

"Evaluation of Colour Stability of Aligners Following Exposure to Different Solutions: An In-Vitro Study"

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Abstract:

Background: Clear aligners are increasingly used as an aesthetic alternative to conventional orthodontic appliances. However, discolouration during use may compromise their aesthetic appearance. The present study aimed to compare the colour stability of Erkodur and UU Ortho aligner materials after different periods of exposure.

Materials and Methods: An in-vitro comparative study was conducted to evaluate colour change (ΔE) in Erkodur and UU Ortho aligner materials. Colour measurements were assessed after 24 hours and 7 days of experimental exposure. The mean colour change was compared between the two materials at each time interval using an independent-samples t-test. Statistical significance was set at $p < 0.05$.

Results: At 24 hours, the mean ΔE was 1.713 ± 0.152 for Erkodur and 2.164 ± 0.165 for UU Ortho, with a statistically significant difference between the materials ($p < 0.001$). After 7 days, the mean ΔE increased to 2.037 ± 0.179 for Erkodur and 2.662 ± 0.179 for UU Ortho, and the difference remained statistically significant ($p < 0.001$). Erkodur consistently demonstrated lower colour change than UU Ortho at both time intervals.

Conclusion: Erkodur demonstrated better colour stability than UU Ortho under the tested experimental conditions. Although colour change increased with exposure time in both materials, Erkodur exhibited comparatively lower ΔE values throughout the study period.

Keywords:

Clear aligners, Erkodur, UU Ortho, Colour stability, Colour change. Orthodontic materials, Aesthetic orthodontics.

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I. Introduction:

The increasing demand for aesthetic orthodontic treatment has contributed to the widespread use of clear aligners as an alternative to conventional fixed appliances. Their transparent appearance, removable nature and relatively good patient acceptance have made them particularly attractive to adult patients. Since aesthetics are an important consideration in clear aligner therapy, maintaining the transparency and colour of the aligner throughout its period of use is clinically relevant.¹ Clear aligners are fabricated from thermoplastic polymers such as polyethylene terephthalate glycol (PETG), polyurethane (PU) and polycarbonate, with differences in material composition and surface characteristics influencing their optical properties and susceptibility to staining.² The parent study by Liu et al. demonstrated that different aligner materials respond differently to staining solutions, with greater colour changes observed in some polyurethane-based aligners compared with PETG- and polycarbonate-based materials.¹ Pigment adsorption and penetration into the material surface may contribute to discoloration.¹ In clinical use, aligners may be exposed to beverages such as tea and coloured soft drinks, particularly when patients do not consistently remove them before drinking. Liu et al. reported that colour changes

became more evident with increasing exposure time, whereas colourless control solutions produced minimal changes.¹ Recent studies have similarly demonstrated that aligner material, staining solution and duration of exposure can influence colour stability.²⁻⁵ Objective assessment of colour change can be performed using spectrophotometric or colorimetric analysis based on the CIE L*a*b* system, with the overall colour difference expressed as ΔE .^{1,3,4} Recent investigations have used spectrophotometric assessment to compare the colour stability of different aligner systems following exposure to commonly consumed beverages.³⁻⁵ Erkodur, a PETG-based thermoplastic material, has demonstrated favourable optical characteristics in previous investigations.² Liu et al. reported relatively good colour stability for the PETG-based Smartee aligner,¹ while more recent research has also reported favourable colour stability of thermoformed PETG-based aligners following exposure to staining agents.⁶ Although previous studies have evaluated aligner colour stability following exposure to coffee, tea, wine and other staining agents, further comparison of commercially available materials under different commonly encountered exposure conditions remains relevant.¹⁻⁶ Therefore, the present in-vitro study was undertaken to evaluate the colour stability of selected clear aligner materials following immersion in artificial saliva, Sting energy drink, vodka and tea. Colour changes were assessed at baseline, after 24 hours and after 7 days using spectrophotometry, with particular emphasis on comparing the colour stability of Erkodur and UU Ortho aligner materials.

II. Materials and Methods:

An in vitro experimental study was carried out to evaluate the colour stability of two commercially available clear aligner materials after exposure to artificial saliva and Sting energy drink. An impression of an ideal maxillary dentition was made and poured with dental stone to obtain a standardized master cast. The cast was carefully examined to ensure that it was free from any defects or irregularities that could interfere with aligner fabrication. Clear aligner sheets obtained from two different manufacturers were then thermoformed over the standardized maxillary cast following the respective manufacturer's recommended procedure. After thermoforming, the aligners were carefully removed from the cast and trimmed to obtain specimens of uniform dimensions. The specimens were examined for any visible defects, such as cracks, folds, or irregularities, and defective specimens were excluded.

Sample Size Determination

The sample size was determined using G*Power software (version 3.1.9.4) based on an assumed effect size of 0.5, 80% statistical power, and a 5% level of significance ($\alpha = 0.05$). Based on the study design and statistical comparison planned, the required sample size was determined, and a total of 40 aligner specimens were included in the present study. The specimens were equally distributed between the two immersion media, with 20 specimens immersed in artificial saliva and 20 specimens immersed in Sting energy drink. Specimens fabricated from both aligner materials were represented within each immersion group, allowing comparison of the colour stability of the two materials under similar experimental conditions.

Artificial saliva was used as the control medium to simulate the oral environment, while Sting energy drink was selected as the experimental beverage. Each specimen was individually labelled and placed in a separate container containing the assigned immersion medium. The specimens were completely immersed in the solutions throughout the experimental period to ensure adequate exposure to the respective media. All immersion procedures were carried out under standardized laboratory conditions.

Colour measurements were recorded at three time points: before immersion (T0), after 24 hours of immersion (T1), and after 7 days of immersion (T7). Baseline colour measurements were first recorded before placing the specimens in the immersion media. After 24 hours, the specimens were removed from their respective solutions, air, dried and subjected to colour measurement. The same procedure was followed at T7 for the final colour measurement.

Colour measurements were recorded using the CIE L*a*b* colour system. The L* parameter represents lightness, a* represents the red-green axis, and b* represents the yellow-blue axis. The total colour change (ΔE) was calculated as:

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

where ΔL^* , Δa^* and Δb^* represent the differences in L*, a* and b* colour parameters between baseline (T0) and the respective post-immersion time point (T1 or T7).

The colour stability of the two aligner materials was assessed by comparing the ΔE values obtained after 24 hours and 7 days of immersion. Comparisons were made between the two aligner materials within each immersion medium, between artificial saliva and Sting energy drink for each material, and between the two exposure periods. To maintain consistency throughout the experiment, the same master cast, thermoforming procedure, immersion conditions, rinsing and drying procedure, and spectrophotometric measurement protocol were used for all

specimens. The spectrophotometer was calibrated before measurements, and all colour assessments were performed under standardized laboratory conditions.

The recorded colour values and ΔE measurements were entered into Microsoft Excel and analysed using [SPSS version]. Descriptive statistics were used to summarize the colour measurements and ΔE values. Data distribution was assessed using an appropriate test for normality, followed by the application of suitable parametric or non-parametric statistical tests based on the distribution and study design. Statistical significance was set at $p < 0.05$.

III. Results:

Quantitative evaluation of colour change revealed significant differences between the two materials at both time points (Table 1; Figure 1). At 24 hours, the Erkodur group exhibited a significantly lower ΔE value (1.713 ± 0.152) than the UU Ortho group (2.164 ± 0.165 , $p < 0.001$). After 7 days, the Erkodur group (2.037 ± 0.179) also showed significantly lower colour change than the UU Ortho group (2.662 ± 0.179 , $p < 0.001$). Overall, Erkodur exhibited lower colour change than UU Ortho at both tested time intervals.

Table 1. Intergroup comparison of colour change (ΔE) between Erkodur and UU Ortho at different time intervals

Time interval	Erkodur (Mean $\pm$ SD)	UU Ortho (Mean $\pm$ SD)	<i>t</i>	df	<i>p</i> value
24 hours	1.713 $\pm$ 0.152	2.164 $\pm$ 0.165	-8.970	38	<0.001
7 days	2.037 $\pm$ 0.179	2.662 $\pm$ 0.179	-11.030	38	<0.001

Note: Values are expressed as mean $\pm$ SD. Independent-samples *t*-test was used for intergroup comparison. Lower ΔE values indicate lower colour change and greater colour stability. $p < 0.05$ was considered statistically significant.

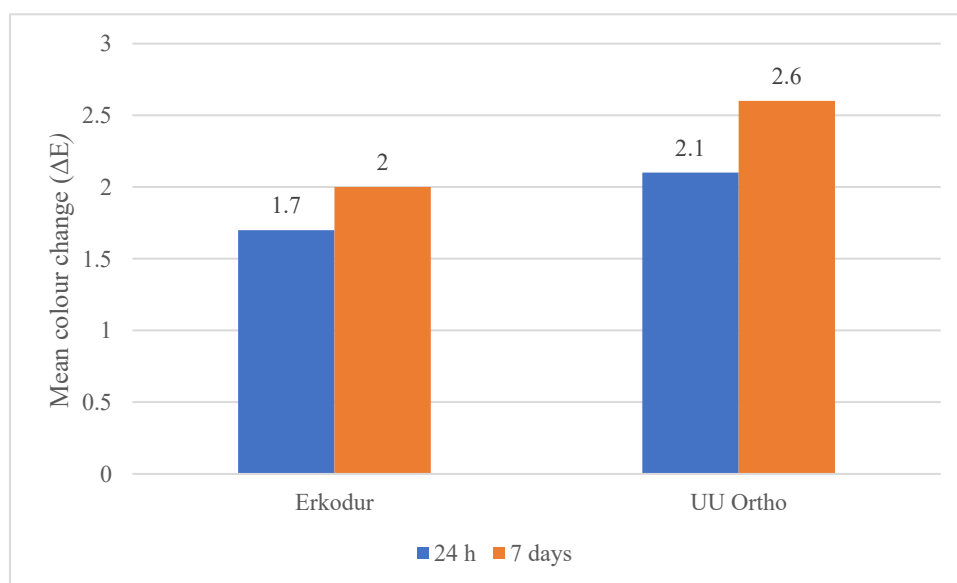


Figure 1. Colour changes in Erkodur and UU Ortho at 24 hours and 7 days.

IV. Discussion:

The present study evaluated the colour stability of Erkodur and UU Ortho by assessing colour change (ΔE^*) at 24 hours and 7 days. A significantly lower mean ΔE^* value was observed for Erkodur compared with UU Ortho at both time intervals. At 24 hours, Erkodur showed a mean ΔE^* of 1.713 ± 0.152 , whereas UU Ortho showed 2.164 ± 0.165 ($p < 0.001$). After 7 days, the mean ΔE^* increased to 2.037 ± 0.179 for Erkodur and 2.662 ± 0.179 for UU Ortho, with the difference remaining statistically significant ($p < 0.001$). Thus, Erkodur demonstrated lower colour change than UU Ortho throughout the tested period.

The progressive increase in colour change observed from 24 hours to 7 days in both materials is consistent with the findings of Liu et al.¹, who evaluated the colour stability of three types of clear aligners following exposure to coffee, black tea, red wine, and distilled water. They reported relatively slight colour changes after 12 hours, whereas colour alteration became more pronounced after 7 days of exposure, particularly in the presence of staining agents. Their findings indicate that prolonged exposure can contribute to increased

pigmentation of aligner materials. This temporal pattern is comparable with the present study, in which both Erkodur and UU Ortho exhibited higher ΔE^* values after 7 days than after 24 hours.

Differences in colour stability among aligner materials may also be related to their polymer composition and physicochemical characteristics. Daniele et al.² comparatively evaluated commercially available PETG- and polyurethane-based aligners, including Erkodur, and reported differences in optical properties and resistance to staining among the materials. Their findings indicated that PETG-based materials demonstrated favourable transparency-related properties, although staining after prolonged exposure was still observed. In the present study, the lower ΔE^* values observed for Erkodur may therefore be related, at least in part, to differences in polymer composition and material characteristics. However, direct comparison of ΔE^* values between studies should be made cautiously because the materials, staining agents, exposure conditions, and measurement protocols were not identical.

The present findings are further supported by Olteanu et al.³, who investigated the colour stability of different clear aligner systems after immersion in commonly consumed staining beverages. Their study demonstrated that colour changes varied according to both the aligner system and the staining beverage, with prolonged exposure contributing to greater discoloration. These findings support the observation in the present study that colour stability is material-dependent and may change with increasing exposure duration.

Similarly, Domingo-Jiménez et al.⁴ evaluated three types of clear aligners after exposure to distilled water and coffee, with colour measurements performed at baseline, 12 hours, and 7 days. They reported that colour changes differed according to the aligner type and exposure medium, with more noticeable changes observed following coffee exposure. The authors also demonstrated alterations in lightness and chromatic parameters with increasing exposure time. The use of similar time points in that study and the present investigation further supports the relevance of evaluating colour stability at both an early exposure period and approximately one week.

More recently, Perumalla et al.⁵ compared the colour stability of direct-printed and thermoformed aligners following 7 days of exposure to common staining agents. Erkodur, a thermoformed PETG-based aligner material, demonstrated a mean ΔE^* of 2.56, compared with 9.82 for TC85 and 3.59 for TA28, with statistically significant differences between the groups ($p < 0.001$). The study additionally reported smoother surface morphology and greater chemical integrity for the thermoformed Erkodur material. These findings are particularly relevant to the present study because Erkodur was also evaluated and demonstrated comparatively low colour change after 7 days. Nevertheless, the absolute ΔE^* values cannot be directly compared because Perumalla et al. used different staining agents and experimental conditions.

From a clinical perspective, colour stability is an important characteristic of clear aligners because their aesthetic advantage depends on maintaining acceptable transparency and minimal visible discoloration during treatment. Clear aligners may be exposed to saliva, dietary pigments, beverages, humidity, and other oral environmental factors during their period of use. The studies by Liu et al.¹ and Domingo-Jiménez et al.⁴ demonstrate that exposure duration and staining conditions can influence the colourimetric properties of aligner materials. Therefore, the lower ΔE^* values observed for Erkodur in the present study indicate comparatively lower colour alteration under the tested experimental conditions.

Further support for the influence of material composition and manufacturing technique comes from Šimunović et al.⁶, who compared thermoformed and 3D-printed polyurethane-based aligners exposed to coffee, black tea, Coca-Cola and Red Bull for up to 7 days. Their findings demonstrated that both the aligner brand and manufacturing method significantly influenced colour stability, with 3D-printed aligners generally showing greater colour change than thermoformed materials. They also reported that aligners incorporating a PETG outer layer were more resistant to staining and chemical alterations. These findings provide further support for the role of material composition and fabrication technique in determining colour stability.

Ajwa et al.⁷ evaluated the colour stability of four commercially available clear aligner systems after exposure to different beverages for 7 days. Significant colour changes were observed over time, with differences between 12 hours and 7 days. However, the authors reported minimal differences in discoloration among the different manufacturing materials. This suggests that although exposure duration and staining solution can substantially influence colour change, the magnitude of material-related differences may vary depending on the experimental conditions and specific aligner systems evaluated.

More recently, Kobkiatkawin et al.⁸ investigated the colour stability of four clear aligner brands after exposure to tea, coffee and cola for 6 and 12 hours. Coffee produced the greatest colour change, followed by tea and cola, while artificial saliva produced minimal changes. The authors also reported greater colour differences for polyurethane-based Invisalign compared with polyester- and PET-based materials under some staining conditions. These findings reinforce the importance of both polymer composition and the nature of the staining agent in determining the colour stability of clear aligners.

In a recent comparative study, Narkhede et al.⁹ evaluated four commercially available aligner materials—Invisalign, ClearCorrect, Illusion and Graphy TC-85—after exposure to tea, coffee, cola and red wine over 14 days. Their results demonstrated that both time and beverage type significantly influenced ΔE , with coffee and cola producing greater discoloration in several materials. The study further highlighted that polymer chemistry

plays an important role in colour stability, with different materials demonstrating different responses to individual staining agents. These findings are consistent with the present study, in which the magnitude of colour change increased over time and differed between Erkodur and UU Ortho.

Jancauskaite et al.¹⁰ also demonstrated a progressive increase in colour change during exposure of clear aligners to staining beverages. In their study, black coffee produced the greatest colour change after 7 days, followed by coffee with milk, kombucha and green smoothie. The progressive increase in ΔE over the observation period further supports the time-dependent pattern observed in the present study.

The influence of manufacturing parameters on colour stability was further demonstrated by Wu et al.¹¹, who investigated the effects of printing layer thickness and build orientation on the colour stability of 3D-printed clear aligner resin. Although printing parameters influenced colour stability in artificial saliva, all tested specimens demonstrated high susceptibility to coffee staining. Their findings indicate that colour stability may be influenced not only by the chemical composition of the material but also by processing and manufacturing characteristics.

The role of surface characteristics in colour alteration has also been reported by Kobkiatkawin et al.⁸, who observed greater surface roughness and porosity in some aligner materials and found corresponding differences in colour change following exposure to staining beverages. Similarly, Başal et al.¹² evaluated staining and cleaning effects on Invisalign aligners and found that staining agents significantly affected colour change, with coffee producing the greatest discoloration. Their study also demonstrated that staining agents significantly influenced surface roughness, suggesting that changes in surface characteristics may contribute to the aesthetic deterioration of aligners.

Kılıç et al.¹³ investigated the effect of different cleaning agents on the colour and surface roughness of Invisalign aligners in a randomized crossover clinical trial. Their findings demonstrated that cleaning protocols can influence the aesthetic properties of aligners, with differences in colour change observed between cleaning agents. Although cleaning procedures were not evaluated in the present study, these findings indicate that post-exposure care may also influence the final colour stability of aligner materials during clinical use.

Similarly, Aşık et al.¹⁴ investigated the ability of different cleaning protocols to improve and maintain the colour stability of coffee-stained aligners. After 7 days of coffee exposure, the aligners underwent different cleaning protocols followed by a second discoloration cycle. Their study emphasizes that colour stability is not determined solely by the initial material composition but may also be influenced by cleaning procedures and repeated exposure to staining agents.

In addition, Bilginer et al.¹⁵ evaluated tooth discoloration in the presence of clear aligners and attachments following exposure to common staining beverages. Although their investigation focused on tooth rather than aligner colour, the study demonstrated that staining beverages can produce clinically perceptible colour changes during simulated aligner use. This further emphasizes the importance of considering the interaction between the aligner, staining environment and oral tissues when interpreting aesthetic changes during clear aligner therapy.

Taken together, the available evidence indicates that colour stability of clear aligners is a multifactorial phenomenon influenced by material composition, manufacturing technique, exposure duration, staining agent, surface characteristics and cleaning procedures. The findings of the present study add to this evidence by demonstrating a significant difference in colour change between Erkodur and UU Ortho at both 24 hours and 7 days. The consistently lower ΔE values observed for Erkodur suggest that the material exhibited comparatively better resistance to colour alteration under the conditions evaluated. However, differences in experimental protocols among published studies—including staining solutions, exposure duration, temperature, measurement systems and cleaning procedures—should be considered when making direct comparisons between ΔE values. The present findings, together with previous evidence, suggest that selection of an aligner material with favourable colour stability may contribute to maintaining the aesthetic appearance of clear aligners during treatment. Nevertheless, clinical studies incorporating realistic oral conditions, dietary exposure, saliva, mechanical wear and patient cleaning practices are necessary to determine whether the differences observed in vitro translate into clinically meaningful differences in long-term aesthetic performance.

V. Conclusion

Erkodur demonstrated better colour stability than UU Ortho under the tested experimental conditions, showing significantly lower colour change (ΔE) at both 24 hours and 7 days. Although colour change increased with time in both materials, Erkodur consistently exhibited lower ΔE values, indicating comparatively greater resistance to colour alteration during the study period. However, the observed differences in colour change may not necessarily be clinically significant. These findings suggest that Erkodur may provide greater aesthetic stability during the period of aligner use.

VI. Limitations

The study was conducted in vitro and had a relatively short observation period of 7 days. Only Erkodur and UU Ortho were evaluated, limiting the generalizability of the findings to other aligner materials. The complex

oral environment, including saliva, temperature and pH fluctuations, dietary habits, biofilm accumulation, and mechanical forces, could not be fully reproduced. Additionally, the study focused primarily on colour change and did not assess other material properties such as surface roughness, transparency, mechanical strength, or chemical changes. Further long-term clinical studies are recommended to confirm these findings.

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