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The color stability of esthetic brackets

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Objective: To evaluate and compare the discoloration of the esthetic ceramic brackets after stimulating staining in vivid-colored food solutions and coffee.

Materials and methods: 108 ceramic brackets from 4 brands (Inspire Ice™, Radiance Plus™, Clarity™, and W&H) were immersed in 4 solutions (Tom-Yum-Goong, yellow curry, green curry, and coffee) at 37°C for 3 and 7 days. Distilled water was used as a solution in the control group. Color changes (ΔE) were measured by a spectrophotometer for CIE L*, a* and b* system. Then, the National Bureau of Standards (NBS) value was calculated. Statistical analysis was done using the Kruskal-Wallis test and the Mann-Whitney U Test ($\alpha = 0.05$).

Results: Immersed longer, there was a perceptible change of color in all ceramic brackets in Tom-Yum-Goong, yellow curry, and coffee, but no change was noticed in distilled water ($\Delta E^* < 3.7$). The color alteration of brackets in green curry was found in Clarity™ and W&H brackets.

Conclusion: Time, various vivid-colored food solutions, and coffee affect changes in the color of esthetic ceramic brackets. However, the same crystal formation, either monocrystalline or polycrystalline, does not follow the same pattern in color change, varying according to bracket manufacturing fabrication.

Keywords: Brackets, Color stability, Esthetic, Stain

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Introduction

In contemporary orthodontics, there has been a significant increase in the search for an attractive appearance during treatment with fixed orthodontic appliances. Technologies have been developed and new, increasingly discrete colorless or white esthetic brackets have appeared on the market. The main factor that may justify the search for such appliances includes the larger demand among patients, especially adults who now seek orthodontic treatment. [1-3] Among many options for more esthetic orthodontic appliances, the lingual brackets, and transparent orthodontic aligners (Invisalign, Align Technology, Santa Clara, California, U.S.A.) are the least visually perceptible; however, only esthetic brackets allow a conventional orthodontic procedure to be performed. [4, 5] Furthermore, plastic and ceramic brackets have become popular and have been available for clinical use for approximately twenty years in spite of several uncertain physical and mechanical properties. [6-9]

Although color features of ceramic brackets are their major advantage over metallic brackets, there is limited number of reports analyzing their optical properties over time. [8, 10, 11] Esthetic brackets become discolored after long wear, even in patients with excellent oral hygiene. Various studies have reported color changing of brackets *in vitro* after immersed in certain food or beverage, such as red wine and high caffeine containing products (coffee, tea). [2, 8, 10, 12-18] This can result in an esthetic problem. Current *in vitro*

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study has shown that the optical properties of both ceramic and plastic brackets is affected by thermal cycling, while the crystal structure of the ceramic brackets does not influence color stability. [19] Discoloration of brackets is caused by intrinsic and extrinsic factors. Intrinsic color alteration is generated by water absorption, incomplete polymerization of the adhesive resins, bracket matrix composition, the content and the size of the particles. [20-22] Whereas, extrinsic discoloration is generated by the contact with pigment-containing-food or beverage, colored mouth rinses, [23-25] colored saliva, [26] nicotine, [27] lipsticks, [22, 25] heat, [2] surface roughness of brackets, [23, 25] duration and intensity of polymerization. [28]

The efficient method for measuring color should be reliable, easy to use, and allow outcome assessment. Spectrophotometer is an instrument widely used for measuring surface color, due to its reliability, precision, and accuracy. [29] Assuming that exposure to certain food and beverages can compromise the long-lasting esthetic effect of ceramic brackets, it is important to assess susceptibility to staining of these materials by those particular diets. Moreover, there is no study of discoloration of ceramic brackets after exposed to Thai food. The purpose of this study therefore, was to evaluate and compare *in vitro*, the discoloration of the esthetic ceramic brackets of various commercial brands after they were exposed to vivid-colored food solutions and coffee with digital spectrophotometer.

Materials and methods

Ceramic brackets

This study was designed to be an experimental study. One hundred and eight maxillary right central incisor ceramic brackets, slot size 0.022 x 0.028-inch in Roth prescription of four commercial brands (n = 27) were selected (Table 1). Bonding surfaces at the base of all brackets were worn with a diamond drill bit to prevent the surface of different brands from interfering in the staining process.

The brackets were immersed in solutions of Tom-Yum-Goong, Thai yellow curry, Thai green curry, coffee, and distilled water which was used as a control. In the experimental group, Thai food-simulating, staining vivid color solutions and coffee solution were prepared in the same concentration everyday by dissolving seasoning powder in distilled water (Table 2). [15, 30-32] Each of these solutions was distributed into glass chambers with partitions to separate the different brands of brackets. These containers were placed in an incubator at a temperature of 37°C, [12, 14, 15, 18, 30, 33] wrapped in black plastic bags to eliminate the interference of light. The solutions were changed every 24 hours and their pH was measured with a pH meter (ORION 3-star, Expotech, Houston, Texas. U.S.A.) at each change to check whether it remained the same. [15]

The first thirteen brackets of each brand were immersed for three days (T1), and the other thirteen were immersed for seven days (T2). All brackets were divided into five groups, according to the solution in which they were immersed (control group; n = 1, experiment group; n = 3). Before immersion, all brackets had initial color measured as baseline data (T0) (n = 1). After complete immersion, the color of each bracket was measured with a portable digital spectrophotometer, (Vita Easyshade® Compact; VITA Zahnfabrik, Bad Säckingen, Germany). Before each color reading, brackets were washed with distilled water in an ultrasonic cleaner (Vibraclean 300, MDT Biologic Company, Gardena, California, U.S.A.) for 5 minutes and were blotted to remove any residual waste from the dyes on the brackets. [2, 14, 15, 30, 32]

Table 1 Distribution of the groups according to the type of bracket, brand, composition, and manufacturer.

Type	Brand	Composition	Manufacturer
Translucent	Inspire Ice™	Monocrystalline	Ormco® (Orange, California, U.S.A.)
Translucent	Radiance Plus™	Monocrystalline	American Orthodontics® (Sheboygan, Wisconsin, U.S.A.)
Nontranslucent	Clarity™	Polycrystalline	3M Unitek® (Monrovia, California, U.S.A.)
Nontranslucent	W&H	Polycrystalline	W&H Tech® (Zhejiang, China)

Table 2 Solutions, brands, and preparation method.

Solution	Brand	Preparation
Distilled water	-	Solution ready for consumption.
Tom-Yum-Goong	Lobo (Globo Foods Ltd., Samutprakan, Thailand)	Solution prepared by pouring 200 ml of boiling distilled water through 20 g of seasoning powder placed in a paper filter.
Yellow curry	Lobo (Globo Foods Ltd., Samutprakan, Thailand)	Solution prepared by pouring 200 ml of boiling distilled water through 40 g of seasoning powder placed in a paper filter.
Green curry	Lobo (Globo Foods Ltd., Samutprakan, Thailand)	Solution prepared by pouring 200 ml of boiling distilled water through 40 g of seasoning powder placed in a paper filter.
Coffee	Nescafe (Nestlé, Frankfurt, Germany)	Solution prepared by pouring 200 ml of boiling distilled water through 50 g of seasoning powder placed in a paper filter.

The colorimetric readout of the labial surface of the brackets was performed with a digital portable spectrophotometer positioned perpendicularly to the bracket with a prefabricated holder under the same room lighting condition. The brackets were arranged on a mirrored surface because the spectrophotometer did not read this kind of surface. Also, this surface did not influence the color of the brackets as the black and white surface, thus avoiding the influence of background. [30, 34] To exclude any environmental factors, we used a black opaque cardboard mask with a central window covered the size of the bracket. Then, measurements were made without moving the position of the spectrophotometer. [14, 30, 34-36] Color was evaluated according to the Commission Internationale l'Eclairage (CIE) color scale relative to the D65 illumination pattern. A three-dimensional color graph consisting of L*, a*, and b* co-ordinates can be produced by means of mathematical transformations. The L* parameter corresponds to the degree of lightness and darkness and the a* and b* values to the chroma, where +a* is red, −a* is green, +b* is yellow, and −b* is blue. [37, 38] The advantage of this system for color measurement is that it more closely represents human sensitivity to color and the equal distances in this system approximately equal perceived color differences. [37]

Three measurements were made for each bracket without removing the spectrometer from its position. The value obtained for each bracket (L * a * b *) was the mean of these measures. The color change (ΔE^*) between the means was calculated by using the equation below, where L_1^*, a_1^* and b_1^* were the values obtained from brackets in baseline group (T0).

$$\Delta E^* = [(L_1^*-L_2^*)^2 + (a_1^*-a_2^*)^2 + (b_1^*-b_2^*)^2]^{1/2}$$

To relate the amount of color change (ΔE*) recorded by the spectrophotometer to a clinical environment, the data were converted to the National Bureau of Standards (NBS) units through this equation, where critical remarks of color differences were expressed in terms of NBS units. These values are shown in Table 3. [39]

$$\text{NBS units} = \Delta E^* \times 0.92$$

The surfaces of the brackets were evaluated by scanning electron microscope (SEM, JSM-6610LV, JEOL Ltd., Tokyo, Japan) at 25, 150, 1,000, and 10,000 magnifications to observe any differences in bracket roughness. Images were captured to compare the bracket surfaces to assess the degrees of staining.

Statistical analysis

Statistical analysis was performed using SPSS® 12.0 (Statistical Package for the Social Science, SPSS Inc., Chicago, U.S.A.). Descriptive statistics were calculated for ΔE* and NBS results. To evaluate the error of the method, two measurements were made for each variable. Reproducibility was assessed by means of the Intraclass Correlation Coefficient (ICC). Tests of normality using Kolmogorov-Smirnov and Shapiro-Wilk test found that data was not normally distributed. The group comparison of each bracket brands was performed using the Kruskal-Wallis test, and the Mann-Whitney U test with significance level set at 95%, respectively. The Mann-Whitney U test was used to compare ΔE* mean values intergroup at day3 and day7 with significance level set at 95%.

Results

Results of intraclass correlation coefficients (ICC) revealed that the method for measuring color of ceramic brackets was effective. A high degree of reproducibility as obtained for parameter of color (ΔE*) indicated negligible method error (ICC = 0.87).

The results of ΔE* for assessing color change over time are presented in Table 4. Color of ceramic brackets changes over time was founded in every brand and solution. Furthermore, there was no similarity of color change over time among all brackets. Coffee was the solution that caused the most intense staining of almost every bracket brand tested except W&H. The next staining was followed by Tom-Yum-Goong in Inspire Ice™ and Radiance Plus™ brackets, including green curry in Clarity™ brackets. The most intense staining solution of W&H brackets was Tom-Yum-Goong, followed by coffee.

Table 3 Description of visible color change equivalent to given ranges of NBS units of color difference.

Values (NBS units)	Description of visible change
0.0–0.5	Trace: extremely slight change
0.5–1.5	Slight: slight change
1.5–3.0	Noticeable: perceptible change
3.0–6.0	Appreciable: marked change
6.0–12.0	Much: extremely marked change
12.0 or more	Very much: change to another color

Table 4 Means and standard deviations of color alteration (ΔE^*) produced by solutions on ceramic brackets over time.

Time of immersion	Distilled water	Tom-Yum-Goong	Yellow curry	Green curry	Coffee
	ΔE^*	ΔE^*	ΔE^*	ΔE^*	ΔE^*
	Mean ± S.D.	Mean ± S.D.	Mean ± S.D.	Mean ± S.D.	Mean ± S.D.
Inspire Ice™					
Day3	1.35 ± 0.87	5.37 ± 0.12	1.24 ± 0.53	1.23 ± 0.57	13.65 ± 0.71
Day7	1.45 ± 0.68	6.41 ± 0.79	4.90 ± 1.16	2.35 ± 0.96	15.00 ± 3.48
Radiance Plus™					
Day3	2.26 ± 0.14	3.36 ± 0.42	3.41 ± 0.47	2.74 ± 0.22	5.81 ± 1.85
Day7	2.31 ± 0.20	3.69 ± 0.58	3.76 ± 0.67	3.62 ± 1.10	7.75 ± 0.89
Clarity™					
Day3	3.53 ± 0.17	4.44 ± 0.59	3.53 ± 0.56	5.55 ± 0.74	14.06 ± 0.66
Day7	3.67 ± 0.19	6.54 ± 1.51	4.37 ± 0.85	6.97 ± 0.52	14.84 ± 0.80
W&H					
Day3	2.10 ± 0.33	6.96 ± 0.56	6.07 ± 0.31	3.08 ± 0.49	5.33 ± 0.50
Day7	1.99 ± 0.07	7.31 ± 0.40	7.14 ± 0.55	5.70 ± 1.05	6.80 ± 0.95

Comparative study of various solutions for color change produced on brackets within each immersion time

In this analysis, solutions were compared for color alterations produced on brackets of each brand tested within each time period (Table 4). The threshold for clinical perception of color alteration was considered with values of $\Delta E^* > 3.7$. [19] Thus, distilled water did not produce major changes distinguished by the naked eye. Oppositely, Tom-Yum-Goong, yellow curry, and green curry promoted visible changes, in general, on day7. Coffee promoted visible changes on day3.

Comparative staining study of ceramic bracket brands by solution and immersion time

Bracket brands (two monocrystalline and two polycrystalline) were investigated for color change produced by each solution within each time period (Table 5 and Figure 1). After being immersed in distilled water in both day3 and day7, no statistically significant color alteration presented in every brand which meant stable color change in every group. An overall pattern of increasing color change for all brands was showed from day3 to day7. However, brackets with the same crystal structure did not follow similar patterns of color change. In other words, monocrystalline or polycrystalline structures did not relate to the staining of brackets.

When immersed in Tom-Yum-Goong on day3, W&H presented statistically significant ($p < 0.05$) color alterations in comparison to other bracket brands. On day7, W&H still presented the most staining capacity to Tom-Yum-Goong but not statistically significant with Inspire Ice™. Furthermore, W&H showed statistically significant ($p < 0.05$) color alterations when immersed in yellow curry in comparison to other bracket brands on both day3 and day7. The most staining of green curry was found in Clarity™ brackets. Finally, Inspire Ice™ and Clarity™ presented statistically significant ($p < 0.05$) color alterations when immersed in coffee in comparison to other bracket brands on day3, as well as day7.

Table 5 Means and standard deviations of color alteration (ΔE*) of ceramic brackets in each solution and time.

Time of immersion	Inspire Ice™	Radiance Plus™	Clarity™	W&H
	ΔE*	ΔE*	ΔE*	ΔE*
	Mean ± S.D.	Mean ± S.D.	Mean ± S.D.	Mean ± S.D.
		Distilled water		
Day3	1.35 ± 0.87	2.26 ± 0.14	3.53 ± 0.17	2.10 ± 0.33
Day7	1.45 ± 0.68	2.31 ± 0.20	3.67 ± 0.19	1.99 ± 0.07
		Tom-Yum-Goong		
Day3	5.37 ± 0.12	3.36 ± 0.42	4.44 ± 0.59	6.96 ± 0.56
Day7	6.41 ± 0.79	3.69 ± 0.58	6.54 ± 1.51	7.31 ± 0.40
		Yellow curry		
Day3	1.24 ± 0.53	3.41 ± 0.47	3.53 ± 0.56	6.07 ± 0.31
Day7	4.90 ± 1.16	3.76 ± 0.67	4.37 ± 0.85	7.14 ± 0.55
		Green curry		
Day3	1.23 ± 0.57	2.74 ± 0.22	5.55 ± 0.74	3.08 ± 0.49
Day7	2.35 ± 0.96	3.62 ± 1.10	6.97 ± 0.52	5.70 ± 1.05
		Coffee		
Day3	13.65 ± 0.71	5.81 ± 1.85	14.06 ± 0.66	5.33 ± 0.50
Day7	15.00 ± 3.48	7.75 ± 0.89	14.84 ± 0.80	6.80 ± 0.95

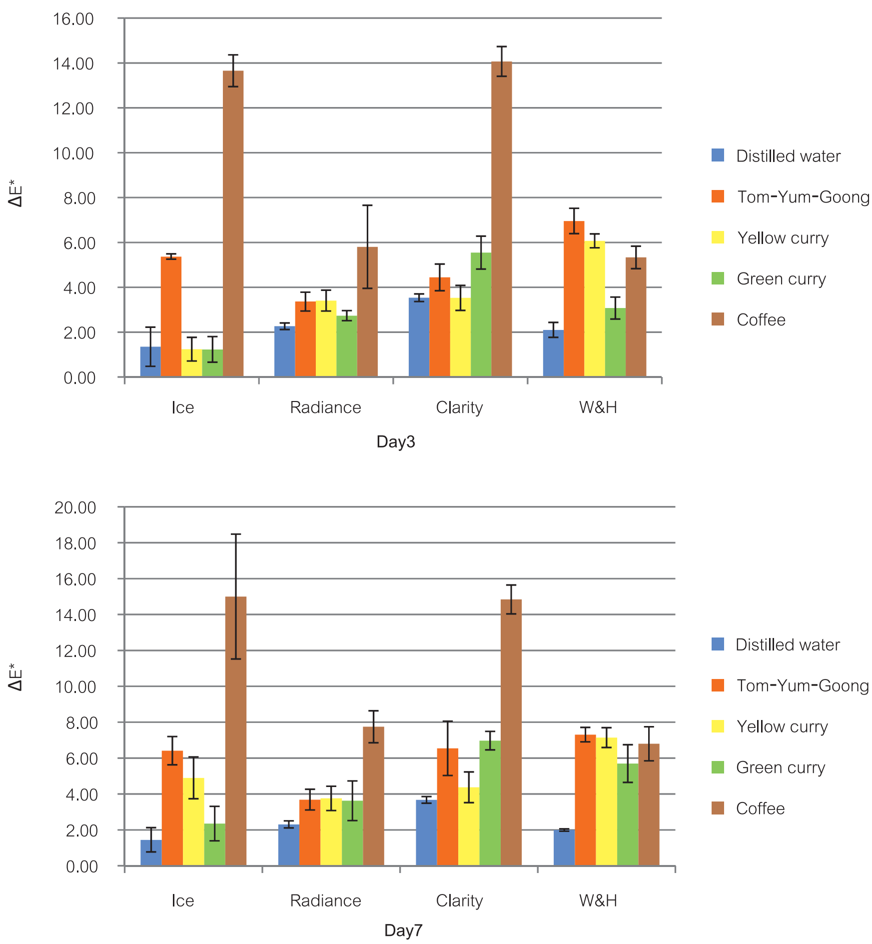

Figure 1 Mean values and S.D. of color change by brand in distilled water, Tom-Yum-Goong, yellow curry, green curry, and coffee at day3 and day7.

Visual Inspection

Color changes were found in all brands of brackets analyzed after day3 of immersion. Thereafter, there was progressive staining of brackets after day7 of immersion (Figure 2). Brackets immersed in distilled water revealed no visible color changes after day7 of immersion (Figure 2A). Bracket immersed in Tom-Yum-Goong did not change color markedly despite having a high ΔE^* value (Figure 2B).

The NBS values

The NBS indexes of each group were also determined (Table 6), and showed that all brackets had some color changes when immersed in all solutions. The NBS indexes of Inspire Ice™ and Clarity™ brackets that immersed in coffee for both 3 days and 7 days were higher than 12.0. This means, those brackets with changes from the initial color were potentially perceptible to the human eye (Figure 3).

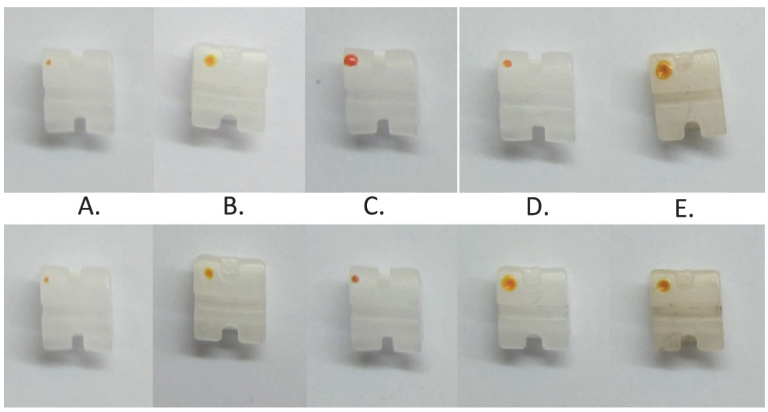

Figure 2 W&H brackets after day3 (top) and day7 (bottom) immersion: A) distilled water, B) Tom-Yum-Goong, C) Yellow curry, D) Green curry, E) Coffee.

Table 6 NBS values of brackets immersed in different solutions and over different periods of time.

Time of immersion	NBS values				
	Distilled water	Tom-Yum-Goong	Yellow curry	Green curry	Coffee
Inspire Ice™					
Day3	1.24	4.94	1.14	1.13	12.56
Day7	1.33	5.90	4.51	2.16	13.80
Radiance Plus™					
Day3	2.08	3.09	3.14	2.52	5.34
Day7	2.12	3.39	3.46	3.33	7.13
Clarity™					
Day3	3.25	4.09	3.24	5.10	12.94
Day7	3.38	6.02	4.02	6.42	13.65
W&H					
Day3	1.93	6.40	5.58	2.83	4.91
Day7	1.83	6.72	6.57	5.24	6.25

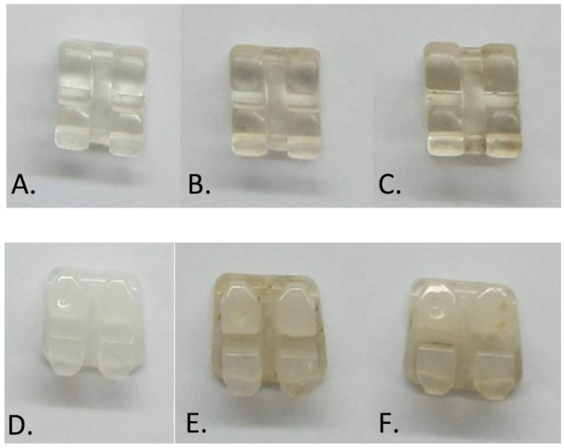

Figure 3 Comparison of control brackets (left) to those immersed in coffee on day3 (middle) and on day7 (right); Inspire Ice^{TM} (A, B, and C), and Clarity^{TM} (D, E, and F).

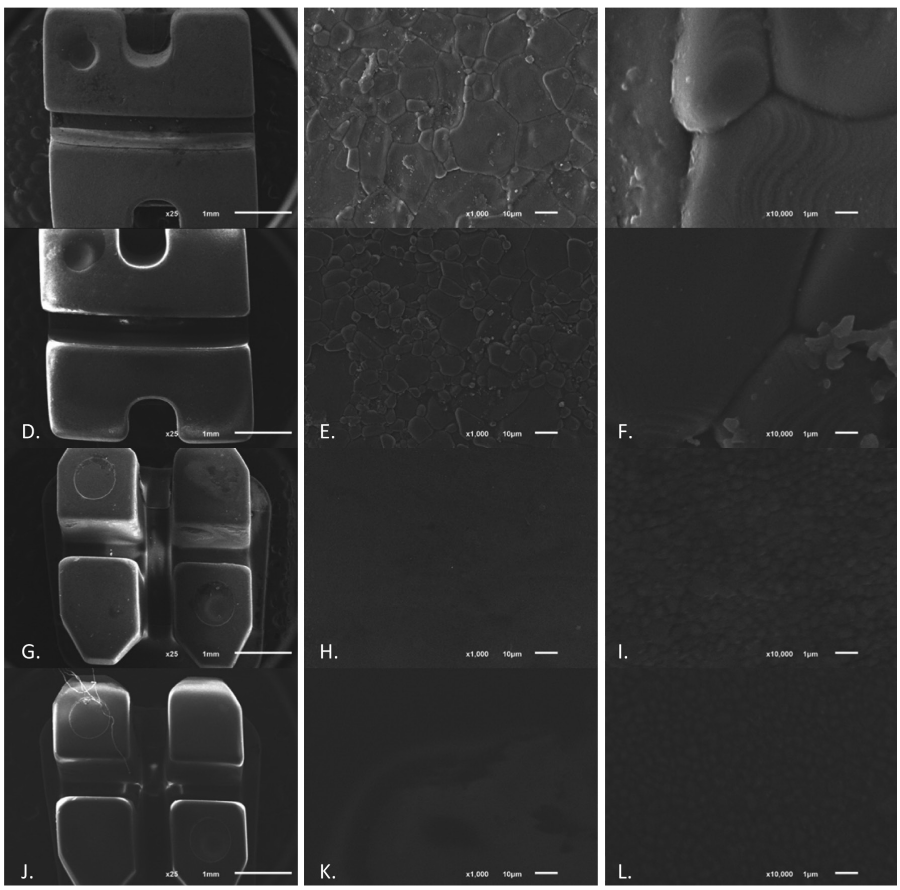

Figure 4 SEM photomicrographs of the surfaces of the esthetic brackets during the experiment at different magnifications (25, 1,000, and 10,000): images A, B, and C are the W&H bracket that immersed in Tom-Yum-Goong. Images D, E, and F are the W&H bracket that immersed in coffee. Images G, H, and I are the Clarity^{TM} bracket that immersed in Tom-Yum-Goong. Images J, K, and L are the Clarity^{TM} bracket that immersed in coffee.

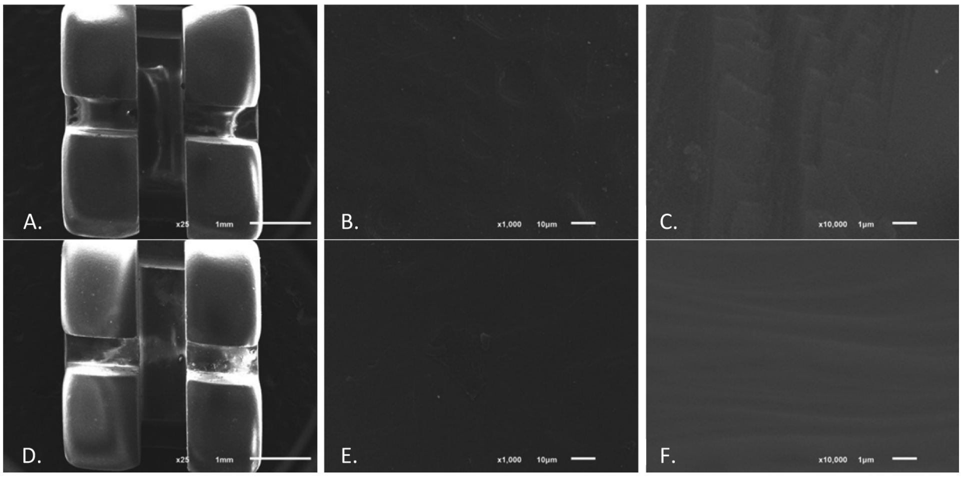

Figure 5 SEM photomicrographs of the surfaces of the esthetic brackets at different magnifications: images A, B, and C are the bracket that showed the greatest color alteration during the experiment at magnifications of 25, 1,000, and 10,000, respectively. Images D, E, and F are the bracket that showed the least color alteration during the experiment at magnifications of 25, 1,000, and 10,000, respectively.

Evaluating surfaces of the brackets

From the SEM studies, the surface evaluations of the brackets showed topographical differences, with evidence of greater roughness in polycrystalline brackets immersed in Tom-Yum-Goong. That is, W&H brackets (Figure 4 A-C) exhibited more intense staining when immersed in Tom-Yum-Goong than in coffee (Figure 4 D-F). Oppositely, Clarity^{TM} brackets, another polycrystalline brackets with evidence of greater roughness when immersed in Tom-Yum-Goong (Figure 4 G-I), exhibited staining capacity lower than those immersed in coffee significantly (Figure 4 J-L). Moreover, the surface roughness of most staining bracket was similar to the least staining bracket (Figure 5). Therefore, no correlation could be found between the surface roughness of the brackets and the staining values.

Discussion

Few previous studies regarding color changes of different esthetic ceramic brackets after immersion in solutions were reported. [12, 15, 18, 40] According to them, the color of ceramic brackets changes over time when exposed to potentially staining solutions commonly present in people's diet. In addition, staining is cumulative; it increases as the time of exposure to the coloring elements increases. Nevertheless, only a few studies could compare with the results similarly to this study, because most of them compared ceramic with plastic brackets. However, those studies show the results in accordance with our findings.

From this study, brackets with the same crystalline structure did not follow similar patterns of color alteration when exposed to the same solutions under the same conditions. This finding coincided with the study of Yu and Lee. [41] The size, shape, and thickness of brackets could be different by bracket brand, which will influence their aesthetic color performance. Moreover, brackets in the same composition category produced by different manufacturers might be used with different materials; they might also have distinctive properties compared with brackets using different compositions. The factors that affect different staining capacities were manufacturing process of each brands, total exposure time, and the staining properties of solutions.

Evaluation of the brackets by SEM showed that color alteration was mainly due to stain adsorption and sub-surface stain absorption taking place between the staining solution and the ceramic brackets which is in concurrence with a previous study.[25] Moreover, greater porosities and surface roughness from acid destruction [42] in the brackets immersed in Tom-Yum-Goong may facilitate higher penetration of pigments that contributes to a greater degree of brackets discoloration. Park et al. [43] also showed that pH was not the main element responsible for color changes.

Regarding the staining potential of each solution, an interesting result was observed. Tom-Yum-Goong, the experimental acidic solution that caused little color changes by visual inspection (Figure 2B), yielded high ΔE^* values from the assessment by spectrophotometry. A possible explanation is that, due to its acidity, this solution had the ability of changing the material surface as shown from SEM, leading to greater absorption of coloring pigments from the solution, which could be detected accurately by the spectrophotometer while not detected by the human eye.

It is important to mention that these results should not be extrapolated to the real clinical outcome because of the methodological limitations when assessing color alterations of brackets *in vitro*. In addition, the condition presented in oral cavity is quite complex due to several factors, such as the complex normal flora and its by-products, [44] the biofilm deposition at the surface of brackets, quality and quantity of saliva. Therefore, further clinical studies investigating color stability of esthetic brackets should be conducted in order to serve orthodontic patients' demand.

Conclusions

1. Time, bracket manufacturing fabrication, various vivid-colored food solutions, and coffee affect changes in color of esthetic ceramic brackets.

2. The most staining capacity on Inspire Ice™, Radiance Plus™, and Clarity™ brackets was found in coffee, whereas on W&H brackets was found in Tom-Yum-Goong.

3. Food composition partly plays an important role in color susceptibility of esthetic ceramic brackets.

4. No significant relationship was found between the degree of color alteration and the degree of surface roughness of brackets.

5. The most surface roughness of brackets was found in Tom-Yum-Goong.

6. This study was *in vitro*. Clinical study may be needed.

Conflict of interest

All authors have no conflict of interest in this study.

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