Research Article

Evaluation of Color Stability of Two Different Rhodium-Coated Archwires Immersed in Potentially Staining Solutions using Spectrophotometry Analysis – An In Vitro Study

Dr. Anjana S Nair[1], Dr. Pavithra H*[2], Dr. Amal S Nair[3], Dr. Janu S Nair[4], Dr. Jerbin Vijai VM[5]

[1]Reader, Department of Orthodontics and Dentofacial Orthopaedics, Sree Mookambika Institute of Dental Sciences, Kulasekharam.
[2]Postgraduate, Department of Orthodontics and Dentofacial Orthopaedics, Sree Mookambika Institute of Dental Sciences, Kulasekharam
[3]Professor and Head of the Department, Department of Orthodontics and Dentofacial Orthopaedics, Sree Mookambika Institute of Dental Sciences, Kulasekharam
[4]Reader; Department of Orthodontics and Dentofacial Orthopaedics, Sree Mookambika Institute of Dental Sciences, Kulasekharam
[5]Senior Lecturer, Department of Orthodontics and Dentofacial Orthopaedics, Sree Mookambika Institute of Dental Sciences, Kulasekharam

Abstract

Objective: The purpose of the study is to use spectrophotometric analysis to assess the color stability of rhodium-coated archwires from two different manufacturers submerged in two distinct staining solutions.

Materials and Methods: Twenty-four rhodium-coated archwire samples from two distinct manufacturers Tomy Pak of Orthosystems (OS) and Iconix of American Orthodontics (AO) were assessed following 14 and 28 days of submersion in a solution of tea, and coffee. A Commission Internationale de l'Eclairage L∗a∗b∗ system-based computed spectrophotometer was used to assess color variations (delta ΔE∗). Color measurements were repeated 14 and 28 days after the solution was submerged.

Results: After 28 days of immersion, both brands of archwires showed a noticeable color shift. Iconix American orthodontic archwires have been found to cause greater color instability in tea solution, and the value of color change increases with longer immersion time.Conclusion: All archwires assessed showed appreciable color change after 28 days. The Iconix American orthodontic brand showed the highest amount of color change.

Keywords: Orthodontic Wires, Spectrophotometry, Color, Beverages, Coated Materials.

1. Introduction

Orthodontic wires are commonly utilized as part of orthodontic equipment throughout therapy. These wires are constructed from metal alloys such as stainless steel (SS), cobalt-chromium-nickel (Co-Cr-Ni), beta-titanium (beta-Ti), and nickel-titanium (Ni-Ti). [1] The advantage of using metal alloys in orthodontic wires is that they have better mechanical qualities than other materials like polymers and ceramics. However, one disadvantage of metallic wires is their opaque appearance, which deters many patients from seeking orthodontic treatment. [2] To address this, esthetic arch wires were introduced. In today's cosmetic dentistry market, invisible orthodontics is in high demand.

Metal brackets and steel appliances are being replaced with lingual or aesthetic brackets. [3] Metal archwires covered with tooth-colored resin materials are used to mimic tooth color. The benefits of coated archwires include reduced surface roughness and friction. [4] However, some downsides have been identified, such as the coating's poor endurance in the oral environment, color change, cracking and pitting, and increased surface roughness. According to the study, 25% of the coating is lost intraorally within 33 days, causing the wire to lose its aesthetic attractiveness. [5] Discoloration of the aesthetic archwires can be caused by both internal and external sources, such as food dyes and colored mouthwash. [6] Our everyday consumption of tea and coffee might also cause wire discoloration. In light of this, the current study aims to assess the color stability of two brands of rhodium-coated archwires immersed in potentially staining solutions.

2. Materials And Methods:

This study compared two types of rhodium-coated nickel-titanium (NiTi) archwires (0.019 × 0.025 inches): Tomy Pak (Orthosystems) and Iconix (American Orthodontics) (Figure 1). The wires were cut into short segments and assembled into strips using light-cured composite resin (Figure 2). A total of 24 specimens were prepared, with 12 from each brand. Each brand was further subdivided into tea and coffee immersion groups, with six specimens in each subgroup (n = 6).

2.1. SOLUTION PREPARATION:

Different solutions were prepared using 100 ml of distilled water. After mixing and boiling, the solutions were cooled to room temperature and then filtered. A coffee solution was made using 3g of commercially available coffee powder mixed with 100 ml of boiling distilled water and stirred until evenly distributed. Tea was made by adding 3g of commercially available tea powder to 100 ml of boiling distilled water and stirred to ensure uniform mixing. The solutions were separated into two equal parts of 50 ml each. Figure 3. The solution was refreshed every two days. To reduce particle precipitation, the liquid was stirred once a day for 1 minute.

2.2. Color Measurements:

Prior to immersion in the solution, the specimens were kept in distilled water at 37°C for 24 hours. After 24 hours (T0) of immersion into distilled water, the color of each sample was assessed using a spectrophotometer. Following the initial measurement (T0), the samples were placed in a beaker containing the prepared solution. The color measurements were repeated after 14 days (T1) and 28 days (T2) of immersion in the solution. Before each measurement, samples were removed from the solution and cleansed with distilled water in an ultrasonic cleaning bath for 5 minutes. Excess water from the surfaces was removed with tissue paper, and the samples were allowed to dry.

2.3. Baseline Color Measurements: Prior to performing the measurements, the spectrophotometer was calibrated according to the manufacturer's instructions. Baseline measurements were done for each specimen at visible wavelengths between 400-700nm by CM5 - Spectrophotometer. Color changes were characterized using the Commission Internationale de I'Eclairage L*a*b* color space (CIE L*a*b*).

2.4. Measurement of Color Changes: Following immersion in solutions, samples have been put in a glass container along with prepared solutions (tea and coffee solution) at a temperature of 37° C. The solution was changed two days once and the color measurements have been repeated 14 (T1) and 28 days (T2) after the immersion. The samples have been removed out of the solution then rinsed with distilled water for a duration of five mins before each measurement. The samples were given time to dry after excess water on surfaces has been removed away using a tissue paper Then the L*, a*and b* values of each specimen after immersion in solutions were measured. The color difference between baseline measurement and measurement after immersion in solution as follows:

$$\Delta L^* = L2 _ L1, \Delta a^* = a2 - a1, \Delta b^* = b2 - b1$$

Then the total color differences Δ E* for each specimen (distance between the 2 point in color space) were calculated by following equation:

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

The ΔE* of each subgroup was compared with others, to distinguish which type of coating material was more unstable in color and which staining solution cause more color change in aesthetic archwires. To relate the amount of color change (ΔE*) to a clinical environment, the data were converted to National Bureau of Standards (NBS) units as the following:

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

The definitions of color changes quantified by NBS units were used. These values were suggested by Koksal and Dikbas, and the interpretation scale used for comparison is **[Table 1]**

NBS Units	Color Difference Perception
0.0 – 0.5	**Trace**
0.5 – 1.5	**Slight**
1.5 – 3.0	**Noticeable**
3.0 – 6.0	**Appreciable**
6.0 – 12.0	**Much**
> 12.0	**Very much**

Table 1: NBS Color Difference Scale

2.5. Statistical Analysis:

The data were statistically analyzed using SPSS software (version 25.0).

1. Repeated Measures ANOVA was used to compare changes in L*, a*, and b* values within each group at different time intervals (baseline, 14 days, and 28 days).
2. An independent-samples t-test was used to compare the two independent groups at each time interval.
3. One-way ANOVA was used to compare the mean ΔE values among the four experimental subgroups (AO Tea, AO Coffee, OS Tea, and OS Coffee) at 14 and 28 days.

A p-value of less than 0.05 was considered statistically significant.

3. Results:

In all groups **[Table 2]**, a progressive reduction in L* values was observed, indicating darkening over time. AO Tea showed a progressive and significant reduction in L* values over time, indicating darkening (baseline: 69.73 ± 0.59; 14 days: 68.12 ± 0.48; 28 days: 65.62 ± 0.73; $p < 0.001$). a* and b* values increased significantly, reflecting greater redness and yellowness (a*: 1.16 → 2.15; b*: 2.11 → 5.86; $p < 0.001$). ΔE values demonstrated a substantial color difference over time (2.44 at 14 days; 5.67 at 28 days), while NBS units indicated a progression from noticeable (2.24) to appreciable (5.19) color change.

AO Tea exhibited the highest overall staining among all groups. AO Coffee showed a significant but less pronounced reduction in L* values with increases in a* and b* values. **[Table 3]** ΔE values increased from 1.40 at 14 days to 3.68 at 28 days.

Corresponding NBS units progressed from slight (1.28) to appreciable (3.38), indicating moderate staining over time, less than AO Tea. OS Tea exhibited significant reductions in L* values with corresponding increases in a* and b* values. **[Table 4]** ΔE values increased from 1.56 at 14 days to 3.81 at 28 days. NBS units reflected a change from slight (1.43) to appreciable (3.50). **[Table 5]** OS Tea caused moderate staining, lower than AO Tea but comparable to AO Coffee. OS Coffee showed a significant decrease in L* values with increases in a* and b*. ΔE values increased from 1.23 at 14 days to 4.54 at 28 days.

NBS units indicated progression from slight (1.13) to appreciable (4.17). **[Table 6]** Although OS Coffee showed the least initial discoloration, it demonstrated appreciable staining by 28 days.

Groups		Intervals	Mean	Std. Deviation	P value	95% confidence interval of mean	
						Lower bound	Upper bound
AO Tea group	L value	Baseline	69.7300	.59137	**<0.001****	69.109	70.351
		After 14 days	68.1267	.48438		67.618	68.635
		After 28 days	65.6267	.73487		64.855	66.398
	a value	Baseline	1.1617	.06242	**<0.001****	1.096	1.227
		After 14 days	1.3833	.12549		1.252	1.515
		After 28 days	2.1550	.16968		1.977	2.333
	b value	Baseline	2.1167	.37644	**<0.001****	1.722	2.512
		After 14 days	3.9083	.40686		3.481	4.335
		After 28 days	5.8667	.09585		5.766	5.967
AO Coffee group	L value	Baseline	71.5050	.69192	**0.018***	70.779	72.231
		After 14 days	71.3217	.56425		70.730	71.914
		After 28 days	68.7900	1.09953		67.636	69.944
	a value	Baseline	1.0200	.14199	**0.009***	.871	1.169
		After 14 days	1.1717	.09261		1.074	1.269
		After 28 days	1.4067	.18790		1.209	1.604
	b value	Baseline	2.0517	.24943	**<0.001****	1.790	2.313
		After 14 days	3.0533	.35155		2.684	3.422
		After 28 days	4.3583	.36723		3.973	4.744
OS Tea group	L value	Baseline	74.0383	.59570	**0.004***	73.413	74.663
		After 14 days	72.9800	.61838		72.331	73.629
		After 28 days	71.5167	.39348		71.104	71.930
	a value	Baseline	.8233	.02160	**<0.001****	.801	.846
		After 14 days	1.0933	.04590		1.045	1.142
		After 28 days	1.4900	.05865		1.428	1.552
	b value	Baseline	2.3500	.07430	**0.002***	2.272	2.428
		After 14 days	3.3183	.28414		3.020	3.617
		After 28 days	5.0350	.65677		4.346	5.724
OS Coffee group	L value	Baseline	75.0267	.52206	**0.001***	74.479	75.575
		After 14 days	74.0950	.57110		73.496	74.694
		After 28 days	71.7333	1.23439		70.438	73.029
	a value	Baseline	.8167	.06250	**0.002***	.751	.882
		After 14 days	1.1050	.41712		.667	1.543

		After 28 days	1.6617	.18563		1.467	1.856
	b value	Baseline	2.2133	.11994	**<0.001****	2.087	2.339
		After 14 days	2.7417	.37317		2.350	3.133
		After 28 days	5.1783	.73115		4.411	5.946

Table 2 – Repeated Measures ANOVA

Intragroup comparison	Intervals		Groups	Mean	Std. Deviation	Mean difference	P value
AO Tea and AO Coffee	Baseline	L value	AO Tea	69.7300	.59137	-1.775	0.001*
			AO Coffee	71.5050	.69192		
		a value	AO Tea	1.1617	.06242	0.142	0.061
			AO Coffee	1.0200	.14199		
		b value	AO Tea	2.1167	.37644	0.065	0.732
			AO Coffee	2.0517	.24943		
	After 14 days	L value	AO Tea	68.1267	.48438	-3.195	<0.001**
			AO Coffee	71.3217	.56425		
		a value	AO Tea	1.3833	.12549	0.212	0.008*
			AO Coffee	1.1717	.09261		
		b value	AO Tea	3.9083	.40686	0.855	0.003*
			AO Coffee	3.0533	.35155		
	After 28 days	L value	AO Tea	65.6267	.73487	-3.163	<0.001**
			AO Coffee	68.7900	1.09953		
		a value	AO Tea	2.1550	.16968	0.748	<0.001**
			AO Coffee	1.4067	.18790		
		b value	AO Tea	5.8667	.09585	1.508	<0.001**
			AO Coffee	4.3583	.36723		
OS Tea and OS Coffee	Baseline	L value	OS Tea	74.0383	.59570	-0.988	0.012*
			OS Coffee	75.0267	.52206		
		a value	OS Tea	.8233	.02160	0.006	0.810
			OS Coffee	.8167	.06250		
		b value	OS Tea	2.3500	.07430	0.137	0.039*
			OS Coffee	2.2133	.11994		
	After 14 days	L value	OS Tea	72.9800	.61838	-1.115	0.009*
			OS Coffee	74.0950	.57110		
		a value	OS Tea	1.0933	.04590	-0.012	0.947
			OS Coffee	1.1050	.41712		
		b value	OS Tea	3.3183	.28414	0.576	0.013*
			OS Coffee	2.7417	.37317		
	After 28 days	L value	OS Tea	71.5167	.39348	-0.217	0.691
			OS Coffee	71.7333	1.23439		
		a value	OS Tea	1.4900	.05865	-0.171	0.074
			OS Coffee	1.6617	.18563		
		b value	OS Tea	5.0350	.65677	-0.143	0.728
			OS Coffee	5.1783	.73115		

Table 3 – Comparison between tea and coffee subgroups within each brand.

Intergroup comparison	Intervals		Groups	Mean	Std. Deviation	Mean difference	P value
Comparison of AO tea and OS Tea	Baseline	L value	AO Tea	69.7300	.59137	-4.308	<0.001**
			OS Tea	74.0383	.59570		
		a value	AO Tea	1.1617	.06242	0.338	<0.001**
			OS Tea	.8233	.02160		
		b value	AO Tea	2.1167	.37644	-0.233	0.167
			OS Tea	2.3500	.07430		
	After 14 days	L value	AO Tea	68.1267	.48438	-4.853	<0.001**
			OS Tea	72.9800	.61838		
		a value	AO Tea	1.3833	.12549	0.290	0.002*
			OS Tea	1.0933	.04590		
		b value	AO Tea	3.9083	.40686	0.590	0.016*
			OS Tea	3.3183	.28414		
	After 28 days	L value	AO Tea	65.6267	.73487	-5.89	<0.001**
			OS Tea	71.5167	.39348		
		a value	AO Tea	2.1550	.16968	0.665	<0.001**
			OS Tea	1.4900	.05865		
		b value	AO Tea	5.8667	.09585	0.832	0.012*
			OS Tea	5.0350	.65677		
Comparison of AO Coffee and OS Coffee	Baseline	L value	AO Coffee	71.5050	.69192	-3.522	<0.001**
			OS Coffee	75.0267	.52206		
		a value	AO Coffee	1.0200	.14199	0.203	0.009*
			OS Coffee	.8167	.06250		
		b value	AO Coffee	2.0517	.24943	-0.162	0.183
			OS Coffee	2.2133	.11994		
	After 14 days	L value	AO Coffee	71.3217	.56425	-2.773	<0.001**
			OS Coffee	74.0950	.57110		
		a value	AO Coffee	1.1717	.09261	0.067	0.710
			OS Coffee	1.1050	.41712		
		b value	AO Coffee	3.0533	.35155	0.312	0.167
			OS Coffee	2.7417	.37317		
	After 28 days	L value	AO Coffee	68.7900	1.09953	-2.943	0.001*
			OS Coffee	71.7333	1.23439		
		a value	AO Coffee	1.4067	.18790	-0.255	0.040*

			OS Coffee	1.6617	.18563		
		b value	AO Coffee	4.3583	.36723	-0.82	0.034*
			OS Coffee	5.1783	.73115		

Table 4 – Comparison between brands within tea and coffee groups.

Delta E and NBS values	Groups	Mean	Std. Deviation	95% Confidence Interval for Mean		P value
				Lower Bound	Upper Bound	
Delta E Value 14th day	AO Tea	2.4433	.30323	2.1251	2.7616	**<0.001****
	AO Coffee	1.3967	.57486	.7934	1.9999	
	OS Tea	1.5550	.29269	1.2478	1.8622	
	OS Coffee	1.2317	.25888	.9600	1.5033	
Delta E Value 28th day	AO Tea	5.6650	.52748	5.1114	6.2186	**0.002***
	AO Coffee	3.6783	.99234	2.6369	4.7197	
	OS Tea	3.8100	.59659	3.1839	4.4361	
	OS Coffee	4.5367	1.08389	3.3992	5.6741	
NBS Value 14th day	AO Tea	2.2417	.27931	1.9485	2.5348	**<0.001****
	AO Coffee	1.2783	.52958	.7226	1.8341	
	OS Tea	1.4333	.26920	1.1508	1.7158	
	OS Coffee	1.1367	.24443	.8802	1.3932	
NBS Value 28th day	AO Tea	5.1933	.47710	4.6926	5.6940	**0.002***
	AO Coffee	3.3783	.91285	2.4204	4.3363	
	OS Tea	3.5000	.55064	2.9221	4.0779	
	OS Coffee	4.1700	.99866	3.1220	5.2180	

Table 5 – Comparison of ΔE and NBS values using One-way ANOVA.

Groups	Intervals	NBS units	Color change
AO tea	After 14th day	2.24	Noticeable
	After 28th day	5.19	Appreciable
AO coffee	After 14th day	1.28	Slight
	After 28th day	3.38	Appreciable
OS tea	After 14th day	1.43	Slight
	After 28th day	3.5	Appreciable
OS coffee	After 14th day	1.13	Slight
	After 28th day	4.17	Appreciable

Table 6 – Interpretation of NBS units.

FIGURE 1:
Orthodontic archwires used in the study: (A) Bioforce (Tomy Pak Orthosystems), (B) Iconix (American Orthodontics),

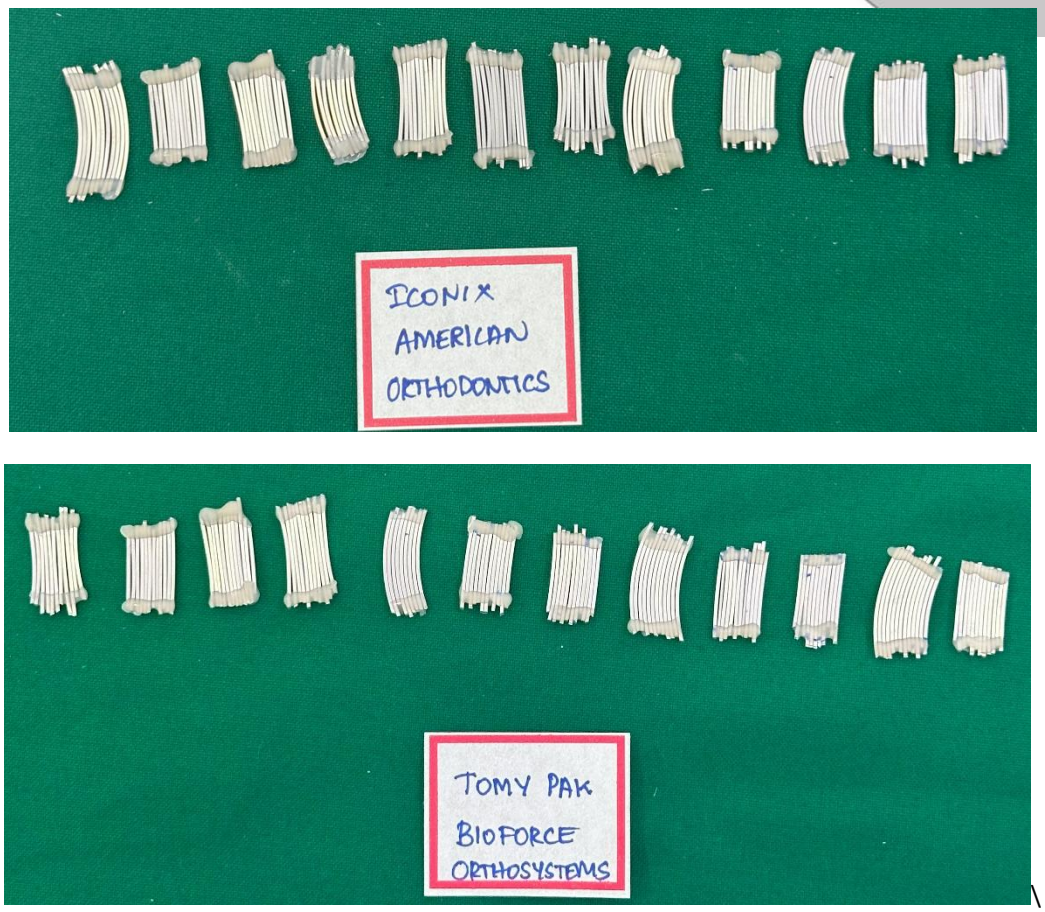


FIGURE 2:
(A) Immersion of Bioforce (Tomy Pak Orthosystems) and Iconix (American Orthodontics) archwires in distilled water and (B) Immersion of Bioforce (Tomy Pak Orthosystems) and Iconix (American Orthodontics) archwires in different staining solutions.

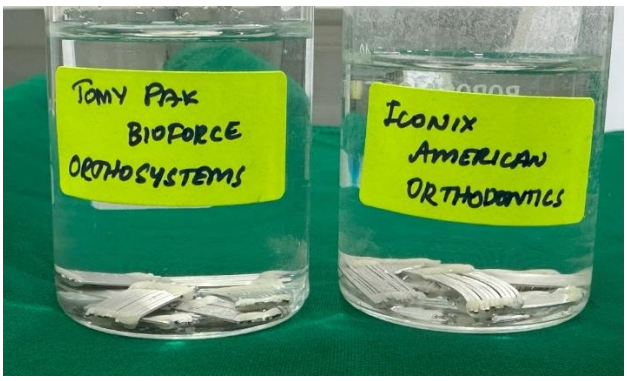




FIGURE 3: CM-5 Spectrophotometer (Konica Minolta) Used for Color Measurement



FIGURE 4: Comparison of L*, a*, and b* Color Parameters of AO and OS archwires in Tea and Coffee Immersion Over Time

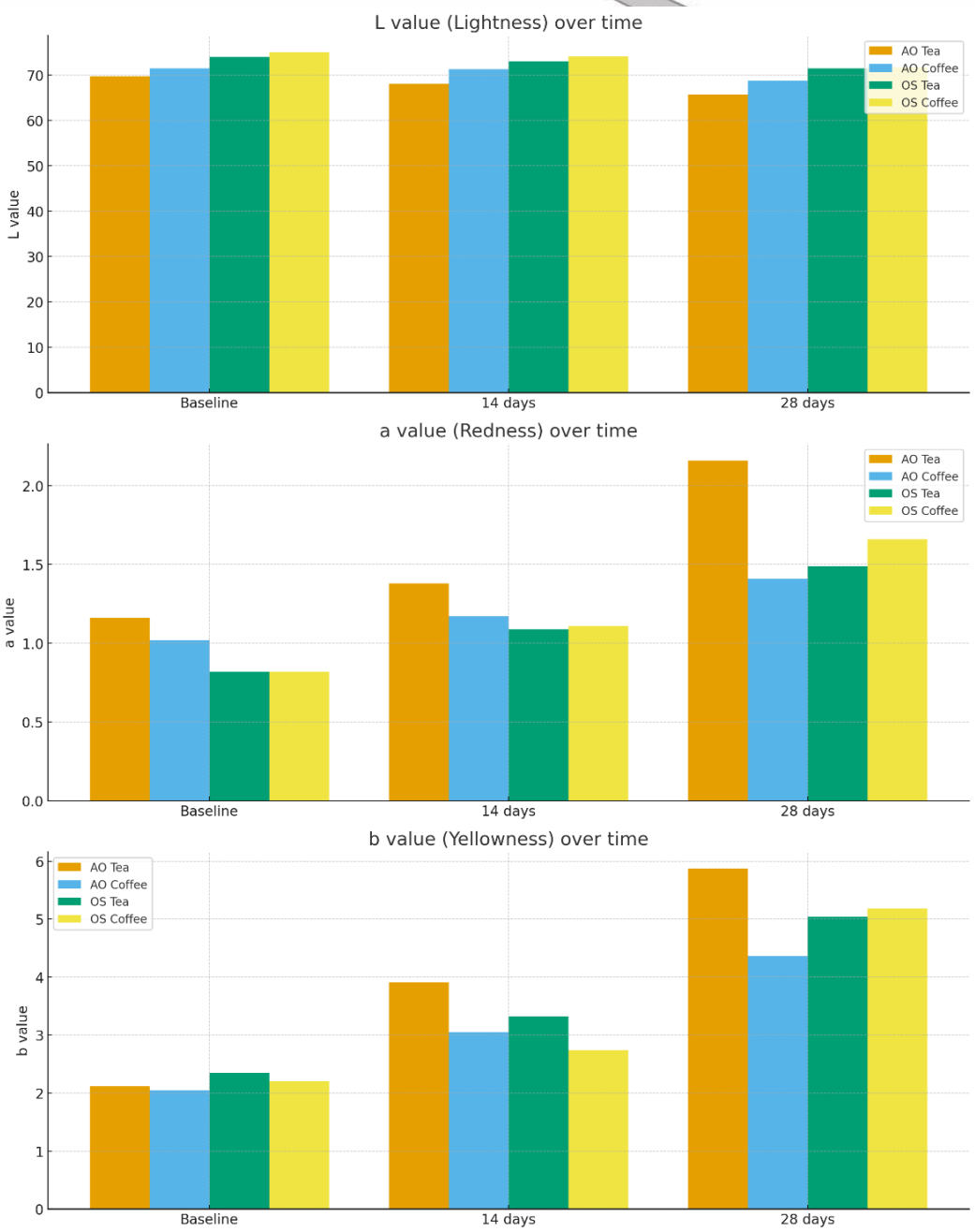
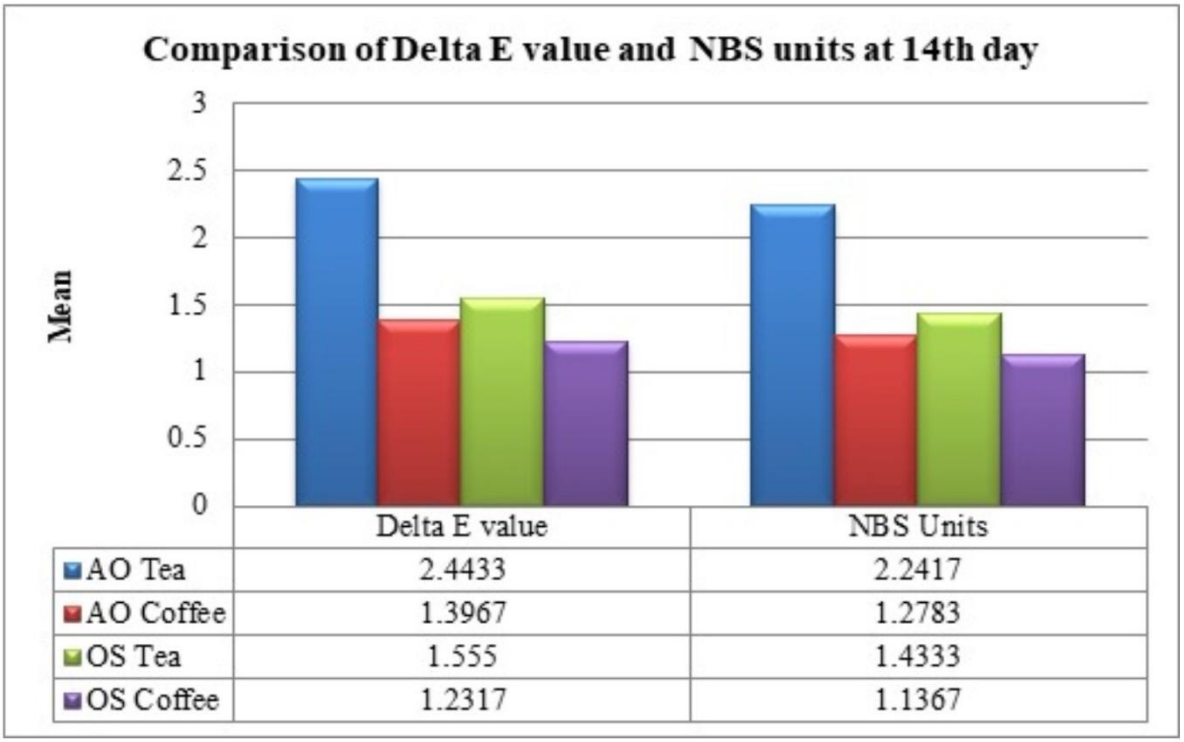
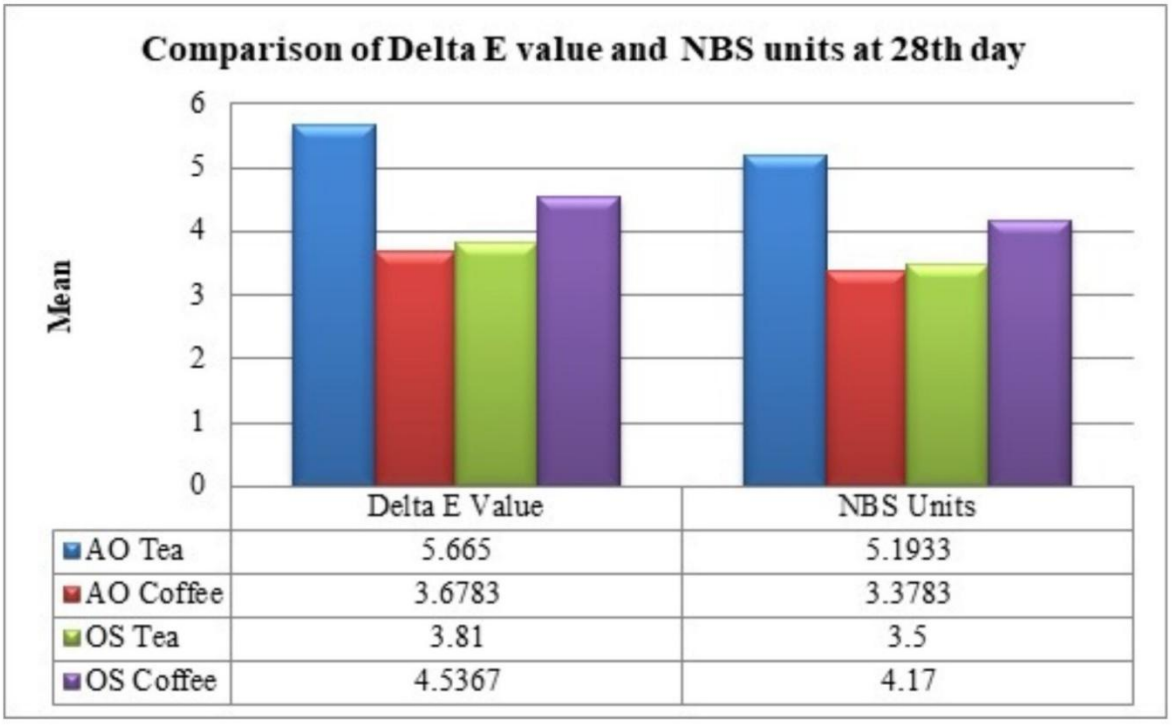


FIGURE 5: (A) Comparison of ΔE and NBS Units at 14 Days, (B) Comparison of ΔE and NBS Units at 28 Days



	Delta E value	NBS Units
AO Tea	2.4433	2.2417
AO Coffee	1.3967	1.2783
OS Tea	1.555	1.4333
OS Coffee	1.2317	1.1367



	Delta E Value	NBS Units
AO Tea	5.665	5.1933
AO Coffee	3.6783	3.3783
OS Tea	3.81	3.5
OS Coffee	4.5367	4.17

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FIGURE 1: Orthodontic archwires used in the study:
(A) Bioforce (Tomy Pak Orthosystems),
(B) Iconix (American Orthodontics),

FIGURE 2 : (A) Immersion of Bioforce (Tomy Pak Orthosystems) and Iconix (American Orthodontics) archwires in distilled water and
(B) Immersion of Bioforce (Tomy Pak Orthosystems) and Iconix (American Orthodontics) archwires in different staining solutions.

FIGURE 3: CM-5 Spectrophotometer (Konica Minolta) Used for Color Measurement

FIGURE 4: Comparison of L*, a*, and b* Color Parameters of AO and OS archwires in Tea and Coffee Immersion Over Time

FIGURE 5: (A) Comparison of ΔE and NBS Units at 14 Days
(B) Comparison of ΔE and NBS Units at 28 Days

Wires Received from:

1. Iconix NiTi Aesthetic wire from American orthodontics
   3524 Washington Avenue, Sheboygan, Wi 53081.
2. Bioforce Tomy Pak NiTi Aesthetic wire from Orthosystems
   Tentora building, Fuchu city, Tokyo 183-0006

SPSS version 25.0 software was utilized to analyze the data.

4. Discussion

The present study evaluated the colour stability of two different Rhodium coated orthodontic arch wires, from Tomy pak (Orthosystem) and Iconix (American orthodontics). Spectrophotometric test was used to evaluate the colour changes and were characterized by using the CIE L*a*b* color space. The CIE L*a*b* color space is currently one of the most popular and widely used systems of color measurement, and it is well suited for the determination of small color difference. Spectrophotometer has been used in many previous studies to measure color change by comparing the values of L∗a∗b∗ before and after treatment according to the CIE L*a*b* system, but the value of ΔE∗represents relative color changes that an observer might report for the materials after immersion. Thus, ΔE∗is more meaningful than the individual L∗,a∗,b∗ value. [7] Arch wire with a rectangular cross section (0.019∗0.025inch) was chosen because it is easier to make a strip, and the total width of each sample had to be at least 10 mm to provide a large surface area for proper color measurement.

In the current study, both rhodium coated arch wires show color changes after 28th days of immersion into staining solutions. Previous studies by Mujawar et al. [8] evaluated a total of 120 samples after 7, 14, and 21 days of immersion in staining coffee solution, and all the esthetic arch wires assessed showed noticeable color change after 21 days. Some studies [9,10] concluded that coffee was the most chromogenic agent in comparison with other staining substances, such as tea and cola drinks; in accordance with that da Silva et al [11] used coffee to evaluate color stability and found archwires displayed discernible color change over coffee immersion, and the quantity of color change increased with time.

The present study evaluated the staining potential of tea and coffee on two different material groups (AO and OS) by analyzing L*, a*, b* values, ΔE, and NBS units over 14 and 28 days. The findings revealed that all groups exhibited progressive color changes over time, though the degree of discoloration varied. AO tea demonstrated the **highest discoloration** at both intervals, with marked reductions in L* values and significant increases in both a* and b*. This indicates that AO tea specimens became darker, redder, and more yellow over time. The pronounced staining effect of tea may be attributed to the presence of **tannins and polyphenolic compounds**, which have strong affinity for binding to material surfaces.

The greater discoloration observed in AO archwires may be related to differences in the surface characteristics of the coating materials; however, these properties were not evaluated in the present study. AO coffee and OS tea exhibited **moderate discoloration**, reflecting the cumulative effect of both chromogenic content and material surface properties.

While coffee contains chromogens and acidic components, its staining ability was found to be comparatively lower than tea in this study, which supports previous reports highlighting tea as a stronger staining agent. OS coffee initially showed the **least discoloration** but demonstrated **appreciable staining by 28 days.** This suggests that although OS materials are initially more resistant to staining possibly due to smoother surfaces or less porosity prolonged exposure eventually leads to significant discoloration as pigments diffuse or accumulate over time. From a clinical perspective, NBS analysis confirmed that color changes were **noticeable to appreciable** in most groups by 28 days, with AO tea showing the highest clinical impact. This highlights the importance of dietary habits, especially frequent tea consumption, on the esthetic longevity of orthodontic archwires.

5. Future Scope

Further studies can be done by increasing the immersion media, comparative groups can be increased and pH variation can be done to see the color change differences.

6. Conclusion

Within the limitations of this study, it can be concluded that all materials exhibited progressive discoloration when exposed to tea and coffee, with AO tea showing the greatest staining potential. OS coffee demonstrated the least change initially but revealed appreciable discoloration with prolonged exposure. Clinically, material selection and patient dietary counseling play a crucial role in maintaining esthetics, particularly for individuals with high tea and coffee consumption.

7. References

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