

Evaluation of color stability of orthodontic aligners: *in vitro* study

Avaliação da estabilidade da cor de alinhadores transparentes: estudo *in vitro*

Roberto Hideo SHIMIZU^a , Maria Fernanda Castoldi DIAVÃO^a , Mariana DALLEDONE^a ,
Gil Guilherme GASPARELLO^a , Beatriz Almeida SHIMIZU^b , Evelise Machado de SOUZA^c ,
Ana Cláudia Moreira Melo TOYOFUKU^{a*} 

^aILAPEO, Departamento de Ortodontia, Curitiba, PR, Brasil

^bUSP – Universidade de São Paulo, Faculdade de Odontologia de Bauru, Departamento de Ortodontia, Bauru, SP, Brasil

^cPUCPR – Pontifícia Universidade Católica do Paraná, Departamento de Odontologia, Curitiba, PR, Brasil

How to cite: Shimizu RH, Diavão MFC, Dalledone M, Gasparello GG, Shimizu BA, Souza EM, et al. Evaluation of color stability of orthodontic aligners: *in vitro* study. Rev Odontol UNESP. 2025;54:e20250010. <https://doi.org/10.1590/1807-2577.20250010>

Resumo

Introdução: A estética dos alinhadores ortodônticos está diretamente relacionada à estabilidade óptica dos materiais termoplásticos utilizados na confecção desses dispositivos. **Objetivo:** Este estudo teve como objetivo avaliar a estabilidade da transparência de materiais termoplásticos utilizados na confecção de alinhadores ortodônticos após a exposição a soluções pigmentantes. **Material e método:** Foram preparados 160 corpos de prova, divididos em dois grupos conforme o material: ClearQuartz (QTZ) e SmartTrack (INV), com 80 amostras em cada grupo. Cada grupo foi subdividido em cinco subgrupos (n = 16) de acordo com a solução de imersão: café, chá, Coca-Cola, vinho tinto e saliva artificial (controle). As medições de transparência foram realizadas com o espectrofotômetro VITA EasyShade Compact, com foco na superfície vestibular dos primeiros e segundos molares inferiores. Os corpos de prova foram imersos nas soluções por 14 dias, com substituição diária dos líquidos. As avaliações foram realizadas em quatro momentos: inicial (T0), 24 horas (T1), 7 dias (T2) e 14 dias (T3), em ambiente controlado. **Resultado:** As soluções de chá, vinho tinto e café produziram diferenças estatisticamente significativas na transparência entre os grupos QTZ e INV em todos os momentos avaliados. No grupo Coca-Cola, não houve diferença significativa entre os materiais no intervalo T1-T0, mas diferenças foram observadas nos tempos subsequentes. Para a saliva artificial, foi identificada diferença estatisticamente significativa apenas no intervalo T3-T0, sem variação significativa nos momentos anteriores. **Conclusão:** As amostras do grupo SmartTrack apresentaram menor estabilidade de transparência em comparação ao grupo ClearQuartz, especialmente após exposição a agentes pigmentantes como chá, café, Coca-Cola e vinho tinto, na maioria dos períodos avaliados.

Descritores: Alinhadores estéticos; pigmentação; ortodontia; colorimetria; alinhadores transparentes.

Abstract

Introduction: The esthetics of orthodontic aligners is directly related to the optical stability of the thermoplastic materials used in their fabrication. **Objective:** This study aimed to evaluate the transparency stability of thermoplastic materials used in the fabrication of orthodontic aligners after exposure to staining solutions. **Material and method:** A total of 160 specimens were prepared and divided into two groups based on the material: ClearQuartz (QTZ) and SmartTrack (INV), with 80 specimens each. Each group was further subdivided into five subgroups (n = 16) according to the immersion solution: coffee, tea, Coca-Cola, red wine, and artificial saliva (control). Transparency measurements were performed using a VITA EasyShade Compact spectrophotometer, focusing on the buccal surface of the lower first and second molars. The specimens were immersed in the solutions for 14 days, with daily replacement of the liquids. Assessments were conducted at four times: baseline (T0), 24 hours (T1), 7 days (T2), and 14 days (T3), under controlled environmental conditions. **Result:** Tea, red wine, and coffee solutions produced statistically significant differences in transparency between QTZ and INV at all evaluation time points. In the Coca-Cola group, no significant difference was observed between the materials at T1-T0, but differences emerged at later intervals. For the artificial saliva control, a significant difference was found only at T3-T0, with no significant variation at earlier time points. **Conclusion:** SmartTrack specimens demonstrated lower transparency stability compared to ClearQuartz, particularly after exposure to staining agents such as tea, coffee, Coca-Cola, and red wine, across most time intervals evaluated.

Descriptors: Aesthetic aligners; pigmentation; orthodontics; colorimetry; clear aligners.



This is an Open Access article distributed under the terms of the [Creative Commons Attribution](https://creativecommons.org/licenses/by/4.0/) license (<https://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

INTRODUCTION

Thermoplastic orthodontic aligners are an alternative to conventional fixed appliances, such as braces^{1,2}. These removable devices are especially popular among adults seeking a more aesthetic option with less metal visibility³ and their efficiency have been studied^{4,5}.

Orthodontic aligner manufacturers recommend that users remove their devices before consuming solid food or any beverage (except water). This recommendation prevents color changes in the transparent thermoplastic material used for the fabrication of aligners⁶. Currently, several materials are used in their manufacture⁷⁻⁹, including polyvinyl chloride, polyurethane (PU), polyethylene terephthalate (PET), and glycol-modified polyethylene terephthalate (PETG). From an aesthetic standpoint, the color and transparency of orthodontic aligners is crucial during the usage period, typically 2 weeks⁹. Beverages such as coffee, black tea, and red wine have been reported to cause staining on aligners^{9,10}. On the other hand, protocols for aligners cleaning and disinfection are being studied. A systematic review has shown that the combination of a mechanical and a chemical method seems to be the best approach^{11,12}.

Considering the growing usage of clear aligners in orthodontics and the importance of its esthetic appeal to patients, the present study aims to analyze and compare the color stability of two commercial brands of orthodontic aligners when exposed to potentially common staining agents.

MATERIAL AND METHOD

The sample consisted of orthodontic aligners with two different thermoplastic material compositions used in their manufacture. The commercial brands selected for this *in vitro* study were Invisalign® (INV) (Align Technology Inc., San Jose, CA, USA) and ClearCorrect® (CC) (ClearCorrect LLC, Rock Round, TX, USA). The INV aligners, SmartTrack, are produced from a multi-layer thermoplastic polyurethane combined with an integrated elastomer. On the other hand, the CC devices, ClearQuartz, consist of three layers-two external layers of copolyester and one internal elastomer layer - manufactured by Bay Materials (USA).

The sample consisted of 160 test specimens, divided into 2 groups (QTZ and INV), with 80 test specimens in each group. These were further subdivided into 5 solutions with 16 test specimens each: soluble coffee (Nescafé® Original, Nestlé, Vevey, Vaud, Switzerland), tea (English Breakfast Tea, Twinings, Andover, England), coca-cola carbonated beverage (Coca-Cola, Coca-Cola Company, Atlanta, GA, USA), red wine (Cordero con Piel de Lobo Malbec 2023, Mosquita Muerta Wines, Mendoza, Argentina), and a control solution of artificial saliva.

For the preparation of the test specimens, the distovestibular segment of the aligner was perforated with a diamond bur (model 8392; Komet Brasil, Santo André, São Paulo, Brazil) (Figure 1) to insert the test specimens into a fixed rack. Each test specimen was trimmed with gold scissors in the occlusal, mesial, and distal regions (Figures 2A-C) of first molars and the mesial of lower second molars and randomly distributed within their respective groups.



Figure 1. Position of the diamond bur.

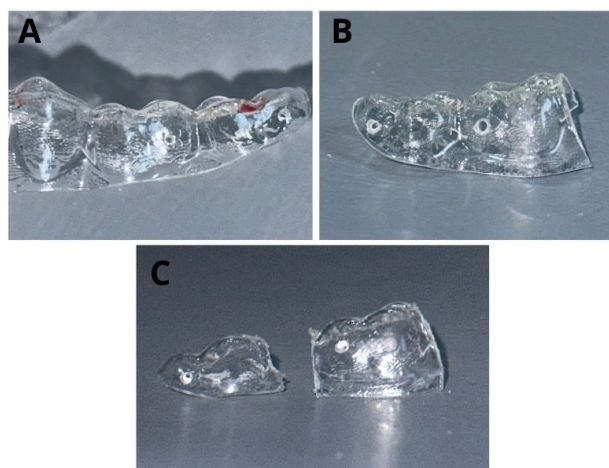


Figure 2. Sequence of specimen cuts. (A) Specimens after perforation; (B) Specimens being cut at the mesial of the lower first molar; (C) Finished specimens.

For the immersion of the test specimens, a fixed rack model was used, where the test specimens were positioned at an average distance of 2 millimeters apart. Two elastic bands in silver and black (Orthometric, Marília, São Paulo, Brazil) were used to ligate between each test specimen.

The experimental procedure was carried out in a controlled laboratory environment. The solutions with the samples were kept in an incubator at a controlled temperature of $37^{\circ}\text{C} \pm 1.5^{\circ}\text{C}$ until the completion of the research, to mimic the temperature of the oral cavity¹³.

The preparation of the solutions adhered to the manufacturers' guidelines, with the solutions being measured, prepared, and replaced daily until the final reading day of each sample. The readings were taken at baseline (T0 - before immersing the aligners in the solution), 24 hours (T1), 7 days (T2), and 14 days (T3), using 500 milliliters of each solution daily. For each time point, five lidded glass containers were prepared, one for each of the solutions (test and control), containing the corresponding test specimens from both groups (QTZ and INV).

For the daily solution replacing, the test specimens were temporarily transferred to containers with distilled water until the solutions were replenished. The test specimens were then promptly returned to their respective containers with the different solutions.

Colorimetry

The color reading of the aligners was performed on the buccal surface of the lower first and second molars, always at the same location using a template and maintaining a controlled distance from the cutouts to ensure they did not influence the eventual color change of the thermoformed materials. All aligners were thermoformed using the same STL file and printed model to ensure uniformity across samples.

The VITA EasyShade Compact® spectrophotometer (VITA Zahnfabrik, Bad Säckingen, Germany) was used in "single tooth" mode for all evaluation times (T0, T1, T2, and T3). Data collection measurements were performed three times to ensure accuracy. For statistical analysis, a descriptive analysis of the data was initially conducted, with estimates for mean, median, standard deviation, 25th and 75th percentiles, and interquartile range.

Color readings were taken at the above-mentioned time points and the dye solutions used were Tea, Red Wine, Coca-Cola, Coffee, and Saliva (control solution). All deltas analyzed in this study were calculated based on the moments T1 - T0, T2 - T0, and T3 - T0. The average of the $L^*a^*b^*$ parameter of the International Commission on Illumination (CIE)10 was also calculated¹⁴.

The deltas for each moment (ΔL^* , Δa^* , and Δb^*) were calculated by subtracting the color hue parameters such as L^* referring to luminosity, a^* and b^* referring to chromatic hue at different times applied in the study. Regarding a^* , when the value is positive, the color will be more reddish; when negative, the color will be greener. When b^* is positive, the chromatic hue of the aligner will be more yellowish, and when negative, it will be more blush. The ΔE , used to measure the color change between the groups, was calculated using the following formula:

$$\Delta E = [(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2]^{1/2} \quad (1)$$

For ΔL^* , since in all cases the L^* values are equal to 100, when calculating the difference between the moments for this delta, all values resulted in zero, making it impossible to analyze this variable.

For the quantitative variables, the Shapiro-Wilk test was conducted to test the adherence of the data to a normal distribution.

Regarding the comparison using the delta variables between moments and Delta E, for groups that presented normality, the ANOVA test followed by the Tukey mean comparison test (post hoc test) was used to determine in which groups there were differences when the variable in question showed statistical significance. For those that did not present normality, the Kruskal-Wallis test followed by the Dunn post hoc test was used to check which groups showed statistically significant differences. The significance level used was 5%, and all analyses were performed in R 4.1.3¹⁵.

The chosen area was the buccal surface of the lower first and second molars. The National Bureau of Standards (NBS) system was used to provide a clinical interpretation (perception) for the color change values (ΔE) obtained¹⁴.

All test specimen readings were evaluated with a white background, with controlled and equal lighting for all, by the same calibrated evaluator (Figure 3).



Figure 3. Positioning of the VITA EasyShade Compact spectrophotometer for specimen reading.

RESULT

Analysis of ΔE

For the ΔE related to the moment T1 (after 24 hours) - T0 (before immersion) of the Coca-Cola solution, T1 - T0, and T2 (after 7 days) - T0 of the Saliva solution, no significant differences were found between the groups under study. For all other solutions, statistically significant differences were observed between the groups at each moment, as shown in Table 1.

Table 1. Comparison of the ΔE of each material (Solution) in relation to the study group

Variable	ΔE	Group								p-value
		CC				INV				
		M	MD	DP	IIQ	M	MD	DP	IIQ	
Tea	T1 - T0	1.64	1.65	0.20	0.20	4.39	4.10	0.81	1.12	<0.001*
	T2 - T0	1.72	1.63	0.36	0.53	10.65	10.65	1.73	2.48	<0.001*
	T3 - T0	3.15	3.09	0.51	0.58	12.03	11.54	1.45	1.90	<0.001*
Red wine	T1 - T0	1.28	1.22	0.18	0.17	6.66	6.56	0.64	0.41	<0.001*
	T2 - T0	0.79	0.77	0.22	0.36	22.90	22.41	1.79	2.10	<0.001*
	T3 - T0	1.38	1.39	0.18	0.24	28.88	28.26	2.16	3.57	<0.001*
Coca-Cola	T1 - T0	2.13	2.05	0.29	0.33	2.21	2.14	0.27	0.41	0.423**
	T2 - T0	1.14	1.10	0.30	0.30	2.39	2.30	0.33	0.42	<0.001*
	T3 - T0	0.96	0.92	0.32	0.23	2.17	2.15	0.19	0.25	<0.001*
Coffee	T1 - T0	2.44	2.37	0.28	0.39	15.91	15.67	1.25	2.09	<0.001*
	T2 - T0	4.28	4.17	0.84	0.98	45.42	45.79	3.68	3.94	<0.001*
	T3 - T0	9.00	8.99	1.13	1.87	55.24	55.91	2.70	4.58	<0.001*
Saliva (CG)	T1 - T0	0.80	0.79	0.22	0.23	0.64	0.63	0.42	0.55	0.202**
	T2 - T0	0.26	0.26	0.088	0.12	0.24	0.19	0.20	0.15	0.243*
	T3 - T0	0.28	0.26	0.13	0.14	0.48	0.48	0.26	0.42	0.012*

*U Mann-Whitney Test; **t Student test; M = mean; MD = median; DP = standard deviation; IIQ = interquartile range.

Analysis of Δa^*

For the Δa^* related to the moment T3 (after 14 days) - T0 (before immersion) of the coffee solution, no significant differences were found between the groups under study. For all other solutions, statistically significant differences were observed at each moment of Δa^* , as shown in Table 1.

Analysis of Δb^*

As shown in Table 2, for the Δb^* related to T1 (after 24 hours) - T0 (before immersion) of the Coca-Cola solution, no significant differences were found between the groups under study. Similarly, for all moments of the Saliva material, it was not possible to statistically differentiate the Δb^* between the groups. For all other solutions, statistically significant differences were observed between the groups at each moment of Δb^* , as shown in Table 2.

Table 2. Comparison of the Δa^* and Δb^* of each material (Solution) in relation to the study group

Material	Δa^*	Group								p-value
		CC				INV				
		M	MD	DP	IIQ	M	MD	DP	IIQ	
Tea	T1 - T0	0.35	0.33	0.08	0.09	-0.13	-0.10	0.13	0.20	<0.001*
	T2 - T0	0.44	0.43	0.18	0.27	-0.46	-0.43	0.13	0.16	<0.001*
	T3 - T0	0.78	0.77	0.16	0.20	-0.28	-0.27	0.15	0.09	<0.001*
Red wine	T1 - T0	0.81	0.82	0.12	0.14	-0.29	-0.27	0.23	0.28	<0.001*
	T2 - T0	0.70	0.68	0.21	0.36	-1.62	-1.52	0.35	0.40	<0.001*
	T3 - T0	1.26	1.27	0.17	0.26	-0.58	-0.50	0.47	0.62	<0.001*
Coca-Cola	T1 - T0	0.25	0.27	0.07	0.11	0.12	0.12	0.08	0.09	<0.001**
	T2 - T0	-0.06	-0.05	0.09	0.12	-0.34	-0.33	0.09	0.08	<0.001*
	T3 - T0	0.25	0.20	0.13	0.06	0.04	0.00	0.11	0.13	<0.001**
Coffee	T1 - T0	0.27	0.28	0.06	0.08	-2.60	-2.20	1.68	0.41	<0.001*
	T2 - T0	0.15	0.18	0.16	0.18	-3.35	-3.33	0.34	0.41	<0.001*
	T3 - T0	0.53	0.57	0.20	0.27	0.34	0.37	0.67	0.84	0.396*

Table 2. Continued...

Material	Δa^*	Group								p-value
		CC				INV				
		M	MD	DP	IIQ	M	MD	DP	IIQ	
Saliva	T1 - T0	0.09	0.10	0.08	0.06	-0.004	-0.03	0.13	0.14	0.022**
	T2 - T0	0.15	0.13	0.08	0.10	0.03	0.03	0.09	0.08	0.001**
	T3 - T0	0.16	0.17	0.08	0.10	0.35	0.30	0.23	0.25	0.008*
Material	Δb^*	M	MD	SD	IIQ	M	MD	SD	IIQ	p-value
Tea	T1 - T0	1.61	1.60	0.19	0.19	4.38	4.10	0.82	1.14	<0.001**
	T2 - T0	1.65	1.60	0.36	0.57	10.64	10.63	1.73	2.49	<0.001*
	T3 - T0	3.05	3.02	0.51	0.55	12.03	11.53	1.45	1.91	<0.001*
Red wine	T1 - T0	0.97	0.92	0.20	0.18	6.65	6.55	0.63	0.40	<0.001*
	T2 - T0	0.33	0.33	0.20	0.11	22.84	22.37	1.79	2.05	<0.001*
	T3 - T0	0.51	0.48	0.22	0.14	28.87	28.25	2.16	3.54	<0.001*
Coca-Cola	T1 - T0	2.11	2.03	0.29	0.33	2.21	2.13	0.27	0.40	0.360**
	T2 - T0	1.13	1.10	0.31	0.31	2.36	2.27	0.33	0.42	<0.001*
	T3 - T0	0.92	0.83	0.33	0.23	2.17	2.15	0.19	0.26	<0.001*
Coffee	T1 - T0	2.42	2.35	0.28	0.38	15.62	15.43	1.16	1.35	<0.001*
	T2 - T0	4.28	4.17	0.84	0.97	45.30	45.68	3.70	4.00	<0.001*
	T3 - T0	8.98	8.97	1.13	1.86	54.99	55.88	2.60	4.68	<0.001*
Saliva	T1 - T0	0.79	0.78	0.22	0.23	0.56	0.62	0.52	0.64	0.115**
	T2 - T0	-0.06	-0.08	0.21	0.37	-0.14	-0.13	0.27	0.17	0.402**
	T3 - T0	0.021	0.00	0.26	0.40	0.17	0.083	0.31	0.37	0.149**

*Mann-Whitney U Test; **Student t test; M = mean; MD = median; SD = standard deviation; IIQ= interquartile range.

DISCUSSION

The present study aimed to evaluate the transparency stability of thermoplastic materials used in the fabrication of orthodontic aligners, when exposed to pigmenting solutions. Our results showed that QTZ group, characterized by two external layers of copolyester, presented better results, what's in accordance with other studies^{10,16} that also observed that aligners with an outer layer of PETG demonstrated higher resistance to staining. In another study⁶ on the mechanical and chemical properties of aligners, polyurethane, which has interesting characteristics such as high elasticity, flexibility, chemical resistance, oxidation resistance, mechanical strength, and ease of processing, was the thermoplastic used in INV devices. It showed high hardness and elastic modulus but lower resistance to deformation. In particular, the INV sample exhibited greater changes, probably due to its thermoforming process. The hypothesis is that the surface porosity of INV aligners, combined with the polar nature of polyurethane, may explain their susceptibility to staining compared to CC aligners (also made of polyurethane).

Color changes in aligners may be related to the characteristics of the materials and associated with pigment absorption or penetration into the material surface⁹. Regarding the color variations of aligners after immersion in staining agents, all the solutions considered contributed to altering the aesthetic characteristics of the samples, especially when the aligners were immersed in coffee, red wine, and tea¹⁶. This finding corroborates the results of this study.

The primary advantage of the aligners, compared to traditional fixed orthodontic appliances, lies in the improvement in aesthetics and patient comfort. For these reasons, patients concerned about their appearance or speech are good candidates for treatment with clear aligners. So, the maintenance of color stability as well as mechanical properties is essential during their two-week usage period. However, color stability may be affected by different factors such as staining beverages and mouthwashes, especially when patients consume staining beverages without removing the aligners from their mouths^{6,9,10}, although it's not a recommended habit.

Manufacturers of clear aligners recommend that users remove their devices before consuming solid foods or any drinks (except water). This is to avoid color change within the transparent thermoplastic material from which they are made⁶.

It is observed that for the tea, wine, and coffee solutions used to immerse the test specimens, statistically significant differences between the QTZ x INV groups were found at all three moments. For the Coca-Cola solution, no statistically significant difference was found for the T1 – T0 moment. At the other moments, statistically significant differences were observed between the groups. Finally, for the saliva solution, a statistically significant difference was found for the T3 – T0 moment, with no statistically significant differences between the groups at the other moments.

Studies have shown that adults treated with clear aligners experienced less pain and fewer negative impacts on their lives during the first week of orthodontic treatment compared to those treated with fixed appliances¹⁷. Additionally, aesthetics and removability resulted in superior functional and psychosocial differences compared to fixed appliances^{1,2,17}.

Furthermore, the use of removable aligners facilitates improved oral hygiene. Treatment with aligners has been associated with improved periodontal status, as evidenced by decreased plaque levels, gingival inflammation, bleeding on probing, probing depth, and BANA scores. These results suggest that removable aligners should be considered in the treatment planning for adult orthodontic patients at risk of periodontitis¹⁸.

CONCLUSION

The results of this study demonstrated that the INV group showed lower transparency stability, particularly for staining solutions such as tea, coffee, Coca-Cola, and red wine, compared to the QTZ group, in almost all proposed reading times. However, further studies should be conducted to confirm this evidence.

AUTHORS' CONTRIBUTIONS

Roberto Hideo Shimizu: Conceptualization (Lead), Formal analysis (Lead), Investigation (Lead), Methodology (Lead), Project administration (Equal), Supervision (Lead), and Writing – review & editing (Lead). Maria Fernanda Castoldi Diavão: Data curation (Equal), Investigation (Equal), and Writing – original draft (Equal). Mariana Dalledone: Conceptualization (Supporting), Data curation (Supporting), Methodology (Supporting), Validation (Supporting), and Writing – original draft (Equal). Gil Guilherme Gasparello: Data curation (Supporting) and Validation (Supporting). Beatriz Almeida Shimizu: Data curation (Supporting), Methodology (Supporting), Validation (Supporting), and Writing – original draft (Supporting). Evelise Machado de Souza: Conceptualization (Equal), Formal analysis (Lead), Methodology (Equal), Supervision (Equal), Validation (Equal), and Writing – review & editing (Equal). Ana Cláudia Moreira Melo Toyofuku: Formal analysis (Lead), Investigation (Equal), Methodology (Lead), Supervision (Equal), and Writing – review & editing (Lead).

REFERENCES

1. Cooper-Kazaz R, Ivgi I, Canetti L, Bachar E, Tsur B, Chaushu S, et al. The impact of personality on adult patients' adjustability to orthodontic appliances. *Angle Orthod*. 2013 Jan;83(1):76-82. <http://doi.org/10.2319/010312-6.1>. PMID:22594776.
2. Weir T. Clear aligners in orthodontic treatment. *Aust Dent J*. 2017 Mar;62(S1 Suppl 1):58-62. <http://doi.org/10.1111/adj.12480>. PMID:28297094.

3. Rosvall MD, Fields HW, Ziuchkovski J, Rosenstiel SF, Johnston WM. Attractiveness, acceptability, and value of orthodontic appliances. *Am J Orthod Dentofacial Orthop*. 2009 Mar;135(3):276.e1-12. <http://doi.org/10.1016/j.ajodo.2008.07.011>. PMID:19268820.
4. Buschang PH, Shaw SG, Ross M, Crosby D, Campbell PM. Comparative time efficiency of aligner therapy and conventional edgewise braces. *Angle Orthod*. 2014 May;84(3):391-6. <http://doi.org/10.2319/062113-466>. PMID:24749702.
5. Zheng M, Liu R, Ni Z, Yu Z. Efficiency, effectiveness and treatment stability of clear aligners: a systematic review and meta-analysis. *Orthod Craniofac Res*. 2017 Aug;20(3):127-33. <http://doi.org/10.1111/ocr.12177>. PMID:28547915.
6. Bernard G, Rompré P, Tavares JR, Montpetit A. Colorimetric and spectrophotometric measurements of orthodontic thermoplastic aligners exposed to various staining sources and cleaning methods. *Head Face Med*. 2020 Feb;16(1):2. <http://doi.org/10.1186/s13005-020-00218-2>. PMID:32070379.
7. Ercoli F, Tepedino M, Parziale V, Luzi C. A comparative study of two different clear aligner systems. *Prog Orthod*. 2014 May;15(1):31. <http://doi.org/10.1186/s40510-014-0031-3>. PMID:24934094.
8. Hahn W, Engelke B, Jung K, Dathe H, Fialka-Fricke J, Kubein-Meesenburg D, et al. Initial forces and moments delivered by removable thermoplastic appliances during rotation of an upper central incisor. *Angle Orthod*. 2010 Mar;80(2):239-46. <http://doi.org/10.2319/033009-181.1>. PMID:19905847.
9. Liu CL, Sun WT, Liao W, Lu WX, Li QW, Jeong Y, et al. Colour stabilities of three types of orthodontic clear aligners exposed to staining agents. *Int J Oral Sci*. 2016 Dec;8(4):246-53. <http://doi.org/10.1038/ijos.2016.25>. PMID:27660048.
10. Šimunović L, Agović SC, Marić AJ, Bačić I, Klarić E, Uribe F, et al. Color and chemical stability of 3D-printed and thermoformed polyurethane-based aligners. *Polymers*. 2024;16(8):1067. <http://doi.org/10.3390/polym16081067>. PMID:38674987.
11. Wible E, Agarwal M, Altun S, Ramir T, Viana G, Evans C, et al. Long-term effects of various cleaning methods on polypropylene/ethylene copolymer retainer material. *Angle Orthod*. 2019 May;89(3):432-7. <http://doi.org/10.2319/060818-429.1>. PMID:30605015.
12. Charavet C, Gourdain Z, Graveline L, Lupi L. Cleaning and disinfection protocols for clear orthodontic aligners: a systematic review. *Healthcare*. 2022 Feb;10(2):340. <http://doi.org/10.3390/healthcare10020340>. PMID:35206954.
13. Lombardo L, Arreghini A, Maccarrone R, Bianchi A, Scalia S, Siciliani G. Optical properties of orthodontic aligners--spectrophotometry analysis of three types before and after aging. *Prog Orthod*. 2015;16(1):41. <http://doi.org/10.1186/s40510-015-0111-z>. PMID:26582007.
14. Zafeiriadis AA, Karamouzou A, Athanasiou AE, Eliades T, Palaghias G. In vitro spectrophotometric evaluation of Viverra clear thermoplastic retainer discolouration. *Aust Orthod J*. 2014 Nov;30(2):192-200. <http://doi.org/10.2478/aoj-2014-0017>. PMID:25549522.
15. R Development Core Team. R: a language and environment for statistical computing. Version 4.1.3. Vienna: R Foundation for Statistical Computing; 2022.
16. Daniele V, Macera L, Taglieri G, Spera L, Marzo G, Quinzi V. Color Stability, chemico-physical and optical features of the most common PETG and PU based orthodontic aligners for clear aligner therapy. *Polymers*. 2021 Dec;14(1):14. <http://doi.org/10.3390/polym14010014>. PMID:35012036.
17. Miller KB, McGorray SP, Womack R, Quintero JC, Perelmutter M, Gibson J, et al. A comparison of treatment impacts between Invisalign aligner and fixed appliance therapy during the first week of treatment. *Am J Orthod Dentofacial Orthop*. 2007 Mar;131(3):302.e1-9. <http://doi.org/10.1016/j.ajodo.2006.05.031>. PMID:17346581.
18. Karkhanechi M, Chow D, Sipkin J, Sherman D, Boylan RJ, Norman RG, et al. Periodontal status of adult patients treated with fixed buccal appliances and removable aligners over one year of active orthodontic therapy. *Angle Orthod*. 2013 Jan;83(1):146-51. <http://doi.org/10.2319/031212-217.1>. PMID:22725616.

CONFLICTS OF INTERESTS

The authors Ana Cláudia M. Melo Toyofuku and Roberto Hideo Shimizu declare that they are speakers of ClearCorrect. The other authors declare no conflict of interest.

DATA AVAILABILITY

The contents underlying the research text are included in the manuscript. The contents are already available.

***CORRESPONDING AUTHOR**

Ana Cláudia Moreira Melo Toyofuku, ILAPEO, Departamento de Ortodontia, Rua Jacarezinho, 656, Mercês, 80710-150 Curitiba - PR, Brasil, e-mail: anacmmelo@gmail.com

Received: May 6, 2025

Accepted: September 22, 2025

Edited by

Editor: Rosemary Adriana Chierici Marcantonio