ORIGINAL RESEARCH PAPER

Orthodontics And Dentofacial Orthopaedics

EVALUATION OF FLEXIBILITY, HARDNESS, AND SURFACE ROUGHNESS OF DIFFERENT THERMOPLASTIC ORTHODONTIC RETAINERS UNDER STANDARDIZED LABORATORY CONDITIONS - AN IN VITRO STUDY

KEY WORDS: dental materials, orthodontic retainer, polymers, thermoforming, thermoplastic materials

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ABSTRACT

Background: Orthodontic retention is essential for maintaining post-treatment tooth position and preventing relapse. Clear thermoplastic retainers are widely used because of their aesthetics, comfort, and patient compliance; however, thermoforming may alter their mechanical and surface properties. **Objectives:** This in vitro study evaluated and compared the flexural modulus, surface hardness, and surface roughness of four thermoplastic orthodontic retainer materials—Duran, Erkodur-Al, Avac-A, and Vivera—before and after standardized thermoforming. **Methods:** Twenty-eight thermoplastic sheets (n = 7 per material) were assessed before thermoforming as flat sheets and after thermoforming as specimens sectioned from retainers formed over standardized maxillary casts. Flexural modulus was measured using a three-point bending test, surface hardness by Vickers instrumented indentation, and surface roughness by optical noncontact profilometry. Data were analyzed using one-way ANOVA and Tukey HSD post-hoc tests, with significance set at $p < 0.05$. **Results:** Significant differences were observed between sheet and retainer forms for all evaluated properties ($p = 0.0001$). Thermoforming increased hardness and flexural modulus across all materials. In retainer form, Avac-A showed the highest hardness (179.39 ± 2.30) and flexural modulus (64.98 ± 10.31 MPa), whereas Duran showed the lowest hardness. Surface roughness increased after thermoforming in all materials, with Vivera and Erkodur-Al retainers showing the highest values; Duran sheets showed the smoothest surface. **Conclusion:** Thermoforming significantly changes the mechanical and surface characteristics of thermoplastic orthodontic retainer materials. The sheet-to-retainer transition increases hardness and stiffness but also increases surface roughness. These material-dependent changes highlight the need to evaluate post-thermoforming properties when selecting retainers for long-term orthodontic retention.

INTRODUCTION

Orthodontic retention is critical for stabilizing post-treatment tooth position by facilitating tissue reorganization, limiting growth-related changes, and supporting neuromuscular adaptation (Bondemark et al., 2007). Clear thermoplastic retainers have become the preferred choice among removable options due to their aesthetics, comfort, ease of fabrication, and improved patient compliance (Martin et al., 2023). While no universal guidelines exist for wear duration, the risk of relapse following discontinuation has led many clinicians to advocate for prolonged or lifelong retention (Little et al., 1988), making material durability and biocompatibility essential considerations. The thermoforming process and repeated intraoral exposure to mechanical, thermal, and chemical stresses can alter material properties, potentially leading to fracture, wear, discoloration, and increased replacement frequency (Proffit et al., 2018). Key physical and mechanical properties such as hardness, flexural modulus, and surface roughness directly influence the clinical performance of these appliances in terms of durability, comfort, and hygiene. Although previous research has examined thermoplastic aligner materials under various conditions, comparative data on commercially available retainer-specific materials under standardized laboratory conditions remain (E. Wible et al., 2019). Accordingly, this in vitro study aimed to evaluate and compare the flexural modulus, hardness, and surface roughness of four thermoplastic orthodontic retainer materials — Duran, Erkodur-Al, Avac-A, and Vivera — before and after thermoforming.

MATERIALS AND METHODS

This randomized controlled trial was conducted over one year across the Department of Orthodontics and Dentofacial Orthopaedics, Kannur Dental College, and the Department of Materials Science and Engineering, NIT Calicut. Four thermoplastic retainer materials were evaluated: Duran (Scheu-Dent, Germany), Avac-A (Jaypee, India), Erkodur-Al (Erkodent, Germany), and Vivera (Align Technology, Mexico). Sample size calculation using one-way ANOVA yielded seven specimens per group, resulting in 28 thermoplastic sheets of 1 mm thickness and hard quality. All specimens were thermoformed using a standardized pressure thermoforming machine (Ministar S, Scheu Dental GmbH, Germany) over a single maxillary cast of identical dimensions, following manufacturer protocols with uniform operating parameters to minimize procedural variability. Each specimen was assessed before and after thermoforming for three outcomes: flexural modulus via a universal testing machine, hardness using the Dynamic Ultra Micro Hardness Tester for Plastics DUH-210, and surface roughness using a surface profilometer, with mean values calculated from standardized locations. Pre- and post-thermoforming differences were calculated for each material and compared across brands. Statistical analysis was performed using SPSS version 26.0, with descriptive statistics, Shapiro–Wilk normality testing, one-way ANOVA for intergroup comparisons, and Tukey's HSD post hoc test for pairwise analysis, with significance set at $p < 0.05$. The study was approved by the institutional ethics committee and conducted in accordance with the Declaration of Helsinki.

RESULTS

All variables satisfied the assumption of normality, permitting the use of parametric tests. One-way ANOVA showed statistically significant differences among the study groups for hardness, surface roughness, and flexural modulus ($p = 0.0001$; **Figure 1**). For hardness, the highest value was recorded in the AVAC retainer group (179.39 ± 2.30), followed by AVAC sheet and VIVERA retainer, while the lowest value was observed in the DURAN retainer group (25.52 ± 0.81). Surface roughness also differed significantly among groups, with the lowest value in the DURAN sheet (0.2120 ± 0.0060 μm) and higher values in the AVAC sheet, VIVERA retainer, and ERKODUR retainer, indicating increased roughness after thermoforming (**Figure 2**). Flexural modulus increased substantially in retainer forms compared with sheet forms, with AVAC retainer showing the highest mean value (64.98 ± 10.31 MPa), followed by ERKODUR, VIVERA, and DURAN retainers (**Figure 3**). Tukey HSD post-hoc analysis confirmed significant pairwise differences for most comparisons, indicating that both material type and form (sheet versus retainer) significantly influenced hardness, surface roughness, and flexural modulus.

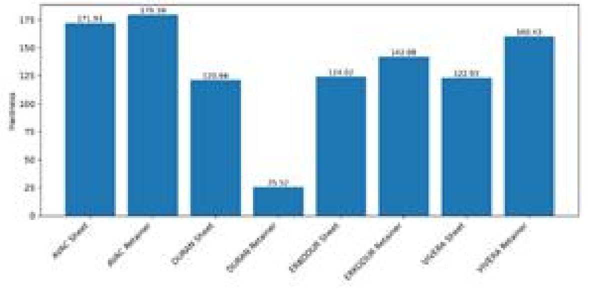

Figure 1: One-way ANOVA statistics for hardness

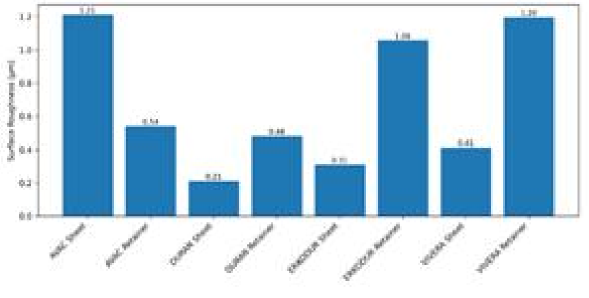

Figure 2: Post-hoc Tukey HSD multiple comparisons of surface roughness.

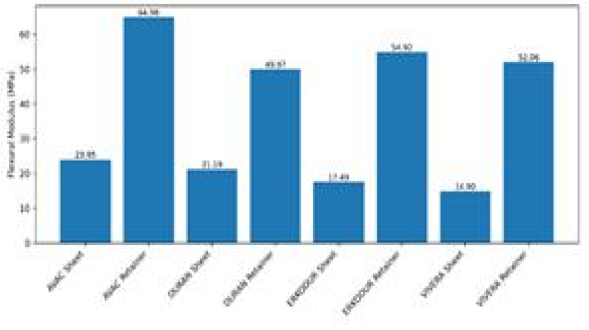

Figure 3: Post-hoc Tukey HSD multiple comparisons for flexural modulus.

DISCUSSION

Thermoplastic retainers are widely preferred for post-orthodontic retention due to their aesthetics, comfort, removability, and cost-effectiveness, with commonly used polyester, copolyester, polycarbonate, polyurethane, and polypropylene, whose crystalline and amorphous phases influence mechanical and thermal properties (Alhendi et al., 2022; Memè et al., 2021). The thermoforming process exposes these materials to heat and pressure, which may alter morphology and mechanical behavior (Schuster et al., 2004; Emily Wible et al., 2019), while repeated insertion, moisture, temperature changes, and masticatory forces may cause microscopic degradation, wear, fracture, and reduced service life(Bichu et al., 2023; Chen et al., 2023; Daniele et al., 2020; Macrì et al., 2022; Mridula et al., 2025; Porojan et al., 2020). As no universal retention protocol exists and lifelong retention is increasingly recommended, durable and resilient thermoplastic materials are essential to reduce replacement frequency and improve cost-effectiveness(Kadhum & Alhuwaizi, 2021; Moda et al., 2024; Padmos et al., 2018; Rowland et al., 2007).

In this study, thermoforming produced statistically significant increases in hardness across all materials, with Avac-A demonstrating the highest post-thermoforming hardness, likely attributable to thermally induced polymer chain rearrangement, partial crystallization, and stronger intermolecular bonding, consistent with findings by Ryu et al.(Ryu et al., 2018) and Albilali et al (Albilali et al., 2023), though differing from Dalaie et al.(Dalaie et al., 2021) who reported reduced hardness, possibly due to differences in cooling rate, residual stresses, and thermoforming protocols (Ryokawa et al., 2006).

Flexural modulus similarly increased across all materials following thermoforming, attributed to polymer densification and molecular alignment, with variable findings reported across previous studies (Ryu et al., 2018; Šimunovi et al., 2023) reflecting the influence of material composition, thickness, and testing methodology. Surface roughness also increased after thermoforming, with Vivera and Erkodur retainers showing the highest post-forming values, remaining largely within clinically acceptable limits (Šimunovi et al., 2023), though rougher surfaces may promote bacterial adhesion and biofilm formation. Collectively, these material-dependent changes emphasize that post-thermoforming properties should guide clinical material selection rather than sheet characteristics alone, and future studies incorporating aging protocols and intraoral simulation are warranted to better predict long-term retainer performance.

CONCLUSION

Within the limitations of this in vitro study, thermoforming was found to significantly alter the mechanical and physical properties of thermoplastic orthodontic retainer materials. Hardness and flexural modulus consistently increased across all materials after thermoforming, indicating greater stiffness and resistance to deformation, while surface roughness also increased, raising potential concerns for plaque accumulation and oral hygiene in clinical settings. These changes were material-dependent, reflecting the influence of polymer composition and processing behavior, with Avac-A showing the greatest gains in hardness and flexural modulus. The findings underscore the importance of evaluating post-thermoforming properties rather than relying on sheet characteristics alone when selecting materials for orthodontic retention.

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