthermore, achieving the desired tooth movement depends significantly on the aligner's fit on both the anchorage unit and the teeth involved in the treatment.[9,10,11]

In orthodontics, thermoplastic appliances have a longstanding legacy, and aligner therapy has more recently gained traction as a compelling option across a variety of clinical scenarios. Contemporary studies underscore that aligners offer not only superior aesthetics but also reliable effectiveness in aligning and straightening dental arches, often matching the outcomes achieved by fixed orthodontic devices. Innovations in aligner materials, force delivery systems, and the sequence of tooth correction have substantially improved in treating complex malocclusionsenhancing predictability and precision.[12]

Clear aligners require consistent full-time wear to facilitate effective tooth movement. Initially, a minimum of 22 hours per day for two weeks was recommended, but this duration often led to patient fatigue and compliance issues, resulting in suboptimal outcomes. As a result, strategies to improve compliance and make treatment more manageable have become a focus in orthodontics.[3,13,14]

This study concentrates on analyzingthe fit of aligners on teeth and to investigate any differences in fit between two distinct aligner materials. By assessing these factors, we hope to contribute valuable insights into the effectiveness and clinical application of different aligner technologies in orthodontic practice.

AIM OF THE STUDY

This study aims to investigate how two different aligner materials affect the adaptation of aligner fit over time at the attachment site, comparing measurements before and after intraoral use.

MATERIALS AND METHODS.

<u>Materials</u>

PET-G- 1mm thickness

Co-polyester- 1 mm thickness

Both these materials have been compared in this study.

<u>Armamentarium</u>

1. Panda intraoral scannerFreqty Technology
2. Phrozen 4K 3D printer
3. Chennai Metco BAINCUT LSS cutting machine
4. Biostar thermoforming machine
5. Scanning electron microscopy setup with JSM IT 300 SOFTWARE

Study Design

This ex vivo experimental study aimed to evaluate the adaptational fit of two aligner materials—Polyethylene Terephthalate Glycol (PETG) and Copolyester—before and after intraoral usage. The null hypothesis proposed that there would be no statistically significant difference in aligner–attachment fit between the two materials or over time.

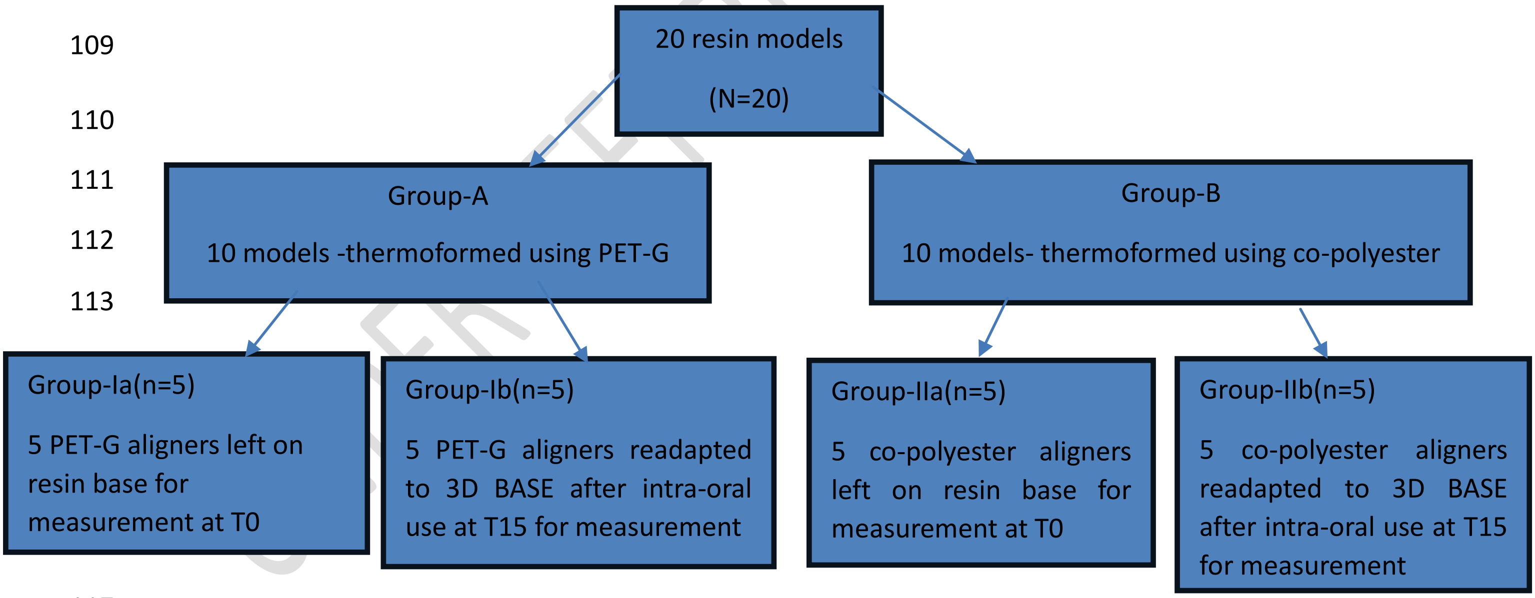
Sample Distribution

A total of 20 aligner appliances were evaluated, comprising 10 PETG and 10 Copolyester samples. Each material was studied at two time points: before intraoral use (T_0) and immediately after 15 days of wear (T_{15}). Thus, each group consisted of five aligners (n = 5 per condition; total N = 20).

Sample Preparation and Clinical Procedure

STL files were generated from intraoral scans of a patient with Class I malocclusion requiring minimal tooth movement, such as cases of mild spacing obtained using the Panda Scanner (Freqty Technology). Accompanying records included digital photographs, orthopantomograms, and lateral cephalometric radiographs. Virtual setups were designed under the supervision of an experienced clear aligner specialist to ensure uniformity across both materials.

A total of 20 resin models were 3D-printed from the STL files using a Phrozen printer (Fig. 1) and thoroughly cleaned prior to use. Ten models were allocated into 2 groups(group-A and group-B). Group-A is thermoformed with PET-G material and group-B thermoformed with co-polyester aligner sheets. Group-A is again sub-divided into group-Iaand group-Ib likewise group-B is subdivided into group-IIa and group-IIb. Where Ia and IIa are used for analysing gap width at T_0 time point and Ib and IIb are used for analysing gap width atT_{15} time point.



Initial aligners were designed without active force application to minimize shape distortion and were fitted onto the corresponding resin models (Fig. 2). Each model was mounted on an aluminum stub and sectioned labio-lingually through the central incisor region containing an ellipsoid attachment using a low-speed cutting machine (BAINCUT LSS, Chennai Metco) under continuous water irrigation to prevent thermal distortion (Fig. 3).

Scanning Electron Microscopy (SEM)

Sectioned samples were oriented perpendicular to the long axis of the central incisors. To minimize electrostatic charging and enhance image clarity, each specimen was sputter-coated with a 10 nm layer of 99% pure gold using a Cressington 208HR High-Resolution Sputter Coater (Watford, UK) (Fig. 4). Imaging was performed using a JSM IT 300 high-performance SEM (JEOL, Japan) (fig. 5) equipped with an energy-dispersive X-ray (EDX) analyzer, operated at 15 kV accelerating voltage and 10 mm working distance, with a resolution of 3.0 nm. Representative micrographs were obtained at 500 μm magnification (Fig. 6).

Measurement Protocol

Micrometric measurements were taken using the JSM IT 300 SEM software on buccolingually sectioned micrographs. Adaptational changes in aligner fit, specifically the microscopic gap between the aligner and the ellipsoid attachment, were monitored at various attachment levels and time intervals (T_0 and T_{15}). A total of fifty measurements at the micrometer level were collected and subjected to analysis, providing a comprehensive assessment of the distances at each specified level.

As shown in figure 7., Level 1 represents Incisal end of the attachment, level 2 as Incisal1/4thof the attachment, level 3 as Labial middle of the attachment, level 4 as Gingival 1/4th of the attachment, level 5 as Gingival end of the attachment.

Statistical Analysis

For statistical analysis, the data enteredinto a Microsoft Excel spreadsheet were analysed using IBM SPSS software version 25. The Mann-Whitney U test was applied for inter-group comparisons. A p-value of less than 0.05 was considered statistically significant for all analyses.

RESULTS

Table 1 and Graph 1 show the changes in mean aligner fit at different levels of the attachment in the PET-Ggroup from $T_0$to T_{15}. The fit at the incisal end decreased from 419.42 to 397.20, and at the incisal one-fourth, it dropped from 345.58 to 313.24. A more significant reduction was seen at the middle of the attachment, where the fit fell from 261.98 to 10.60. In contrast, the gingival one-fourth rose from 334.18 to 567.28 and the gingival end showed an increase from 99.60 to 413.84. All these changes were statistically significant, with p-values ranging from 0.041 to 0.043.

Table 2 and Graph 2 show the intra-group comparison of mean aligner fit at different levels of the attachment in the Co-polyestergroup from$T_0$to T_{15}. At the incisal end, the mean fit increased from 274.30 to 623.80, and at the incisal one-fourth, it rose from 144.52 to 276.00. The middle of the attachment also showed an increase from 64.82 to 130.36, while theat the gingival one-fourth, the fit showed only a slight increase from 223.14 to 223.18, which was not statistically significant ($p = 0.50$). However, gingival end improved from 19.56 to 113.90. All these changes were statistically significant, with p-values ranging from 0.041 to 0.043.

Table 3 and Graph 3 show the inter-group comparison of mean aligner fit at different levels of the attachment atT_0. At the incisal end, the co-polyester group had a higher mean fit(274.30) compared to the PET-G group(419.42), which was statistically significant ($p = 0.009$). Similarly, at the incisal one-fourth, the mean fit was 345.58 in the PET-Ggroup and 144.52 in the Co-polyestergroup ($p = 0.010$). At the middle of the attachment, the PET-Ggroup showed a mean of 261.98, significantly greater than the Co-polyestergroup's 64.82 ($p = 0.009$). At the gingival one-fourth region, the copolyester group demonstrated a significantly higher mean fit (223.14) compared to theCo-polyestergroup (334.18) (p = 0.010). Additionally,gingival margin the PET-Ggroup exhibited a mean fit of 99.60, whereas the Co-polyestergroup showed a mean fit of 19.56 (p = 0.009).

Table 4 and Graph 4 present the inter-group comparison of mean aligner fit at different levels of the attachment atT_{15}. At the incisal end, theCo-polyestergroup showed a higher mean fit(397.20) compared to the PET-Ggroup(623.80), which was statistically significant (p = 0.008). At the incisal one-fourth, the co-polyester had a slightly higher fit (276.00) than the PET-G group(313.24), also statistically significant (p = 0.009). In the middle of the attachment, the PET-G group had a greater mean fit (10.60) compared to the PET-Ggroup(130.36) (p = 0.009). At the gingival one-fourth, the co-polyester group again showed a higher fit(223.18) compared to the PET-G group(567.28), which was statistically significant (p = 0.009). Lastly,gingival end, the co-polyester group(113.90) had a much higher fit than the PET-G group(413.80), with a significant difference (p = 0.007).

DISCUSSION

This study aims to investigate how two different aligner materials affect the adaptation of aligner fit over time at the attachment site, comparing measurements before and after intraoral use. The attachment on the modelis ellipsoid which is most commonly used for space closure. Multiple factors must be considered when evaluating the efficiency and effectiveness of aligners[15,16]. According to Fang et al., the mechanical characteristics of thermoplastic materials showed no statistically or clinically significant changes after intraoral use[17]. Gaining insight into the biomechanical force dynamics between aligners and attachments is key to enhancing aligner performance.The type of interactionwhether passive oractive,significantly influences treatment outcomes. Fry et al. conducted a clinical trial with 10 moderately complex cases to evaluate the effectiveness of three different aligner change protocolsfor 2 weeks and 1 week combined with AcceleDent. After 12 weeks, all groups demonstrated comparable aligner fit, indicating that, in the short term, the frequency of aligner changes may not significantly influence fit[18].Conversely, Linjawi et al. (2022) demonstrated that a 15-day wear period resulted in better adaptation and the least width between the attachment and aligner, as observed through scanning electron microscopy (SEM)[1]. Their study showed that while width remained relatively consistent across days 3, 7, and 10, it varied depending on the location of attachment.

Comparison of Initial Fit (T_0)

At baseline (T_0), the Co-polyester aligners exhibited a smaller mean gap width across most attachment levels compared to the PET-G aligners indicating a superior initial fit. This could be attributed to the inherent material properties of Co-polyesterincluding higher rigidity and better thermoforming accuracy, which allow closer adaptation to the attachment surfaces. PET-Gby contrast, possesses greater elasticity and lower form stability upon thermoforming which may result in slightly increased internal stress relaxation and dimensional deviations following fabrication.

These findings align with previous studies suggesting that Co-polyester-based aligners demonstrate enhanced mechanical strength and better reproduction of fine surface details following thermoforming compared to PET-G-based materials[19,20]. The superior adaptation of Co-polyester at T0 thus supports its suitability for applications requiring precise attachment engagement and effective force transmission during the early phase of treatment.

Effect of Intraoral Usage (T_{15})

After 15 days of intraoral usage (T_{15}), both materials exhibited notable alterations in fit, though the direction and magnitude of changes differed between groups. PET-G aligners demonstrated a nonuniform variation in gap width, with a reduction in fit at the incisal and middle levels but an increase at the gingival ends. This irregular pattern suggests localized deformation and potential relaxation of the material due to cyclic thermal and mechanical stresses encountered intraorally such as temperature fluctuations, salivary moisture absorption, and masticatory forces.

Conversely, Co-polyester aligners exhibited more uniform dimensional changes with a general increase in gap width across most attachment levels. Although the increase indicates slight expansion or stress relaxation, the extent of change was smaller and more consistent compared to PET-G. The superior dimensional stability of Co-polyester could be related to its higher glass transition temperature (Tg) and reduced water absorption rate, which minimize distortion during wear. These results corroborate previous investigations that highlighted Co-polyester's improved resistance to deformation under oral conditions1[10,21].

LIMITATIONS

- The repeatability of micrometric measurements has not been done.
- Smaller sample size.

CONCLUSION

- The PET-G aligners showed a significant decrease in fit at the incisal and middle regions from$T_0$to T_{15}, while the gingival regions exhibited a marked increase in fit, indicating material deformation or relaxation leading to differential adaptation over time.
- The co-polyester aligners demonstrated a significant improvement in fit at most attachment levels over the 15-day period, suggesting better dimensional stability and consistent adaptation, except at the gingival one-fourth where the change was not significant.
- At T_0, the co-polyester aligners exhibited superior fit compared to the PET-G aligners at all attachment levels, indicating better initial adaptation of the co-polyester material immediately after fabrication.
- By Day 15, PET-G aligners showed higher fit values in the incisal and middle regions, while co-polyester aligners maintained better fit at the gingival areas, reflecting materialdependent changes in aligner adaptation over time.

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