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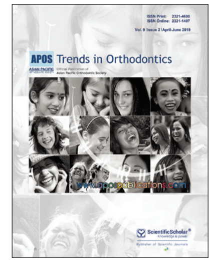

Original Article

Comparison of the frictional resistance and optical properties of aluminum oxide and zinc oxide coated nickel titanium archwires – An *in vitro* study

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ABSTRACT

Objectives: The friction that appears during sliding mechanics poses a clinical challenge to the orthodontist. The primary focus of an ideal tooth movement is to reduce the friction created at the archwire-bracket interface. Various variables (both biological and mechanical) affect the role of friction during orthodontic tooth movement. One among the variables which play a critical role is the archwire used in fixed mechanotherapy. Nickel-titanium (NiTi) archwires are widely used in clinical conditions due to their properties such as low force delivery and wider elastic working range. Innovations in the field of material science have led to the evolution of nickel titanium archwires with coating and surface modification to enhance the esthetics and decrease friction. Esthetics is of major concern in patients undergoing orthodontic treatment. As the esthetic demand keeps rising, the need for developing an esthetically acceptable material is required and it should not compromise on the clinical performance. The study aimed to evaluate and compare the frictional resistance and optical properties of ALUMINIUM oxide and zinc oxide-coated Ni-Ti archwires.

Material and Methods: The archwires were divided into three groups (n = 10), respectively: Group 1 – control group of uncoated NiTi archwires, GROUP 2 – zinc oxide coated NiTi archwires, and Group 3 – ALUMINIUM oxide coated NiTi archwires. The frictional resistance test was done using a universal testing machine, Instron, and optical properties were assessed using a colorimeter. The analysis of variance was used to determine whether a significant difference existed between the groups and a further *post hoc* Tukey test was used to determine the significant difference in the mean ($P < 0.05$).

Results: The two coated archwire groups – zinc oxide and ALUMINIUM oxide archwires showed a significant decrease in frictional resistance. Of the three groups, zinc oxide showed the least frictional resistance compared to the ALUMINIUM oxide-coated group and the uncoated group. Optical properties were calculated using the formula ΔE^*ab for the three groups. Of which zinc oxide coated archwires were closest to VA1 indicating that it matches the shade of the natural tooth while the other two groups did not match the tooth color implying that it is not much esthetic as that of zinc oxide coated archwires.

Conclusion: The zinc oxide-coated archwire resembles tooth color as well as has less frictional resistance compared to the other archwires.

Keywords: Orthodontic wire, Thin film coating, Friction, Esthetics, Orthodontics

INTRODUCTION

Fixed mechanotherapy in orthodontics involves a certain degree of sliding between the archwire bracket interface.[1] The friction present during sliding mechanics poses a challenge to the orthodontist due to the reason that the high level of friction decreases the mechanical efficiency, and desired tooth movement, and also complicates the control of anchorage. The primary goal of orthodontic tooth movement is to decrease friction at the archwire-bracket interface.[2]

Friction is a force that retards or resists the relative motion of two objects in contact.[2,3] Biologic tissue responses and tooth movement occur only when the forces are applied to overcome the friction efficiently at the archwire-bracket interface. The most desired and ideal condition is one in which little or no friction exists between bracket and wire.

Nickel-titanium (NiTi) archwires have been widely used in the clinical scenario because of delivering low force and a wide range of elastic working. Advances in the field of material science have led to the evolution of nickel titanium archwires with coating and surface modification to enhance the esthetics and decrease friction.[4]

The demand for esthetics is constantly increasing, requiring the development of materials that provide acceptable esthetics for patients while also providing adequate clinical performance for clinicians. To maintain the desirable properties of NiTi and to improve esthetics, many coatings have been developed. Several properties and characteristics should be considered in the search for an ideal archwire. Esthetics and friction play a major role in the properties of an ideal archwire.[5]

ALUMINIUM and its alloys possess properties such as low density, electric and thermal conductivity, high strength, and non-magnetic characteristics. Because of their excellent properties in terms of chemical inertness, mechanical strength, hardness, transparency, high abrasive, and corrosion resistance, as well as insulating and optical properties, ALUMINIUM oxide thin films are widely used in many mechanical, optical, and microelectronic applications.[6,7] Zinc oxide-coated archwires addressed the increased demand for esthetics by the property of color, reduction in friction, and antibacterial activity.[8]

In recent times, ALUMINIUM oxide and zinc oxide thin film coatings have been used in metallurgical science as a means of reducing friction in the engineering field. Therefore, the purpose of this study was to evaluate and compare the frictional resistance and optical properties between aluminum oxide and zinc oxide thin film-coated and uncoated NiTi archwires.

MATERIAL AND METHODS

This study consisted of 0.016” NiTi archwires (ORMCO, Chennai, Tamil Nadu, India) in which the coating of archwires is carried out with zinc oxide and ALUMINIUM oxide against the bracket (Gemini series 3M Unitek MBT 0.022” slot, preadjusted edgewise, Chennai, Tamil Nadu, India). A total sample of 30 archwires was divided into three groups comprising 10 archwires in each group: Group 1 denotes uncoated archwires, Group 2 – zinc oxide coated archwires, and Group 3 – ALUMINIUM oxide coated archwires.

Approval for the study design was obtained from the institutional review board – SRMDC/IRB/2019/MDS/No. 103.

Coating procedure

In all the experimental cases before the coating process, the dental alloys were pre-treated/cleaned with Deionized DI water + Ethanol at 80°C for 30 min to get rid of the debris over the surface.

The hydrothermal technique was employed for the thin film layer coating over the surface of the dental accessories.

Zinc oxide and ALUMINIUM oxide thin film coating

For the synthesis of dental NiTi alloy coated zinc oxide (ZnO) and ALUMINIUM oxide nanoparticles, the hydrothermal method was chosen. For 30 min, 0.8 g zinc nitrate solutions and 0.8 g $Al(NO_3)_3$ solutions were prepared separately in 30 ml distilled water while stirring. Meanwhile, 0.4 g of trisodium citrate $Na_3C_6H_5O_7$ solutions were prepared in 100 ml of distilled water while stirring for the same amount of time. Under continuous stirring, $Na_3C_6H_5O_7$ solution is added dropwise to the former solution until the pH of the reactants reaches 10.9. This solution mixture was transferred into Teflon-lined sealed stainless-steel autoclaves containing the dental NiTi alloy and kept in a hydrothermal oven at 90°C for 8 h [Figure 1]. The beaker was then taken outside and allowed to cool naturally at room temperature. The resulting product, dental NiTi alloy coated with zinc oxide and ALUMINIUM oxide separately, was then washed with distilled water and allowed to dry at room temperature.[6,9]

Field emission scanning electron microscope

The archwires which are coated with zinc oxide and ALUMINIUM oxide were confirmed using a field emission scanning electron microscope (Jeol FESEM, Indian Institute of Technology Jammu, India). The uniformity of the coating was confirmed with a uniformity of 1 μm [Figure 2].

Frictional resistance test

A rectangular acrylic plate of size 4 cm wide × 14 cm long × 0.5 cm thick was taken and a notch of size 1.5 cm long × 1.2 cm wide was placed 2 cm from one of the ends. Four

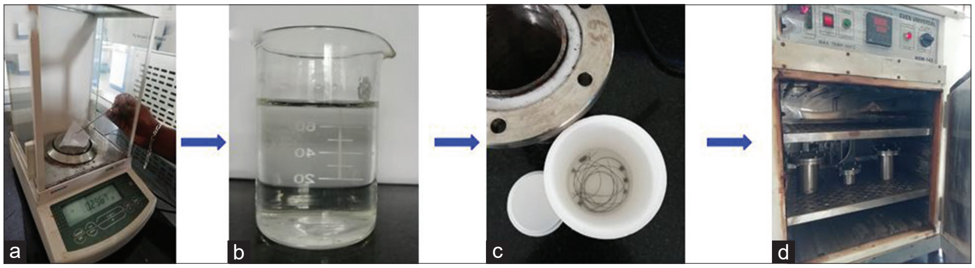

Figure 1: Thin film coating (a) ALUMINIUM oxide coating – 0.8 g $Al(NO_3)_3$+0.4 g $Na_3C_6H_5O_7$/Zinc oxide coating – 0.8 g Zn(NO?)? + 0.4 g $Na_3C_6H_5O_7$, (b) ALUMINIUM oxide/zinc oxide mixture + 100 ml of DI H_2O for stir in room temperature (pH = 10.9), (c) mixed solution + Dental NiTi alloy in Autoclave, and (d) 90°C for 8 h in a muffle furnace.

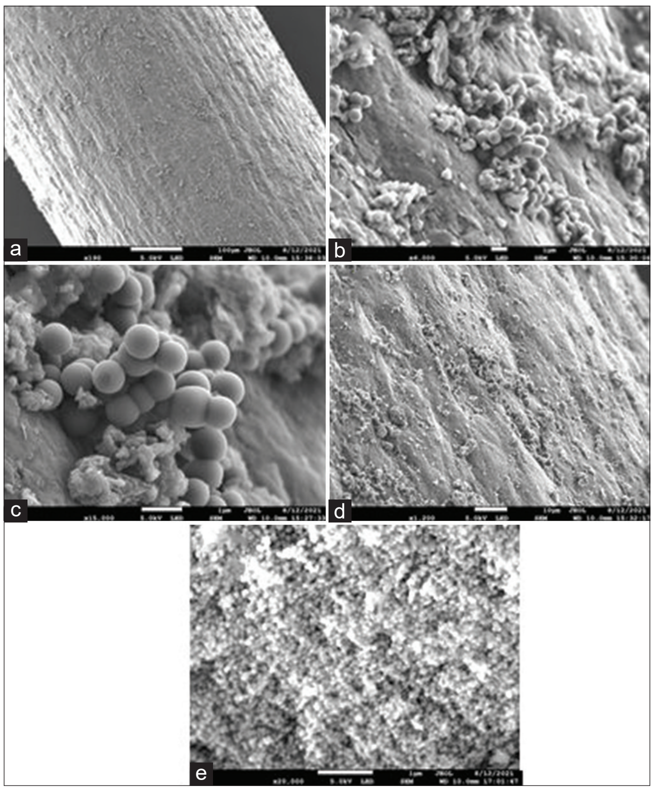

Figure 2: FESEM for zinc oxide and ALUMINIUM oxide thin film coating (a) zinc oxide thin film coating at ×190, (b) zinc oxide thin film coating at ×6000, (c) zinc oxide thin film coating at ×15,000, (d) ALUMINIUM oxide thin film coating at ×1200, and (e) ALUMINIUM oxide thin film coating at ×20,000.

upper premolar metallic brackets (3M Jamuna international, Chennai, Tamil Nadu, India) (MBT edgewise prescription, 0.022” × 0.028” slot) were placed on the acrylic plate and fixed at a distance of 0.8 cm between each bracket and 1.6 cm from the notch. The brackets are fixed to the acrylic plate with the help of cyanoacrylate.

A 0.019” × 0.025” stainless steel wire was placed such that the bracket base was parallel to the acrylic plate before bonding and is removed after polymerization for maintaining all the brackets at the same level.

The test wire of 0.016 inch NiTi wires of length 5 cm was used for the frictional test. To prevent the sliding of the archwires through the bracket slots, the end of the archwires was bent to fit the acrylic plate’s terminal brackets. Each archwire was tied with ligature wires to the brackets and replaced after each test [Figure 3].

The universal testing machine was used to measure the frictional resistance test. The acrylic plate with the archwires to be tested is positioned on the universal testing machine (CIPET, Chennai, Tamil Nadu, India). To perform the frictional test on the archwire, one end of the wire was attached to the bracket and the other end to the system by use of a claw. The test was carried out by moving the wire at 1.0 mm/min with a load of 500 N under the tensile strength [Figure 4].

Optical properties test

The optical properties of the archwires are tested using a colorimeter (VITA EASYSHADE ADVANCE 4.0, Chennai, Tamil Nadu, India). To assess the archwires in colorimeter, the sample should have a minimum width of 3 mm to determine the color of the archwire accurately. For testing the optical properties, a minimum of six NiTi archwire samples were taken and mounted on the tightly rolled utility wax. The measuring tip of the optical sensor was kept perpendicular to the archwire samples and the colorimetric recordings were noted.

The color parameter was based on the Commission Internationale de l’Eclairage (CIE) L*a*b* color space system. L* denoted lightness, a* for red-green hue, and b* for yellow-blue hue in the three-dimensional color system representing the three axes in the color space. The L*-axis represents the brightness, which increases as the value of L* increases, the value of a* denotes the degree of redness (+a*) or greenness (-a*), and the value of b* denote the degree of yellowness (+b*) or blueness (-b*) of an object. Values for L*, a*, and b* were obtained from the colorimeter.

As the tooth color varies in each individual, the samples were compared with the A1 shade guide as a reference as it is the brightest color in the VITA shade guide. The colorimetric measurement of the reference (VA1) was assessed by placing the tip of the optical sensor on the labial surface of the shade guide. The values were recorded 3 times at three different sites – right, left, and center of the archwire and the average value was noted.

The color differences between the archwire and reference (ΔE^*ab) were calculated using the formula:

$\Delta E^*ab=((\Delta L^*)^2+(\Delta a^*)^2+(\Delta b^*)^2)^{1/2}$.

Furthermore, to correlate the degree of color difference to the clinical environment, the obtained values were converted to National Bureau of Standards (NBS) units using the following formula: NBS units=$\Delta E^*ab \times 0.92$.

Statistical analysis

Descriptive statistics for frictional resistance and optical properties including mean, standard deviation, minimum, and maximum values were calculated for each of three groups of archwires. The analysis of variance (ANOVA) was used to see if there were any significant differences between the groups. The *post hoc* Tukey test was used to determine the significance of the mean difference.

Figure 3: Acrylic plate assembly for frictional resistance test.

Figure 4: Frictional resistance test using a universal testing machine.

RESULTS

Test for evaluating frictional resistance

The frictional resistance between the archwires and brackets was analyzed using the universal testing machine, Instron. The values of frictional resistance in Newton were recorded and tabulated. [Table 1] shows the calculated mean and standard deviation of frictional resistance in uncoated archwires, ALUMINIUM oxide, and zinc oxide-coated archwires. [Table 2] represents the intra and intergroup differences in friction between the three groups (uncoated, zinc oxide coated, and ALUMINIUM oxide coated archwires) using one-way ANOVA analysis. The one-way ANOVA shows a significant difference between coated and uncoated groups. The statistical analysis performed between groups shows a significant reduction in friction between coated and uncoated archwires with $P < 0.05$. This study shows the decrease in friction in the following order – control group>ALUMINIUM oxide group> zinc oxide group. [Table 3] shows the results of *post hoc* Tukey analysis exhibiting a significant difference in frictional resistance among each group against each of the other groups.

Test to evaluate optical properties

The optical properties of uncoated, zinc oxide-coated, and ALUMINIUM oxide-coated archwires were compared in

Table 1: Descriptive data showing the mean and standard deviation of frictional resistance (N) of the control group, ALUMINIUM oxide, and zinc oxide coated archwires with a 95% confidence interval.

	Frictional resistance Mean	SD	Std. Error	*P*-value
Control	5.5300	0.14862	0.04700	0.0001
Al.Oxide	4.5500	0.18741	0.05927	
Zn.Oxide	3.7333	0.05443	0.01721	

Table 2: Analysis of variance between the three groups of uncoated archwires, zinc oxide coated, and ALUMINIUM oxide coated archwires.

	Sum of squares	Df	Mean square	F	Significance
Between groups	16.185	2	8.092	403.451	0.000
Within groups	0.542	27	0.20		
Total	16.726	29			

Table 3: *Post hoc* Tukey test.

(I) Group 2	(J) Group 2	Mean Difference (I-J)	P value	95% Confidence Interval	
				Lower Bound	Upper Bound
Control	Al.Oxide	0.98000*	0.000	0.8230	1.1370
	Zn.Oxide	1.79667*	0.000	1.6396	1.9537
Al.Oxide	Control	−0.98000*	0.000	−1.1370	−0.8230
	Zn.Oxide	0.81667*	0.000	0.6596	0.9737
Zn.Oxide	Control	−1.79667*	0.000	−1.9537	−1.6396
	Al.Oxide	−0.81667*	0.000	−0.9737	-0.6596

*Significant difference

Table 4: Comparison of optical properties between groups at various sites.

Site	Group	ΔE*ab Mean	SD	P value
Left	Control	12.112759	1.8845705	0.0001
	Al.Oxide	43.767087	1.1611014	
	Zn.Oxide	66.333333	1.1547005	
	VA1	69.103641	1.0393642	
Right	Control	15.707931	3.0661604	0.0001
	Al.Oxide	48.637570	2.1000545	
	Zn.Oxide	67.000000	1.7320508	
	VA1	69.103641	1.0393642	
Centre	Control	17.963027	1.9142796	0.0001
	Al.Oxide	46.744760	1.2292794	
	Zn.Oxide	68.333333	0.5773503	
	VA1	69.103641	1.0393642	

this study. [Table 4] represents the colorimetric values of each wire on three different sides (right, left, and center) and shade guide (VA1) that were recorded and calculated with the formula $\Delta E^*ab=((\Delta L^*)^2+(\Delta a^*)^2+(\Delta b^*)^2)^{1/2}$.

The mean and standard deviation were calculated using one-way ANOVA analysis which exhibited a significant difference in optical properties between the groups. Further, the significant difference between the group with each other was calculated using the *post hoc* Tukey test. The *post hoc* Tukey test revealed a significant difference in optical properties among each group and against each of the other groups except between Zn Oxide and VA1 group.

[Table 5] represents the converted values of ΔE*ab values according to the NBS units which relates how much the color difference to a clinical environment. Lesser the value, the lesser the difference in color to the reference guide VA1. The zinc oxide group value was significantly lower than other groups.

DISCUSSION

The orthodontic tooth movement is influenced by the ability of wires to slide through brackets and buccal tubes.[10] Friction mechanics thus play a role in the closure of interdental spaces during the alignment and leveling phase of the tooth movement.[11] The resistance to tooth movement increases significantly as a result of the frictional force generated, resulting in increased anchorage demands and a longer treatment time. The intensity of the frictional forces is dependent on the properties and surfaces of the orthodontic materials.[12] Advances in the field of material science have led to the evolution of nickel titanium archwires with coating and surface modification to enhance the esthetics and reduce friction. For instance, as the thickness of the coating material increases, so does the friction. As a result, the esthetic wires' coating layer should ideally be of uniform thickness. A slight change in thickness can result in significant changes in the force system.[13]

In recent times, the demand for esthetics in adult patients is been increasing in the field of orthodontics, which lead to more innovations in brackets and archwires. Newer esthetic wires coated partially or totally with Teflon, epoxy resin, glass fiber-reinforced polymer, and silicon fiber-reinforced nylon are now available.[14] While these aesthetic wires improve the aesthetics of orthodontic appliances, they do have drawbacks, such as increased friction during mechanical archwire sliding.[15]

ALUMINIUM oxide and zinc oxide thin film coatings are currently used in metallurgical science as a means of reducing friction in the engineering field. Many coatings have been developed to sustain the desirable properties of NiTi while improving the esthetics. Various properties and characteristics should be considered in search of an ideal archwire with esthetics and friction playing a significant role.

Due to their excellent chemical inertness, mechanical strength, hardness, transparency, high abrasive and corrosion resistance, as well as insulating and optical properties, ALUMINIUM oxide thin films are widely used in many mechanical, optical, and microelectronic applications.[6,7] Zinc oxide-coated archwires addressed the increased demand for esthetics by their properties of color, reduction in friction, and antibacterial activity.[8]

Table 5: Comparison of optical properties among each group against each of the other groups at various sites.

Dependent Variable	(I) Group	(J) Group	Mean Difference (I-J)	*P*-value
Left	Control	Al.Oxide	−31.6543280*	0.000
		Zn.Oxide	−54.2205744*	0.000
		VA1	−56.9908817*	0.000
	Al.Oxide	Control	31.6543280*	0.000
		Zn.Oxide	−22.5662464*	0.000
		VA1	−25.3365537*	0.000
	Zn.Oxide	Control	54.2205744*	0.000
		Al.Oxide	22.5662464*	0.000
		VA1	−2.7703073	0.133
	VA1	Control	56.9908817*	0.000
		Al.Oxide	25.3365537*	0.000
		Zn.Oxide	2.7703073	0.133
Right	Control	Al.Oxide	−32.9296383*	0.000
		Zn.Oxide	−51.2920687*	0.000
		VA1	−53.3957093*	0.000
	Al.Oxide	Control	32.9296383*	0.000
		Zn.Oxide	−18.3624304*	0.000
		VA1	−20.4660710*	0.000
	Zn.Oxide	Control	51.2920687*	0.000
		Al.Oxide	18.3624304*	0.000
		VA1	−2.1036406	0.633
	VA1	Control	53.3957093*	0.000
		Al.Oxide	20.4660710*	0.000
		Zn.Oxide	2.1036406	0.633
Centre	Control	Al.Oxide	−28.7817325*	0.000
		Zn.Oxide	−50.3703059*	0.000
		VA1	−51.1406132*	0.000
	Al.Oxide	Control	28.7817325*	0.000
		Zn.Oxide	−21.5885734*	0.000
		VA1	−22.3588807*	0.000
	Zn.Oxide	Control	50.3703059*	0.000
		Al.Oxide	21.5885734*	0.000
		VA1	−0.7703073	0.880
	VA1	Control	51.1406132*	0.000
		Al.Oxide	22.3588807*	0.000
		Zn.Oxide	0.7703073	0.880

*Significant difference

Table 6: ΔE*ab value was converted to NBS units.

Wire name	ΔE*ab	NBS units
Uncoated archwire	51.4	47.288
ALUMINIUM oxide coated archwire	22.35	20.562
Zinc oxide coated archwire	0.77	0.7084

NBS: National Bureau of Standards

The results of the present study showed that the highest frictional resistance was seen in the uncoated group (5.53 N) followed by the ALUMINIUM oxide group (4.55 N) and least by the zinc oxide group (3.73 N). A statistically significant reduction in friction was observed in the zinc oxide group and ALUMINIUM oxide group when compared to the control group ($P < 0.05$).

A study conducted by Hammad *et al.* which they had used zinc oxide coating on 0.016” × 0.022” archwire and reduced frictional resistance by 34% compared to the non-coated wires.[16] Kachoei *et al.* stated that zinc oxide coatings done on 0.019” × 0.025” SS reduced mean frictional forces in archwires by 39%, had better anchorage control, and reduced the treatment duration and risk of root resorption.[17] This study correlates with the above previous study in which the reduction of frictional resistance of zinc oxide coating by 32%.

Arici *et al.* found that the ALUMINIUM oxide coatings were resistant to intraoral conditions and the frictional resistance for metal brackets combined with round NiTi was decreased by the ALUMINIUM oxide coating.[18] This study simulated bodily tooth movement and the sliding of a bracket along an archwire. In this study, ALUMINIUM oxide coating reduced friction by 20%.

The reason for choosing zinc oxide and ALUMINIUM oxide coating for this study was because zinc oxide also has additional properties such as antibacterial properties and ALUMINIUM oxide has corrosion resistance properties. The advantage of nickel-titanium was that it has shape memory, pseudoelasticity, and low load deflection rate but the biggest disadvantage remains its high friction. The results of this study clearly show a significant reduction in friction by both the thin film coatings. Thus, thin-film coatings can be a boon to orthodontics.

The study also focuses on optical properties between the archwire and the tooth as a demand of resolving the esthetic issues associated with the orthodontic attachments.

Zinc oxide-coated archwires (ΔE^*ab = 68.33) were not statistically significant with the reference shade group (ΔE^*ab = 69.1), indicating that they synchronize with the shade guide and resemble the tooth color. The ALUMINIUM oxide coated (ΔE^*ab = 46.74) and an uncoated archwire (ΔE^*ab = 17.96) showed statistically significant differences with the reference indicating marked color differences to that of the natural tooth. The color difference values were converted to NBS units which inferred that zinc oxide coated archwires (0.77) were more esthetic with slight changes when compared to the uncoated group (51.4) and ALUMINIUM oxide coated archwires (22.35) which were not esthetic with extremely marked changes.

Various studies have focused on improving esthetics using several coatings on the archwires to accomplish the demands of the patient with reduced friction. Although ALUMINIUM oxide coatings have shown less frictional resistance, they still have marked color differences and can be used in contemporary orthodontics with metal brackets. Zinc oxide coatings on archwire exhibited the least frictional resistance as well as matched the esthetic needs, thereby possibly being a newer promising material in the field of orthodontics.

CONCLUSION

- The frictional resistance was least in the zinc oxide thin film coated archwire group followed by the ALUMINIUM oxide group and the highest frictional resistance was exhibited by the uncoated group
- The zinc oxide group archwires had the best optical properties followed by the ALUMINIUM oxide group and then by the uncoated group.

Declaration of patient consent

Patient's consent not required as there are no patients in this study.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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