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# Original Research

## Color stability of two different aligner materials after exposure to different liquids used in Indian diet- An in vitro comparative study

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***ABSTRACT:***

**Background:** Utilization of clear aligners for orthodontic treatment has grown exponentially over the past decades.The aesthetic appeal of clear aligners is critical for patient satisfaction in orthodontic treatment. However, these aligners are occasionally stained due to the consumption of victuals in the Indian diet, demanding an analysis of their color stability. Hence, this study evaluates the color stability of two aligner materials when subjected to common Indian dietary liquids and artificial saliva. **Aim & Objectives:** To compare the color stability of two different aligner materials when immersed in tea, coffee, orange juice, turmeric-based and artificial saliva based solutions. **Methods:** Two aligner materials were immersed in forementioned liquids for duration of two weeks. Color changes were quantified using a spectrophotometer before and after exposure. Data analysis was performed using bivariate analyses were performed using both Independent t-tests and paired t-tests to assess significant differences in color stability. **Results:** Our results revealed that after being subjected to staining agents such orange juice, tea, and coffee, PU aligners had significantly greater changes in color than PET-G aligners. After fortnight, notable color alterations became apparent with PET-G being more influenced by turmeric water and PU aligners being highly susceptible to coffee stains.**Conclusion:** Material selection is crucial in orthodontics, as dietary habits can influence the longevity and aesthetics of aligners. These results emphasize the need for further research into long-term effects and strategies to mitigate discoloration.

**Keywords:** Aligner materials, Color stability, Dietary liquids, Orthodontics, Discoloration

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### INTRODUCTION

Clear aligners have gained popularity in orthodontics due to their aesthetic appeal and comfort, especially among adult patients seeking "invisible" solutions for esthetic purposes. Especially popular among adult patients seeking discreet esthetic solutions, these transparent appliances gradually reposition teeth without the visibility of traditional metal braces. Perfect for both adults and teens, clear aligners not only enhance smiles but also effectively tackle a range of dental alignment issues, empowering individuals to achieve their dream smiles with confidence and ease. However, their susceptibility to staining from dietary agents poses a significant concern, especially in India, where vibrant beverages and spices are staples.[1] This study investigates the color stability of two common aligner materials—polyurethane (PU) and polyethylene terephthalate glycol (PET-G)—after exposure to staining liquids prevalent in the Indian diet, including tea, coffee, orange juice, turmeric solutions and artificial saliva.[2] Understanding how these materials respond to staining agents is essential, as discoloration can adversely affect patient satisfaction and compliance.[3] By employing spectrophotometric analysis, this in vitro study aims to quantify color changes in PU and PET-G aligners, providing insights into their aesthetic performance and behavior under realistic conditions.[4] The findings will not only guide orthodontists in material selection and dietary recommendations but will also enrich the

growing body of literature on the interaction between orthodontic materials and dietary substances.[5] Moreover, the results may inform strategies for improving the formulations of aligner materials to enhance their resistance to discoloration.[6] Such advancements could lead to longer-lasting aesthetic quality, thereby increasing patient compliance and satisfaction.[7] Ultimately, this research contributes to a more comprehensive understanding of how dietary habits can influence the performance of clear aligners, supporting orthodontic practices in providing effective and aesthetically pleasing treatments for their patients.[8]

## AIM

This study aimed to evaluate the color stability of two different aligner materials after exposure to different liquid media commonly used in the Indian diet.

## OBJECTIVES

To assess color changes between PU & PET-G after 14 days usage of different liquid media. To compare the intensity of staining by different media on the thermoplastic clear aligner.

## METHODOLOGY

### Sample selection

This study consisted of 10 Aligners of which 5 were from Polyurethane (PU) and 5 from Polyethylene terephthalate glycol (PET-G) in the Department of Orthodontics & Dentofacial Orthopaedics, Shree Bankey Bihari Dental College, Ghaziabad.

### Armamentarium

Comprises of Pressure thermo forming machine (Ministar S, Scheu-Dental, Germany),Taglus PU Flex (Vedia Solutions, Mumbai), DURAN+ (Scheu Dental GmbH Iserlohn, Germany), Cutting diamond discbur (NMD Nexus Medodent, Republic of Korea), Glass Measuring cylinders, Artificial saliva, Teabags- Taj, Orange juice-Real, Coffee powder- Nescafe, Turmeric powder-MDH, Spectrophotometer VITA EasyShadeV (Bad Sackingen, Germany), Thermostat water bath, Tweezer, Distilled water (**Figure 1-5**)

### Procedure

**Creation of Ideal cast model:** The ideal cast models were scanned using an optical scanner (shining 3D) and then scanned models were converted into stereo lithographic (stl.) files. The stl files were transferred into Chitu box for printing and the printed resin casts were obtained.

**Thermo forming with pressure moulding:** Thermo forming was done on 10 similar and identical cast, 5 with polyurethane sheets and 5 with PET-G sheets using pressure moulding machine (Ministar)

**Trimming of aligners:** After thermoforming, aligners were trimmed using Scheu burs to achieve the desired aligner shape and fit.

**Preparation of solutions:** Five different liquid media were taken, one being the artificial saliva (Modified Fusyama‘s Solution) and the other four being the commonly used Indian beverages like coffee (Nescafe), tea (Taj Mahal tea bag), turmeric powder (MDH), and orange juice (Real) (**Figure 6,7**). Each media had the volume of 100ml which were maintained at 37 ± 1 °C (room temperature) in a thermostat water bath. Fresh solutions were prepared every day for the total period of 14 days in order to follow the two weeks protocol of aligner exposure to oral environment.


**Figure 1: Pressure thermoforming machine (Ministar S, SCHEU-Dental, Germany)**


**Figure 2: Polyurethane sheets (Taglus PUFlex)**

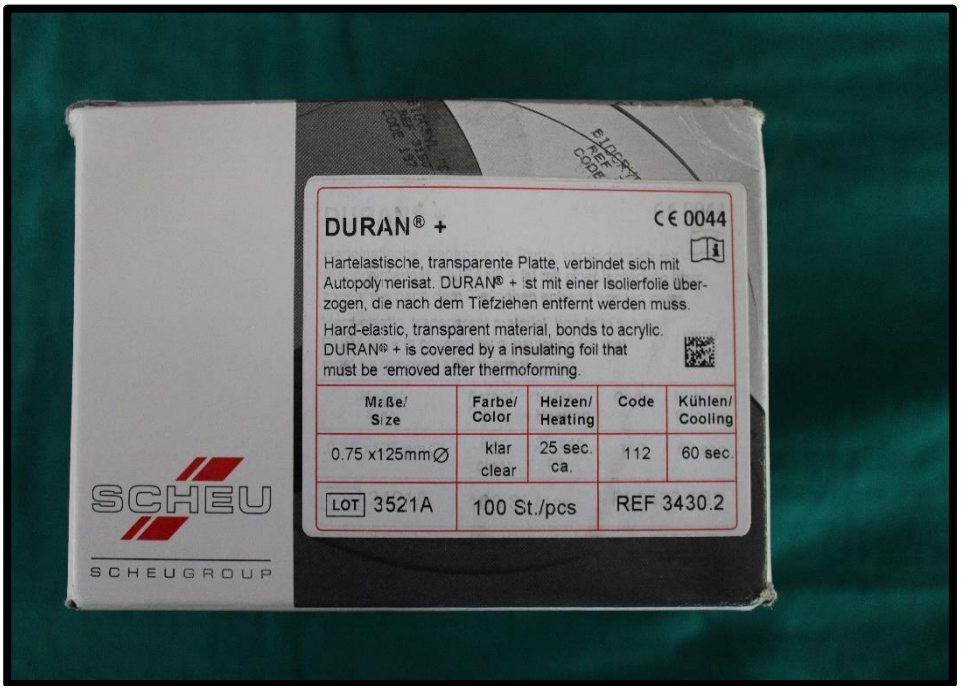


**Figure 3: DURAN + (Scheu Dental GmbH Iserlohn, Germany)**

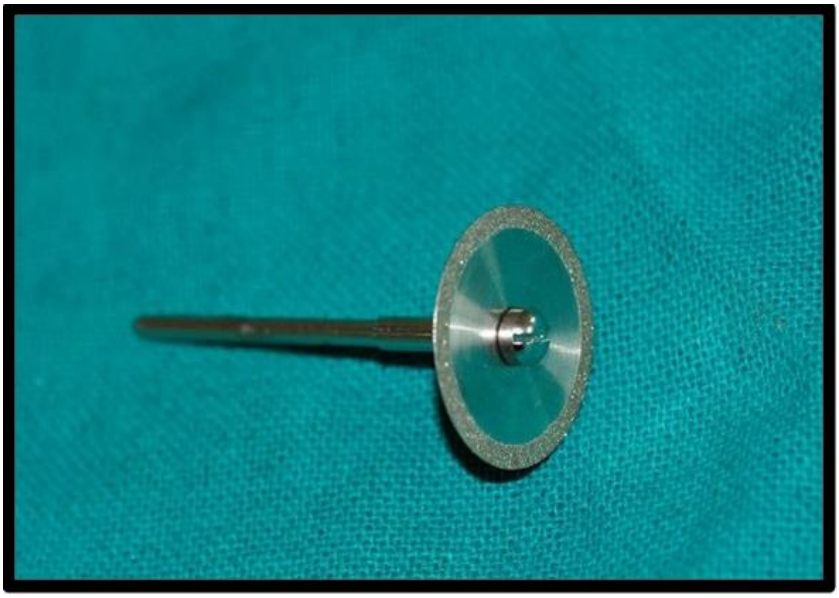

**Figure 4: Double-ended cutting diamond discbur (NMD Nexus Medodent)**


**Figure 5: Spectrophotometer (VITA easy shade)**

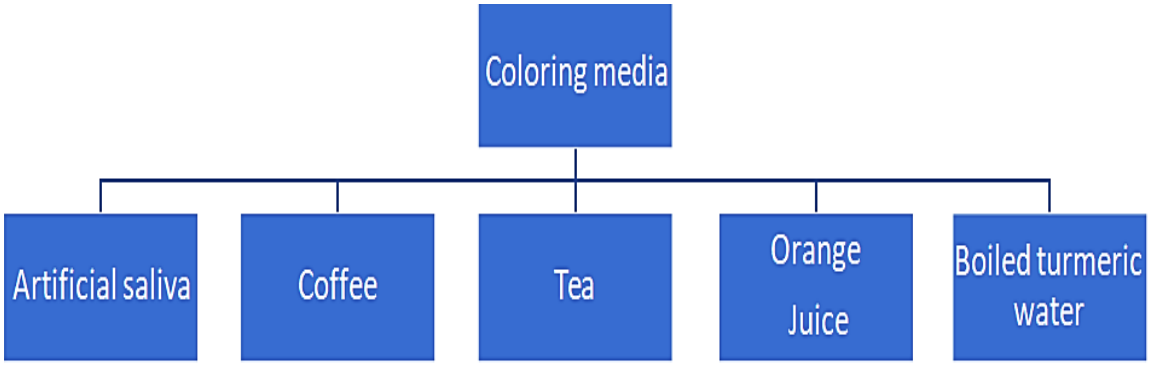


**Figure 6: Types of coloring solutions**

1. For the control 100 ml of artificial saliva (Modified Fusyama‘s Solution) was used.
2. The instant coffee solution was made with 1gm of instant coffee powder per 100 ml of boiling distilled water.
3. For tea1bag per 100ml of boiling distilled water was used.
4. 100 ml orange juice was used.
5. Freshly prepared 100 ml of boiled water with 2 gm of turmeric powder was employed
6. For the control 100 ml of artificial saliva (Modified Fusyama‘s Solution) was used.


**Figure 7: Coloring solution**

**Color measurement protocol via spectrophotometer:** To assess color changes in aligners, half of the arch from five samples of Taglus PUFlex and Duran+ was submerged in various coloring media for 10 minutes. The media included artificial saliva (Group A), orange juice (Group B), tea (Group C), coffee (Group D), and turmeric water (Group F). After immersion, the samples were exposed to a control environment to simulate intraoral conditions, with the procedure repeated three times a day for 14 days at 37±1°C. After the exposure period, the aligners were rinsed with distilled water and measured using a spectrophotometer (**Figure 8**). Color measurements were taken at the labial surface of the central incisor using the Vita Easy Shade Guide, under consistent lighting conditions. Color changes (ΔE) were calculated using the CIE L*a*b* color system, where L* measures luminosity, and a* and b* indicate color on the chromatic scale, allowing for quantification of the color shifts experienced by the aligners:

□E=((□L*)2+(□a*)2+(□b*)2)1/2

ΔL , Δa and Δb are the subtractions of the L*, a* and b* color parameters collected at various times:

$\Delta L = L_{T0} - L_{T1}$ $\Delta a = a_{T0} - a_{T1}$ $\Delta b = bT0 - bT1$

A standard VITA Easy shade compact colorimeter was used to check the change in color, which was evaluated at 2 intervals.

T0: before specimen immersion (as formed).

T1:after14 days exposure to a staining solution

To analyze the color parameters of the aligners, we used a spectrophotometer to measure the shade of the 10 aligners. To ensure accuracy, the spectrophotometer was calibrated with white light before every measurement. After recording values of all the aligners of each group, mean values were calculated for each group respectively. Comparisons of mean color change across various groups (□**E)** were also made.


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**Figure 8: Coloring measurement via spectrophotometer**

**Color change rating:** Color change rating was done with the help of the National Bureau of Standards System (NBS) of expressing color difference. The ΔE value was converted into NBS units with the formula NBS=□E×0.92torelatethe magnitude of color change to clinical relevance standard

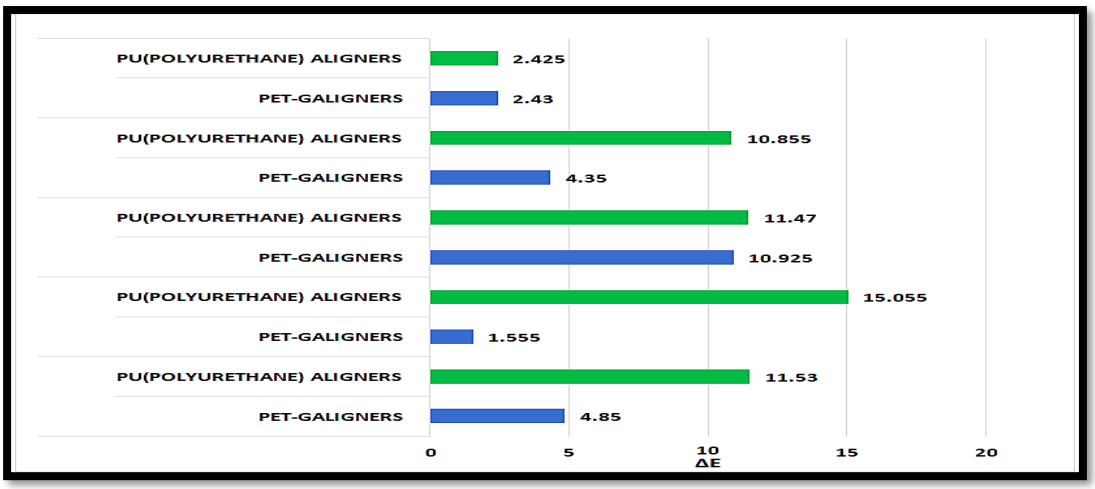
Data was carefully entered into a Microsoft Excel spreadsheet and thoroughly reviewed for inconsistencies to ensure precision. For data analysis, SPSS version 21.0 was employed. The Shapiro-Wilk test was utilized to evaluate the distribution of the variables, confirming that the data adhered to a normal distribution. Consequently, bivariate analyses were performed using both Independent t-tests and paired t-tests for intergroup and intra group comparisons, respectively. A statistical significance threshold was set at $p < 0.05$, underscoring the rigor and dependability of our analytical methodology.

## RESULTS

Photographs of the aligners after immersion at T1 in artificial saliva, tea, orange juice, coffee, and turmeric water. Visual inspection shows that there were significant visual color changes in the coffee group in PU (**Figure 9**) and turmeric group in PET-G (**Figure 10**) aligners at T1.The summarized results are displayed in **Table 1, 2, 3** and depicted in **Graph 1**

**Table1: National Bureau of standards ratings**

| National bureau of standard ratings | Description of color change |
|---|---|
| 0.1– 0.5 | Trace: Extremely slight change |
| 0.5– 1.5 | Slight: Slight change |
| 1.5– 3.0 | Noticeable: Perceivable |
| 3.0– 6.0 | Appreciable: Marked changes |
| 6.0– 12.0 | Much: Extremely marked change |
| 12.0 or more | Very much: Change to other color |




**Graph 1: It depicts the relationship between coloring media with color changes**

**Table 2: National Bureau rating of aligner in each group at T1**

| COLORING MEDIA | ALIGNER GROUP | MEAN | NBS RATING | DESCRIPTIONOF COLOR CHANGE |
|---|---|---|---|---|
| **TEA** | PET-G ALIGNER | 4.8500 | 4.4 | **Appreciable** |
| | PU ALIGNER | 11.5300 | 10.6 | **Extremely marked changes** |
| **COFFEE** | PET-G ALIGNER | 1.5550 | 1.38 | **Slight** |
| | PU ALIGNERS | 15.0550 | 13.84 | **Very much** |
| **TURMERIC WATER** | PET-G ALIGNERS | 10.9250 | 10.04 | **Extremely marked changes** |
| | PU ALIGNERS | 11.4700 | 10.5 | **Extremely marked changes** |
| **ORANGE JUICE** | PET-G ALIGNERS | 4.3500 | 4.002 | **Appreciable** |
| | PU ALIGNERS | 10.8550 | 9.98 | **Extremely marked changes** |
| **ARTIFICIAL SALIVA** | PET-G ALIGNERS | 2.4300 | 2.23 | **Noticeable** |
| | PU ALIGNERS | 2.4250 | 2.22 | **Noticeable** |

**Table 3: Inter group comparison of color change on aligners**

| COLORING MEDIA | ALIGNER GROUP | MEAN | STD. DEVIATION | STD. ERROR MEAN | P [A]VALUE |
|---|---|---|---|---|---|
| **TEA** | PET-GALIGNER | 4.8500 | .02828 | .02000 | **<0.0001*** |
| | PU ALIGNER | 11.5300 | .01414 | .01000 | |
| **COFFEE** | PET-GALIGNER | 1.5550 | .00707 | .00500 | **<0.0001*** |
| | PU ALIGNERS | 15.0550 | .04950 | .03500 | |
| **TURMERICWATER** | PET-GALIGNERS | 10.9250 | .07778 | .05500 | **0.310 NS** |
| | PU ALIGNERS | 11.4700 | .56569 | .40000 | |
| **ORANGEJUICE** | PET-GALIGNERS | 4.3500 | .00000 | .00000 | **0.0001*** |
| | PU ALIGNERS | 10.8550 | .02121 | .01500 | |
| **ARTIFICIALSALIVA** | PET-GALIGNERS | 2.4300 | .15556 | .11000 | **0.986 NS** |
| | PU ALIGNERS | 2.4250 | .31820 | .22500 | |

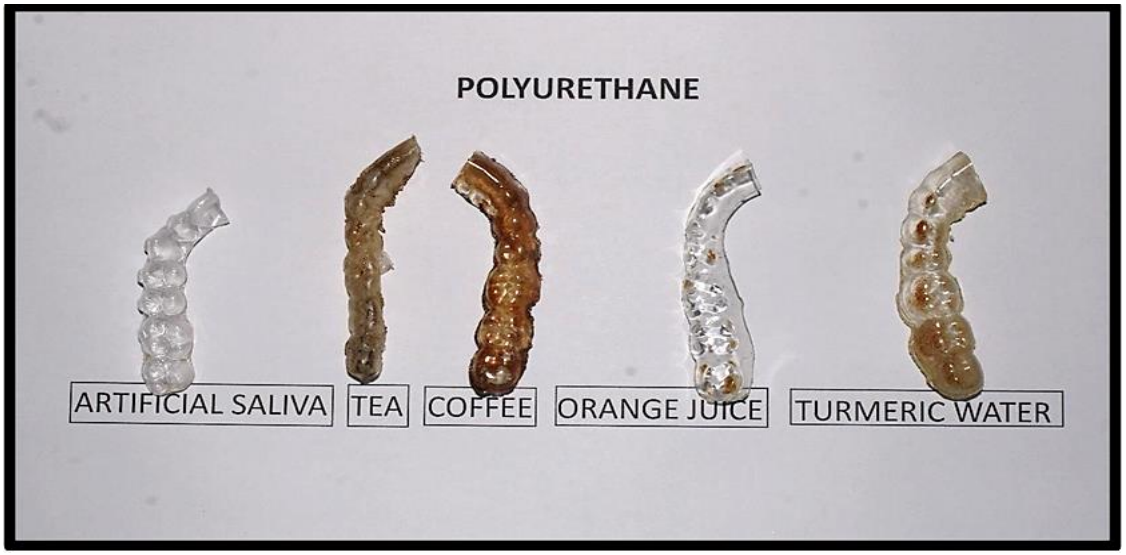



**Figure 9: Visual color changes in polyurethane aligners at T1**

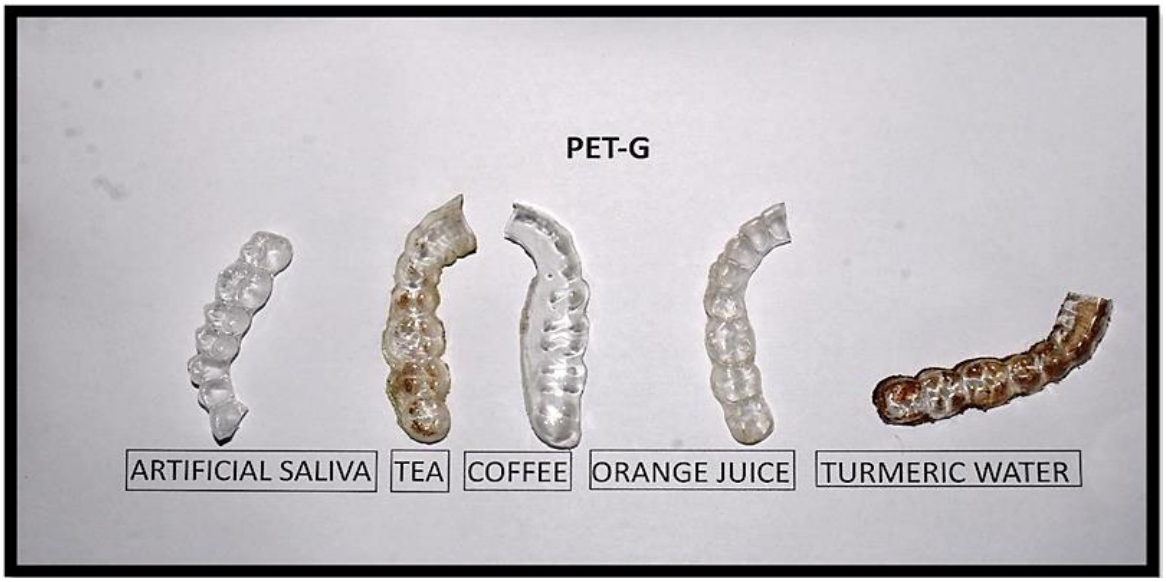



**Figure 10: Visual color changes in PET-G aligners at T1**

## DISCUSSION

In the current study, a spectrophotometer was used to meticulously analyze color parameters of 10 orthodontic aligners made from two materials—polyurethane (PU) and polyethylene terephthalate glycol (PET-G)—subjected to various staining agents.[9] By comparing mean values of color changes (ΔE) at the initial (T0) and final (T1) time points after a 14-day immersion, significant insights into the color stability of these aligners emerged.[10] The results indicated that PU aligners experienced notably greater color alterations than PET-G aligners when exposed to staining agents such as tea, coffee, and orange juice.[11] No significant differences were found for exposure to turmeric water or artificial saliva, highlighting the critical impact of both aligner material and staining medium on aesthetic properties.[12] Within the PU group, coffee caused the most pronounced color change, followed by tea and turmeric.[13]In contrast, PET-G aligners showed the highest ΔE variation with turmeric, emphasizing its strong discoloration potential due to its prevalence in Indian cuisine.[14] After 14 days of immersion, PU aligners displayed more significant color changes, leading to the rejection of the null hypothesis, which posited no difference in color stability between the materials.[15]This reinforces existing literature indicating that dietary choices, particularly the consumption of staining agents like coffee and tea, substantially affect the aesthetics of orthodontic materials.[16]Our findings are crucial for informing dietary guidelines for orthodontic patients, particularly those wearing aligners.[17]While both materials maintained relatively high color stability in

artificial saliva, the changes induced by staining solutions warrant caution. Patients should be advised to limit turmeric-rich foods and other potent staining agents during aligner wear to prevent discoloration.[18] This study lays a vital foundation for future dietary recommendations and highlights the importance of material selection in achieving optimal aesthetic outcomes in orthodontics.[19] Numerous studies corroborate our findings, demonstrating the multifaceted challenges posed by dietary choices on orthodontic materials. For example, research by Eliades et al. in 1999 revealed structural changes in orthodontic ligatures due to staining, and other studies have consistently highlighted the significant impact of common beverages on the color stability of aligners.[20] This body of research collectively emphasizes the importance of material properties and real-world performance, guiding clinicians to optimize treatment outcomes and patient satisfaction.[21]Ultimately, our findings serve as a critical reminder for orthodontic practitioners to be vigilant about the effects of specific dietary choices on aligner aesthetics, ensuring comprehensive care for their patients.[22]Further in vivo studies are necessary to better understand the long-term implications of these findings in actual clinical settings.[23]Numerous studies have investigated the color stability of two aligner materials after exposure to various liquids typically consumed in the Indian diet, highlighting their susceptibility to staining and discoloration. These findings underscore the importance of material selection for maintaining the aesthetic appearance of aligners over time. (**Table 4**).[24-44]

**Table 4: Studies on aligner color stability with Indian liquids**

| Author | Year | Materials analyzed | Findings |
|---|---|---|---|
| Eliades et al. | 1999 | Micro structural changes in elastomeric ligatures | Patterns that could harm dental tissues |
| Boyd et al. | 2000 | Clear plastic overlays | Introduced computer-assisted technology for creating clear plastic overlays for orthodontic appliances |
| Tanner et al. | 2003 | Polyethylene fiber-reinforced composites | Exhibited higher bacterial adhesion linked to surface roughness. |
| Gardner et al. | 2003 | Evaluated thermoplastic materials for retainers, | Revealing superior wear resistance in the C+ copolymer compared to polypropylene. |
| Schuster et al. | 2004 | Insignificant morphological changes in Invisalign appliances after intraoral exposure | No harmful material leaching |
| Ryokawa et al. | 2006 | Eight dental thermoplastic materials in simulated conditions | Significant variations in water absorption and mechanical properties |
| Wriedt et al. | 2007 | Esthetic brackets food immersion caused significant discoloration in aesthetic brackets over ten days. | Caused significant discoloration in aesthetic brackets |
| Silva et al. | 2008 | Nanofilled resin composites when cured with a Soft-start mode | Discovered higher solubility and salivary sorption in |
| Kwon et al. | 2008 | Thinner thermoplastic overlay materials | Delivered higher energy and maintained force delivery better after thermo cycling. |
| Koksal and Dikbas et.al. | 2008 | Porcelain and acrylic denture teeth | Koksal and Dikbas (2008) determined that immersion duration significantly affected color stability |
| Kravitz et al. | 2009 | Invisalign aligners | Effective across various tooth movements with consistent accuracy |
| Gracco et al. | 2009 | Invisalign aligners | Micro cracks and transparency loss after 14 days but found no harmful substance release. |
| Boubakri et al. | 2010 | Thermoplastic polyurethane | Aging conditions significantly |

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|---|---|---|---|
| | | | degraded mechanical properties of thermoplastic polyurethane influenced by temperature and moisture |
| Pascual et al. | 2010 | PETG and Essix-C+ materials | Most oral cleansing agents did not significantly affect fracture initiation energy |
| Trovati et al. | 2010 | Polyurethane resins | Distinct thermal and structural behaviors in polyurethane resins related to their urethane/ester ratios. |
| Min et al. | 2010 | Thermoplastic materials | Thickness and deflection greatly influenced the mechanical performance |
| Kotyk and Wiltshire | 2014 | Orthodontic materials | Measurable BPA leaching from orthodontic materials under simulated intraoral conditions, raising safety concerns |
| Zafeiriadis et al. | 2014 | Vivera clear retainers | Color changes after immersion in staining solutions like coffee and tea |
| Premaraj et al | 2014 | Invisalign plastic | Cellular responses with saline exposure causing increased cell death compared to saliva |
| Lombardo et al. | 2015 | F-22 aligners | Maintained superior transparency even after aging, highlighting material selection importance |
| Alexandropoulos et al. | 2015 | Modern thermoplastic materials | Significant differences in chemical and mechanical properties among modern thermoplastic materials, affecting clinical performance |
| Ahn et al. | 2015 | Vacuum-formed retainers | Thermoforming increased surface roughness and stiffness in vacuum-formed retainers, aiding in predicting longevity |
| Ahn, Kim, and Kim | 2015 | Developed multi-layer clear retainer combining PETG, TPU, and reinforced resin for enhanced durability | |
| Iijima et al. | 2015 | Polyurethane. | Thermal cycling and stress loading significantly impacted orthodontic forces and shape memory effects |
| Liu et al. | 2016 | Clear aligners & Invisalign | Clear aligners experienced discoloration over time, with Invisalign showing initial staining with coffee |
| Bradley et al. | 2016 | Used Invisalign appliances | Conducted a retrieval analysis revealing intraoral aging negatively affected the mechanical properties |
| Lombardo et al. | 2016 | Single-layer aligners | Single-layer aligners had faster stress decay than double-layer versions, illustrating construction impacts on performance. |
| Sifakakis et al. | 2017 | Thermoplastics used for aligners | Do not release harmful monomers post-aging, ensuring safety |
| Sifakakis et al. | 2018 | Aligners and fixed appliances | Found adolescents using aligners had lower plaque and gingivitis scores compared to those with fixed appliances |
| Condo et al. | 2018 | Compared two polymer blends in Invisalign aligners | Finding LD30 had superior mechanical behavior and adaptability |

| | | | |
|---|---|---|---|
| Zafeiriadis et al. | 2018 | Vivera and Essix retainers | Exhibited color changes over time but maintained similar stability |
| Ryu et al. | 2018 | Thermoplastic materials | Revealed thermoforming altered transparency and mechanical performance necessitating thorough evaluation |
| Martina et al. | 2019 | Orthodontic materials | Found varying cytotoxicity levels among orthodontic materials, with Biolon showing the highest cytotoxic effects. |
| Elkholy et al. | 2019 | Established guidelines for standardized bending tests of aligner materials | Water immersion decreased bending forces |
| Papadopoulou et al. | 2019 | Invisalign appliances | Demonstrated that intraoral conditions adversely affected surface roughness and mechanical properties |
| Jindal et al. | 2019 | 3D-printed aligners & Duran aligners | Superior accuracy and strength compared to thermoformed Duran aligners |
| Bernard et al. | 2020 | Aligners | Coffee and red wine notably affected color changes in aligners, while cleaning methods were effective against specific stains. |
| Tamburrino et al. | 2020 | Duran, Biolon, and Zendura aligners | Significant material changes in Duran, Biolon, and Zendura aligners post-thermoforming, affecting performance understanding |
| Porojan et al. | 2020 | Aligners | Surface topography changes in aligners exposed to staining beverages, recommending advanced techniques for assessments |
| Iliadi et al. | 2020 | Thermoplastic appliances | Conducted a systematic review, finding negligible cytotoxic activity and monomer leaching in thermoplastic appliances, but called for further research |
| Xiang et al. | 2021 | PETG aligners | Modified PETG aligners provided better force stability after immersion in artificial saliva, despite overall force decreases |
| Dalaie et al. | 2021 | PETG aligners | Revealed that thermoforming significantly reduced flexural modulus and hardness in PETG aligners, with greater stability in Duran than Erkodur. |
| Daniele et al. | 2022 | PETG-based aligners | ETG-based aligners had superior transparency and significant color changes after immersion in red wine and coffee |
| Alhendi et al. | 2022 | Four clear aligner systems | Invisalign had a more homogeneous structure and smoother surface after saliva exposure |
| Venkatasubramanian et al. | 2022 | Clear aligners | Significant hue changes in clear aligners after exposure to common Indian food products, with turmeric and coffee causing the most impact |

It is documented in literature that coffee, tea, red wine and turmeric water are prevalent dietary beverages

that influences the color stability of the aligners.[45]Similar to our findings, Zafeiriadis et al in 2014 observed apparent changes in color of Vivera clear aligners when immersed in coffee and tea solutions whereas Zafeiriadias et al also noticed color variations in vivera and essix retainers but they maintained similar stability.[6,7] Liu et al al in 2016also reported that over a period of time clear aligners showed signs of discolouration while Invisalign demonstrated preliminary staining from coffee.[33] Bernard et al in 2020 and Daniele et al in 2022 in their studies revealed significant color alterations of aligners when subjected to coffee and red wine resembling our results.[3,42] Parallel to our observations Venkatasubramanian et al. 2022 also observed that clear aligners exhibit significant colour differences when exposed to common Indian food components, while turmeric and coffee makes the largest impact.[45]

**Future Prospects:** This study opens several avenues for future research that can deepen our understanding of aligner material performance in clinical settings. Conducting longitudinal in vivo studies will assess the color stability of PU and PET-G aligners under real oral conditions, accounting for factors like saliva, oral bacteria, and patient habits. Expanding the range of staining agents to include other common beverages and foods will help create a comprehensive profile of each material's susceptibility to discoloration.[46] Additionally, investigating new aligner materials or modifications could lead to enhanced color stability through coatings or treatments that resist staining while maintaining aesthetic qualities.[47] Developing educational materials for orthodontic patients to minimize staining risks via dietary modifications will also be crucial. Integrating measurements of oral conditions, such as pH and bacterial load, in future studies will establish a more accurate correlation between dietary habits and aligner discoloration. Finally, comparative studies involving other orthodontic devices, such as retainers and brackets, will provide a holistic understanding of material behavior under similar dietary conditions. Together, these research directions can optimize orthodontic treatment and enhance patient satisfaction with clear aligners.[48]

## CONCLUSION

This in vitro study evaluated the color stability of two aligner materials—polyurethane (PU) and polyethylene terephthalate glycol (PET-G)—after exposure to common Indian dietary liquids. Significant color changes were observed after 14 days, with PU aligners more susceptible to coffee staining and PET-G affected by turmeric water. These findings highlight the impact of dietary choices on aligner aesthetics. Given that coffee and turmeric are staples in Indian cuisine, patients should be aware of their potential to alter aligner appearance. Limiting these staining agents is crucial. Further in vivo research is needed to validate these results in clinical contexts. This study underscores the importance of understanding staining potential to enhance patient guidance and compliance, ultimately helping to maintain the aesthetic integrity of clear aligners.

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**Conflicts of interest:** There are no conflicts of interest

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