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Original Research Article

To evaluate and compare surface characteristics of different aesthetic nickel-titanium archwires using surface profilometry, sem and stereomicroscopy: A multi-arm split-mouth randomized controlled trial

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ABSTRACT

Objective: This multi-arm split-mouth randomized controlled trial aimed to compare the surface characteristics, coating thickness and coating stability of four different aesthetic coated Nickel-Titanium Orthodontic rectangular archwires before and after oral exposure.

Materials and Methods: To evaluate and compare the surface characteristics of four as-received (Control group) aesthetic nickel-titanium orthodontic rectangular archwires (0.016 x 0.022″ NiTi) from different manufacturers that are BioForce (Group I), Rabbit force (Group II), Libral (Group III), and ORMCO (Group IV) and after oral exposure (Experimental group) of four weeks, 15 patients meeting the inclusion criteria were recruited for this prospective study. Scanning electron microscopy, stereomicroscopy, and 3D profilometry were done for evaluating the surface characteristics of each group of wires.

Results: Four quadrants of every patient were randomized in a 1:1:1:1 ratio to the wires of either BioForce (Group I), Rabbit force (Group II), Libral (Group III), or ORMCO (Group IV). On examination of as-received wires (control group), the maximum coating thickness was seen in Group III c (Teflon coated, Libral), followed by Group IIc (Epoxy coated, Rabbit Force), then Group Ic (Teflon coated, BioForce), and least in Group IVc (Epoxy coated, ORMCO). After 4 weeks of oral exposure, the maximum coating loss was seen in Group II (Rabbit Force) wire, and the least amount of coating loss was seen in Group IV (ORMCO).

Conclusion: The results of this study indicated a low aesthetic value of each of the manufacturer's coated archwires because they presented a non-durable coating after oral exposure.

1. Introduction

Most orthodontic instruments are metallic or silver in appearance, and there were translucent brackets made of ceramic or composite at the beginning of aesthetic manufacturing. Archwires, on the other hand, are now made of metals like titanium molybdenum alloy, nickel-titanium, or stainless steel.[1] The demand for orthodontic appliances has risen sharply as the number of adult patients receiving care has increased, necessitating the use of so-called invisible orthodontic appliances such as aligners and lingual braces.[2]

Aesthetic archwires have rapidly developed in the last decade.[3,4] Archwire fabrics for aesthetic purposes are essentially combining two materials and can be divided into two categories: ceramic polymer composite and metal-polymer composite.[5]

Burstone et al.[6] (2011) introduced self-reinforced polymer polyphenylene thermoplastic archwires which

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showed a flexibility comparable to NiTi and beta-titanium archwires at thin cross-sections without experiencing stress relaxation. Aesthetic archeries have a core of a metallic wire coated with either tooth-colored polymer or inorganic materials to conceal the visibility of the underlying alloy and impart an enamel-like hue to the archwire.[7] Because of its outstanding adhesion, chemical resistance, electric insulation, and dimensional durability, epoxy resin is the most widely used coating material. Polytetrafluoroethylene (PTFE) coating is another popular aesthetic coating material. The PTFE coating is 0.001 inches thick.[8]

The color stability of the aesthetic archwires during an orthodontic procedure is clinically significant, and surface roughness plays a major role in discoloration.[9] Coated archwires have low aesthetic quality, according to Elaygan et al.[4] 25% of the coating is lost in vivo within 33 days and surface quality severely deteriorates. The authors have claimed that uneven surfaces could contribute to plaque accumulation and bracket entrapment within these defects which could affect tooth mobility.[10]

This research is aimed

1. To evaluate and compare the surface characteristics of four different aesthetic Nickel-Titanium orthodontic preformed rectangular archwires (0.016 x 0.022" NiTi) before and after oral exposure of four weeks.
2. To compare coating stability and surface roughness of the same wires which were ligated in the patient's mouth.

Therefore, the null hypothesis of this study is that there is no difference in the surface characteristics of four different aesthetic Nickel Titanium archwires before and after oral exposure of four weeks.

2. Materials and Methods

2.1. Study design

This study was a single centered multi-arm split-mouth randomized control trial with a 1:1:1:1 allocation ratio.

2.2. Sample size

Based on the data from Argalji N et al.[11] (power, 0.80; α= 0.05), the minimum sample size for the planned split-mouth design was calculated to be 52 quadrants (ie,13 per group), where each quadrant of a patient received a wire from a different manufacturer. We recruited 15 to account for losses to follow-up.

2.3. Methodology

Healthy patients with good oral hygiene and complete permanent dentition (mesial to first molars) between the age of 18-30 years with minimal crowding were selected from the orthodontic department of the Dental College and Research Centre. The institution's Ethical Clearance Committee (TMDCRC/IEC/SS/20-21/ORT01) granted ethical clearance. The trial (CTRI/2021/09/036946) had been registered with the National Trail Registry. All the patients were at leveling alignment phase of orthodontic treatment, bonded with the MBT bracket system (3M^{TM} Victory Series^{TM}). All the cavities were restored and periodontal condition was normalized in all patients before the commencement of any procedure related to the study. Patients with a history of smoking, systemic diseases, medication, allergies to accessories, and having poor oral hygiene were excluded. A test for nickel hypersensitivity was conducted while the patients were wearing NiTi archwires, and the results were negative. Patients who satisfied the inclusion criteria were informed about the procedure and encouraged to participate in the trial. Informed permission and informed assent were gained from consenting subjects. The fixed preadjusted Edgewise appliance MBT of 0.022" (3M unitek ^{TM} Gemini Metal Brackets) prescription was applied to all the patient.

2.4. Randomization and allocation

Using a block randomization technique, the four quadrants of each patient were randomly assigned to various archwire groups. The lead investigator was not involved in the randomization process. Block randomisation was used to achieve the required allocation ratio of 1:1:1:1. In the allocation sequence, the patients' quadrant numbers were utilised as input. The patients then selected the hidden sequences in sealed envelopes.

2.5. Participant flow

Randomization of four quadrants of each of the fifteen patients was done in a 1:1:1:1 ratio to either Group 1, Group 2, Group 3, or Group 4. Fifteen patients (mean age 22.36±2.43) were recruited from January 2021 to February 2021. On follow-up, Group I wire was missing in 2 patients, and a single wire was missing in Group II and Group IV in two individual patients (Figure 1).

2.6. Interventions

Anterior and posterior cut sections of four different aesthetic NiTi archwires from different manufacturers were used in the study (Table 1). The wires were grouped in such a way that the posterior section of a particular manufacturer formed an intervention group and the leftover anterior portion became its corresponding control group.

These straight posterior sections of 15 mm wires were piggy-backed with elastic modules on the pre-existing metal archwire extending from the distal side of the canine bracket up to the mesial side of the molar tube.

Table 1: Sample and characteristics of archwires used in the study.

Control Group	Experimental Group	Manufacturer	Wire Coating	Archwires	Sample size
Group Ic	Group I	BioForce	Teflon coated	Nickel-Titanium (0.016 x 0.022″)	15
Group IIc	Group II	Rabbit force	Epoxy Coated	Nickel-Titanium (0.016 x 0.022″)	15
Group IIIc	Group III	Libral	Teflon Coated	Nickel-Titanium (0.016 x 0.022″)	15
Group IVc	Group IV	ORMCO	Epoxy Coated	Nickel-Titanium (0.016 x 0.022″)	15

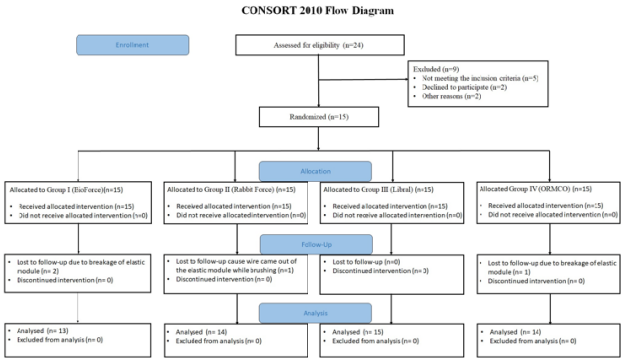

Figure 1: Flow diagram of the consolidated standards of reporting trials (CONSORT).

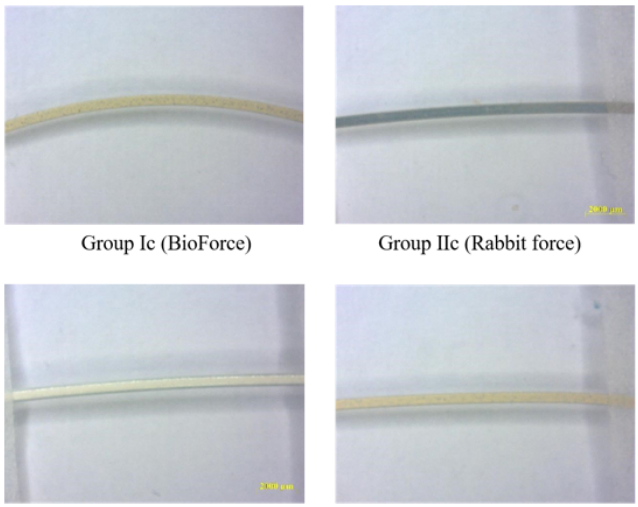

Figure 2: Images obtained from stereomicroscope of as-received aesthetic coatedarchwires (45x magnification).

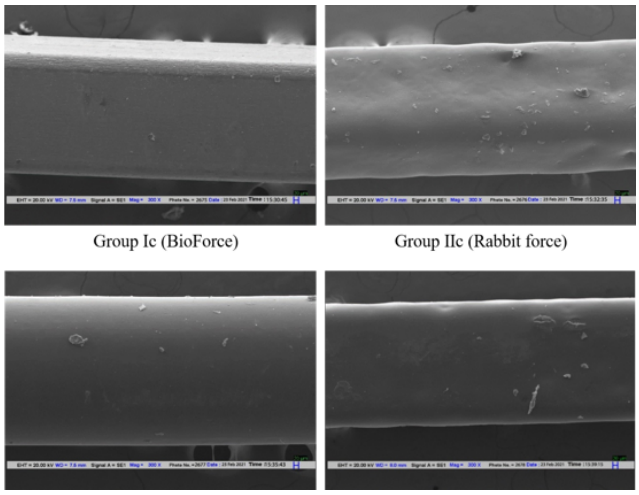

Figure 3: SEM images of as-received aesthetic coated archwires (300x magnification).

2.7. Measurement of coating stability

All the samples of wires were fixed over the slide with wax on both ends. Stereomicroscopic images were obtained for the same specimen (Figure 2). Thus, the 10 mm middle portion of each wire in the posterior segment was evaluated for coating thickness. The overall area of the wire and the area corresponding to the coating loss on the surface was obtained and calculated.

2.8. Scanning electron microscopy (SEM)

The micro morphological features of the archwires were evaluated using a SEM (Philips XL 30; Philips, Eindhoven, The Netherlands) at a magnification of 300x. For each wire, coating thickness was measured at four random points (Figure 3), and the mean value was evaluated. On the visual evaluation of SEM images of as-received wires (control groups), it was seen that Group IIc wire coating had larger surface defects. It showed a lot of surface elevations, which were dispersed as fields. Group IIIc showed a small number of grooves and very fine striations not parallel to the long axis of the wire. Group Ic had minor surface irregular defects with fine striations. Group IVc showed minor surface defects throughout its surface.

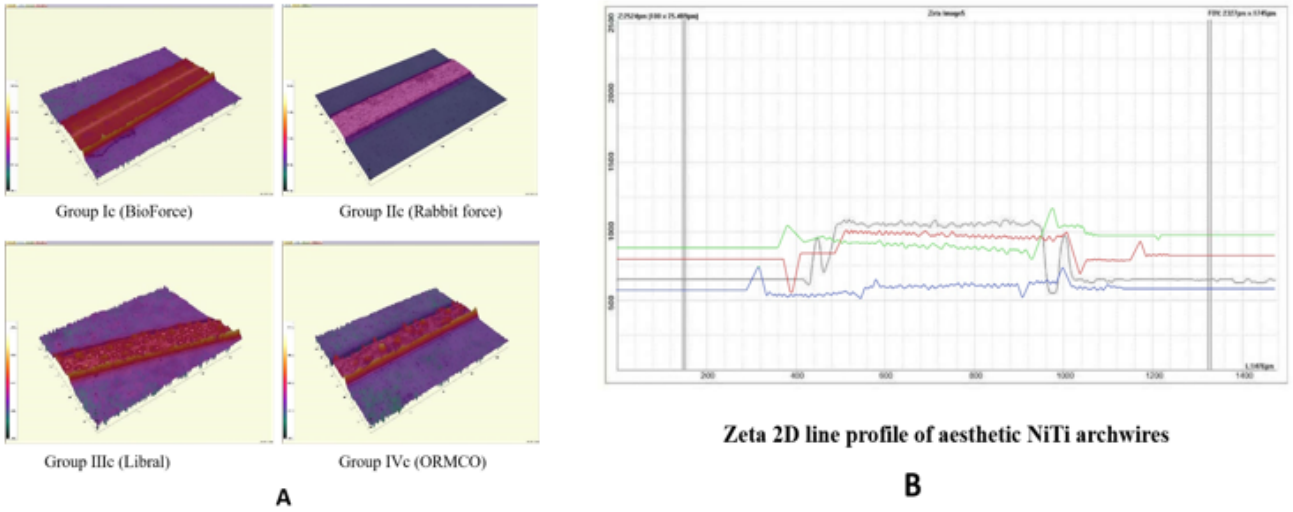

Figure 4: Step height analysis showing Ra via (A) 3D view of four different control group's wire; (B) Zeta 2D line profile of Group Ic (green), Group IIc (black), Group IIIc (red), Group IVc (blue).

2.9. Surface profilometry

The Ra (Surface Roughness) of each specimen was determined using a 3-dimensional surface profilometer (Wyko NT1100; Veeco, Tucson, Ariz) with Zeta-20 Optical Microscope (KLA Zeta 20 ZDot™ technology) that provides metrology and 3D imaging, in the as-received condition and after four weeks of intraoral exposure. The Zeta system scans a sample across a vertical (or Z) range that the user specifies. The Zeta Optics Module captures the XY location and the accurate Z height of the pixels at each Z position. A proper color 3D picture and a 2D composite picture are created using this data (Figure 4). The resultant image has a wide depth of focus, allowing the whole surface to be viewed clearly. The Ra of the wire at four different points was measured. The profilometric mean roughness was measured from the obtained values of the surface profile by the software.

2.10. Outcomes

The main outcome was the loss of coating thickness and a change in Ra. No changes to the study design were made after commencement. During the study, patients were recommended to clean their teeth with an extra-soft toothbrush and identical dentifrices, avoid chewing gum, fluoridated mouthwash, aerated drinks, or antibiotics.

2.11. Interim analyses and stopping guidelines

Not applicable.

2.12. Blinding

Double blinding was used to remove bias, however, blinding the investigator performing the clinical procedure was not feasible. As a result, the patients and the outcome evaluator were blinded.

3. Statistical Analysis

SPSS statistical analysis was used to interpret the obtained data (version 23.0; IBM Corp, Armonk, NY, USA). The Lilliefors test was used to ensure that the data distribution was normal. An independent t-test and one-way ANOVA test were used to calculate mean differences and check for significant variance among groups for normally distributed data. To compare the groups, Tukey's post hoc honestly significant difference test was performed. After four weeks, the same operator measured and checked coating thickness, surface topography, and Ra. The operator's calibration was validated by using the intraclass correlation coefficient (ICC) which was 0.91. The P=0.05 was considered significant in all of the above statistical tools.

4. Results

4.1. Number analyzed for each outcome

The intraoral exposure was 4 weeks for all intervention groups. The wire from all four intervention groups showed a denuded coating surface. As-received coated wires of each group were evaluated using a one-way ANOVA test for coating thickness, it was found to be significant. The maximum coating was seen in group IIIc, followed by Group IIc, then Group Ic, and least in Group IVc. On

Tukey's post hoc comparison, significant differences among groups were observed when Group IIIc was compared to Group IIc, Group Ic, and group IVc (Table 2).

The comparison of the coating thickness after four weeks of intraoral exposure was done using a one-way ANOVA test. It was found to be significant. On post hoc comparison, significant differences were seen among the groups. The maximum coating was seen in group IIIc, followed by group IV, then Group I, and least in Group II (Table 3 and Figure 5).

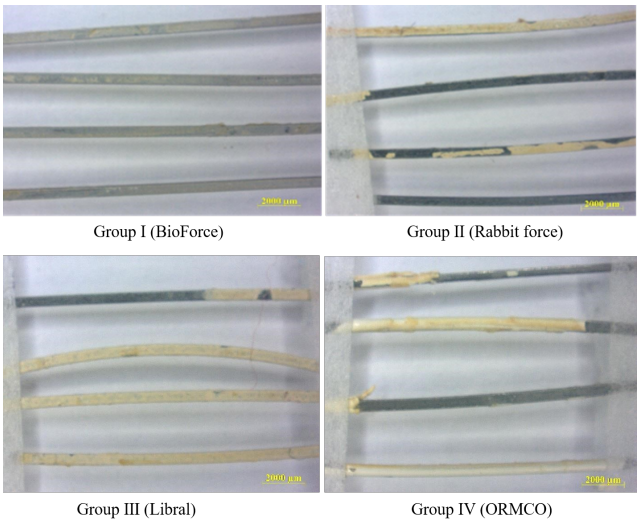

Figure 5: Stereomicroscopic pictures of aesthetic coatedarchwires at 45x magnification after oral exposure.

The following findings were obtained after evaluating coating loss in wires after four weeks of oral exposure (Table 4). The maximum coating loss was seen in wires of Rabbit Force group than the wires of BioForce, Libral group, and least in ORMCO group wires.

On visual inspection of SEM images after oral exposure of four weeks, it is seen that Group I wire has better surface topography than the other wires coating and shows only microcracks on the coated surface after exposure. Group II wires show evident cracks and many surface irregularities. It also shows large-sized striations. Group III wires show small destruction of coating regularity. Group IV shows some areas of coating loss exposing the underlying wire (Figure 6).

The comparison of Ra among the control groups and their corresponding intervention groups (4 weeks of oral exposure) was done using an independent t-test. It was found to be significant between Group II and Group IIc (P=0.010*), and non-significant among the rest of the groups (Table 5 and Figure 7).

After 4 weeks of intraoral exposure, the Ra of wires increased in all groups. When differences of Ra between control and corresponding interventional group wire of

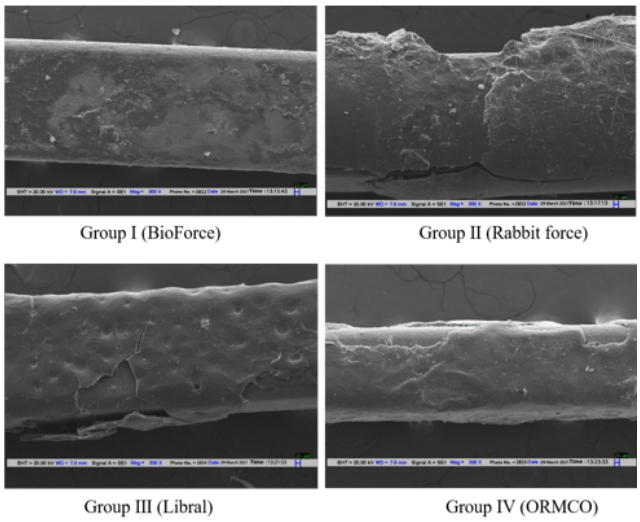

Figure 6: SEM images of different wires after oral exposure (magnification 300x).

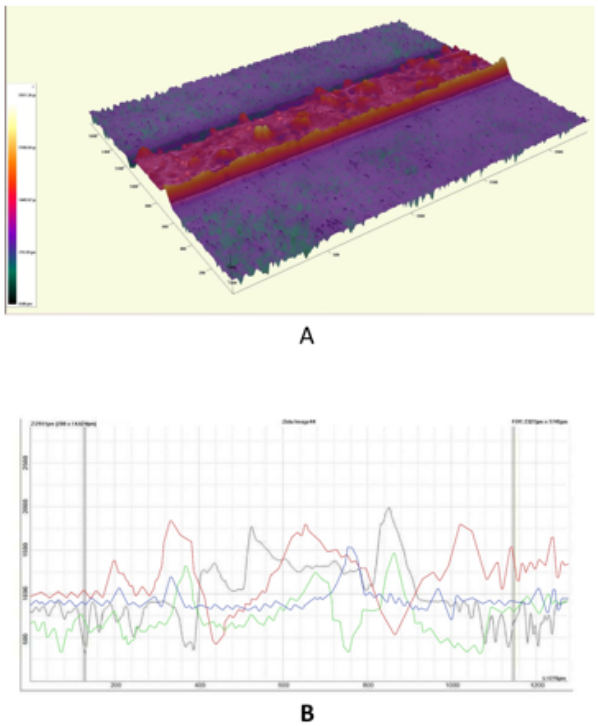

Figure 7: Image and graph produced by a 3D profilometer. A) A general view of wire after four weeks of intraoral exposure. B) Zeta 2D line profile after four weeks of intraoral exposure. Group I (green), Group II (black), Group II (red), Group IV (blue).

Table 2: Comparison of coating thickness among four Control groups of as-received wires using one-way ANOVA and post hoc.

	N	Mean (inches)	Std. Deviation	Std. Error	P-value	Tukey's Post hoc test
Group Ic	15	.0014582^{a}	.00014134	.00007752	<0.001*	Group IIIc> Group IIc, group Ic and Group IVc.
Group IIc	15	.0016282^{b}	.00015045	.00008563		
Group IIIc	15	.0025151^{abc}	.00023696	.00012541		
Group IVc	15	.0014442^{c}	.00011576	.00005113		

N represents the sample size of the control group (as-received)
* Level of significance at P< 0.05.
Different letters (a,b,c) in a row represent a statistically significant difference among groups.

Table 3: Comparison of the coating thickness among intervention groups (after 4 weeks of oral exposure) using one-way ANOVA and post hoc.

	N'	Mean (inches)	Std. Deviation	Std. Error	P-value	Tukey's Post hoc test
Group I	13	0.0011182^{a}	.00012546	.00005749	<0.024*	Group III> Group IV, GroupI, and Group II.
Group II	14	0.0010882^{b}	.00023818	.00015503		
Group III	15	0.0020051^{abc}	.00022419	.00013110		
Group IV	14	0.0011842^{c}	.00023529	.00015487		

N' represents samples retrieved after 4 weeks of oral exposure.
Different letters in a row represent a statistically significant difference among groups.
*Level of significance at P< 0.05.

Table 4: Comparison of coating thickness of as-received wires and after oral exposure for 4 weeks using independent t-test.

Control Group (As-received)				Intervention Group (4 weeks of intraoral exposure)				
	N	Mean (inches)	Std. Deviation		N'	Mean (inches)	Std. Deviation	P-value
Group Ic	15	.0014582	.00014134	Group I	13	.0011182	.00012546	0.258
Group IIc	15	.0016282	.00015045	Group II	14	.0010882	.00023818	0.011*
Group IIIc	15	.0025151	.00023696	Group III	15	.0020051	.00022419	0.105
Group IVc	15	.0014442	.00011576	Group IV	14	.0011842	.00023529	0.123

N represents the sample size of the control group (as-received
N' represents samples retrieved after 4 weeks of oral exposure.
* level of significance at P< 0.05.

Table 5: Surface roughness comparison of as-received wires and orally exposed wires within each group using independent t-test.

Control Group (As-received)				Intervention Groups (4 weeks of intraoral exposure)				
	N	Mean (μm)	Std. Deviation		N'	Mean (μm)	Std. Deviation	P-value
Group Ic	15	607.897	45.1019	Group I	13	684.8052	178.5906	0.610
Group IIc	15	579.191	48.563	Group II	14	1059.401	39.4581	0.010*
Group IIIc	15	709.305	0.1962	Group III	15	814.599	18.6088	0.142
Group IVc	15	614.698	28.8023	GROUP IV	14	633.924	22.4694	0.545

N' Represents the sample size of the control group (as-received
N' represents samples retrieved after 4 weeks of oral exposure.
* level of significance at P< 0.05

different manufacturers were statistically assessed with one-way ANOVA, a significant difference was found. Tukey's post hoc test revealed significant differences between groups. The maximum difference of Ra value was observed in the Rabbit force group wires, followed by the Libral and Bioforce group wires, and the lowest in the ORMCO group wires (Table 4).

4.2. Harms

No serious harms were observed.

5. Discussion

To evaluate and compare the surface characteristics of four as-received (Control group) aesthetic nickel-titanium orthodontic rectangular archwires (0.016 x 0.022′′ NiTi) from different manufacturers that are BioForce (Group I), Rabbit force (Group II), Libral (Group III), and ORMCO (Group IV) and after oral exposure (Experimental group) of four weeks, 15 patients meeting the inclusion criteria were recruited for this prospective study. Each quadrant employed the posterior segment from a certain manufacturer, and the remaining anterior section—which was undamaged and not used in the quadrant—became the corresponding control group. Scanning electron microscopy, stereo microscopy, and 3D profilometry were done for evaluating the surface characteristics of each group of wires.

The evaluation and comparision of the surface characteristics of four different aesthetic NiTi archwires (0.016 x 0.022" NiTi) were done and the results were compared with previous studies. The results of independent t-test for coating thickness showed, a significant change (P=0.011) was observed between Group II and Group IIc (Rabbit Force). The maximum coating loss was seen in Group II Rabbit Force (0.00054±0.000087′′), followed by Group III Libral (0.00051±0.00012′′), then the Group I BioForce (0.00034±0.00015′′) and least in Group IV ORMCO (0.00026±0.00014′′) shown in Table 4. These findings corroborate those of Elayyan et al.[4] who found that the coating was partly lost during clinical use.

On comparing Ra of as-received wires with corresponding orally exposed wires using an independent t-test, a significant difference was found between Group II and Group IIc (Rabbit Force) (P = 0.010*) and non-significant among other groups. The maximum Ra of as-received wires was observed in Group IIIc (709.305±0.1962μm), followed by group IVc (614.698±28.8023μm), then Group Ic (607.897±45.1019μm) and least in Group IIc (579.1910±48.563μm). After 4 weeks of oral exposure, maximum roughness was seen in Group II (1059.401±39.4581μm) and least roughness was seen in Group IV (633.924±22.4694μm) in Table 5 (Figure 7). All the wires after oral exposure showed an insignificant increase in the Ra when compared with the Ra of as-received from the different manufacturers except Group II. This observation is consistent with Wichelhaus et al.[12] findings.

Visual inspection of SEM images revealed that the surface defects in Group II Rabbit Force wire coating were more serious. It exhibited many surface irregularities. Group III wires had a limited number of significant defects and striations that were not parallel to the wire's long axis. Minor surface irregularities with fine striations characterize Group I wires. Group IV wires had small surface flaws all over the surface (Figure 6).

On comparing the mean difference of Ra of as-received wires and orally exposed wires among the four groups using one-way ANOVA and on applying Tukey's post hoc test still, the maximum roughness was seen in Rabbit force (480.210±92.304μm) and then least in ORMCO (19.226±30.08254μm) in Figure 7. After being orally exposed for four weeks, the wire with epoxy coated resin (ORMCO) was found to have the least Ra and coating loss, proving it to be a clinically efficient archwire since a rough surface encourages greater plaque accumulation, influences its friction properties (increases friction), increases root resorption, and may affect tooth movement due to entrapment of braces. When considering Ra, Alavi et al.[13] proposed that epoxy resin-coated archwires were better for both aesthetics and tooth movement. This substantiates our findings, which show that epoxy resin-coated wires have the least coating loss and Ra. Epoxy coated wires have the most significant Ra values, followed by Polytetrafluoroethylene wires, according to previous research.[14]

Ormco's Optiflex was the first aesthetic translucent non-metallic orthodontic mesh, with a silica base, silicone resin middle layer, and stain-resistant nylon outer layer[15] and subsequently developed an aesthetic wire containing S2 glass fibers embedded in a polymeric matrix, although these polymer-based aesthetic wires have an excellent appearance, they have not been clinically prevalent because of their brittle character.[16] On the other hand, metallic archwires coated with polymer materials, such as Teflon and epoxy resin, have also been developed.[17,18] Some authors have experienced difficulties with these coated archwires, claiming that the color tends to change with time and the coating splits during use in the mouth, exposing the underlying metal.[9,18,19]

6. Limitations

The segments of coated archwire used in the trial were not placed into the bracket slot, no wire deflection occurred as would be seen in leveling and aligning phase. Since aesthetic brackets were not employed in this study, future research should test aesthetic wires in conjunction with ceramic or plastic brackets, which would improve the

Table 6: Comparison of mean surface roughness differences of four groups of wire by one-way ANOVA and Tukey's Post hoc test.

	Mean (surface roughness difference between intervention and control group in μm)	Std. Deviation	Std. Error	P-value	Tukey's Post hoc
BioForce	76.907^{a}	15.453	5.50054	<0.001*	Rabbit Force > Libral, BioForce, and ORMCO
Rabbit Force	480.210^{abc}	92.304	29.10024		
Libral	105.294^{b}	14.04832	3.11548		
ORMCO	19.223^{c}	30.08254	6.99859		

Different letters in a row represent a statistically significant difference among groups.
*Level of significance set at P< 0.05.

therapeutic applicability of the findings. Another limitation of our study was that the clinical simulation in our study was inadequate since only fragments of wires were used instead of the complete archwires to test coating thickness and surface characteristics.

6.1. Generalizability

This study was conducted at a single center by a single clinician, the results may be restricted. Even the duration of oral exposure of wires in our study was shorter than the actual time during which orthodontic wires are clinically exposed to the oral environment. To improve generalizations, additional prospective clinical studies on diverse populations with complete archwire for a longer duration of oral exposure should be done.

7. Conclusion

We concluded that all the wires had low aesthetic values, as they presented a non-durable coating after oral exposure. On visual examination of the SEM images, there were variations in the aesthetic wires ranging from microcracks to large-sized striations, and overall destruction of coating regularity was also observed. Coinciding the orthodontic treatment duration, none of the aesthetic wires presented long term for clinical use as it needs to be changed very frequently. Maximum and minimum loss of coating thickness, either Epoxy or Teflon may be due to the manufacturing process.

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9. Declaration of Conflicting Interests

The author(s) declared no conflicts of interest with respect to the research, authorship, and/or publication of this article.

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