ORIGINAL RESEARCH

The Effect of Three Metal Oxide Nanocoatings on the Frictional Resistance of Superelastic Orthodontic Archwires: A Comprehensive *In vitro* Analysis

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Abstract

Aim and objective: To evaluate and compare the impact of nanocoatings made of oxides of Aluminum, Titanium, and Zirconium, on the frictional resistance on three types of superelastic orthodontics archwires namely; nickel titanium, copper nickel titanium and low hysteresis nickel titanium.

Materials and methods: There are 120 archwire segments of equal dimensions were divided into four groups ($n = 30$) with 10 samples each of low hysteresis superelastic archwires; NiTi archwires and CuNiTi archwires. While group A were uncoated, other groups were nanocoated with group B: Aluminum oxide; group C: Titanium dioxide; group D: Zirconium oxide respectively. Upper premolar metal brackets MBT 0.022 slot were used for testing. The frictional properties of the archwires were measured using a Universal testing machine equipped with a custom-made jig. Statistical tests including analysis of variance and *post hoc* tests were used for analysis.

Results: The least frictional resistance among the three types of archwires was seen with low hysteresis (L&H) NiTi wires coated with ZrO_2 (3.1253 ± 0.45822 *N*) and the highest with uncoated CuNiTi archwires (7.1113 ± 1.29031 *N*). Among the nanocoatings, the least value was found for ZrO_2 nanocoatings followed by TiO_2, $Al2O_3$ and highest with uncoated archwires across all three types of archwires.

Conclusion: Low hysteresis NiTi have the least frictional resistance compared to CuNiTi and NiTi archwires. The findings also suggest that all the three metal oxide nanocoatings reduce frictional resistance significantly, among which, ZrO_2 nanocoatings were the most effective. This study underscores the potential efficacy of metal oxide nanocoatings in reducing archwire friction and, consequently, will improve orthodontic treatment efficiency and patient comfort.

Keywords: Friction, Metal oxide, Nanocoating, Nanoparticles, Superelastic archwires.

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Introduction

The effectiveness of orthodontic treatment largely depends on the performance of archwires, which play a crucial role in facilitating tooth movement and ensuring patient comfort. Superelastic archwires, are basically some form of nickel-titanium (NiTi) alloys, which are extensively utilized owing to their exceptional properties, such as shape memory and superelasticity. Nevertheless, the frictional resistance experienced by these wires within the brackets can hinder their efficacy, resulting in prolonged treatment durations and patient discomfort. Therefore, improving these archwires' mechanical qualities through reduction of frictional resistance is one of the major priorities in orthodontic research.

Low hysteresis NiTi archwires is a relatively new archwire. The supposed benefit of this wire includes a stress-induced martensite formation which might reduce the stiffness and thus could be beneficial to decrease the binding friction during sliding with large bending deflections.[1]

Metal oxide nanocoatings have shown promising results in enhancing the properties of orthodontic archwires. Studies have evaluated the impact of nanocoatings on archwire surfaces, frictional properties, load-deflection rates, and mechanical characteristics. According to research, titanium dioxide (TiO_2) nanoparticles perform better on the surface and have lower frictional coefficients when submerged in water or dry conditions.[2] However, the effectiveness of nanotechnology-based orthodontic materials, including metal oxide nanocoatings, on friction requires further investigation to confirm their sustained benefits.[3] Additionally, zirconium oxide (ZrO_2) nano-coating has been explored, showing some efficacy in reducing the frictional resistance.[4] Studies on several types of archwires—including multistranded axial stainless steel, thermal NiTi, and superelastic NiTi—have shown differences in load-deflection rates. Heat-activated NiTi wires are most suited for particular clinical situations.[5] Overall, using metal oxide nanocoatings on orthodontic archwires presents a promising avenue for improving their mechanical properties and performance during orthodontic treatment.

Recent strides in nanotechnology have opened up the possibility of nanocoating archwires with various metal oxides to

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Table 1: ANOVA for evaluation of friction between the groups

Group description	*N*	*Mean*	*Std. deviation*	*Std. error*	*95% Confidence interval for mean*		*Minimum*	*Maximum*
					Lower bound	*Upper bound*		
NiTi uncoated metal	10	7.0060	0.83355	0.21522	6.5444	7.4676	5.27	8.66
CuNiTi uncoated metal	10	7.1113	1.29031	0.33316	6.3968	7.8259	4.55	9.23
L&H NiTi uncoated metal	10	5.1473	1.37272	0.35444	4.3871	5.9075	2.66	7.66
NiTi aluminum oxide coated metal	10	5.6793	1.08464	0.28005	5.0787	6.2800	4.25	7.70
CuNiTi aluminum oxide coated metal	10	6.6113	1.64546	0.42486	5.7001	7.5226	3.50	8.95
L&H NiTi aluminum oxide coated metal	10	5.1367	1.99256	0.51448	4.0332	6.2401	2.18	8.46
NiTi titanium oxide coated metal	10	5.6267	1.25191	0.32324	4.9334	6.3199	3.86	7.52
CuNiTi titanium oxide coated metal	10	5.8940	1.79466	0.46338	4.9002	6.8878	3.28	9.26
L&H NiTi titanium oxide coated metal	10	4.3240	0.99798	0.25768	3.7713	4.8767	3.10	6.09
NiTi zirconium oxide coated metal	10	4.9953	1.44417	0.37288	4.1956	5.7951	2.61	7.46
CuNiTi zirconium oxide coated metal	10	5.4027	1.52733	0.39436	4.5569	6.2485	3.14	7.76
L&H NiTi zirconium oxide coated metal	10	3.1253	0.45822	0.11831	2.8716	3.3791	2.34	3.89
Total	240	7.9834	3.14064	0.16553	7.6579	8.3089	2.18	15.11

enhance their performance. Very few studies have been done on nanocoating of superelastic archwires. No previous studies have studied the effect of nanoparticles on the low hysteresis archwires. Therefore, by comparing the frictional resistance of uncoated NiTi and CuNiTi and low hysteresis (L&H) titan archwires with those nanocoated with the three metal oxides, this research aims to identify the most effective coating material for enhancing archwire performance.

Materials and Methods

The study was done in Chennai, Tamil Nadu, India in the year 2023 after obtaining Institutional Board Clearance.

There are 120 archwire segments of equal dimensions (0.016 × 0.022 inches, Ormco, Brea, CA, USA) and length (10 cm) were divided into four groups (n = 30) with 10 samples each of low hysteresis superelastic archwires (L&H Titan; Tomy Inc., Tokyo, Japan); NiTi archwires (Ormco, Brea, CA, USA) and CuNiTi archwires (Ormco, Brea, CA, USA). While group A were uncoated, other groups were nanocoated with group B: Aluminum oxide; group C: Titanium dioxide; group D: Zirconium oxide respectively.

The nanoparticles used for coating in the study were <50 nm in particle size. The distal ends of the archwires were cut into 10 cm segments, washed thoroughly with ethanol under ultrasonication at 450 HZ for 5 min. Nanoparticle suspensions of 10 mg/100 mL of the three coating were prepared in 0.1% Chitosan and 1 mL glycerol with 10 mL isopropanol. The nanocoating was done using a combination of dip coating with ultra-sonification followed by heat drying method. The wire segments were then inserted into the nanoparticle suspension and kept under ultra-sonication for 10 cycles. This was followed by a process of drying in oven at 200°C for 1 hour. Samples from each group of archwire were verified using FESEM and SEM EDX for the nanocoating.

The frictional resistance between archwires and brackets was assessed using the testing apparatus, which replicated the dynamic conditions of the oral cavity. A customized jig was made consisting of five upper premolar metal brackets (Ormco, Brea, CA, USA) attached to an acrylic plate using cyanoacrylate glue. The distance between the brackets was 10 mm to mimic the inter-bracket distance. All the brackets were secured with 19 × 25 Stainless-steel archwires to maintain the alignment before attaching to the plate. The bracket in the center alone was offset by 3 mm to simulate crowding in the arch.

Prior to testing, the archwires were sterilized using isopropyl alcohol and dried with compressed air. The frictional properties of the archwires were measured using the universal testing machine (Instron, Norwood, MA, USA). A 50 gm load was applied to each archwire and the frictional force was measured as the archwire was pulled through the brackets at the rate of 0.5 mm/min.

Kruskal-Walli's test followed by Dunns *post hoc* test was performed using SPSS software, to compare the frictional resistance among the three uncoated archwires groups (NiTi, CuNiTi and Low hysteresis NiTi archwires). The same tests were reciprocated for the remaining groups (with Al_2O_3, TiO_2, and ZrO_2 coatings). An overall p-value of less than 0.05 considered as statistically significant.

Results

In group A, L&H NiTi archwires showed the lowest frictional force (5.1473 ± 1.37272 *N*) followed by NiTi archwires (7.0060 ± 0.83355 *N*). Uncoated CuNiTi archwires showed the highest frictional force (7.1113 ± 1.29031 *N*) (Table 1). *Post hoc* intergroup comparison showed that the difference in the frictional resistance values between uncoated NiTi archwires and uncoated CuNiTi archwires groups was not statistically significant whereas the values of uncoated L&H NiTi archwires was statistically significant from the other two groups (Table 2).

In group B, Al_2O_3 coated CuNiTi archwires (6.6113 ± 1.64546 *N*) showed the highest frictional force followed by Al_2O_3 coated NiTi archwires (5.6793 ± 1.08464 *N*). Al_2O_3 coated L&H NiTi archwires (5.1367 ± 1.99256 *N*) showed the least frictional force (Table 1). *Post hoc* intergroup comparison showed that the difference in the frictional resistance values only between Al_2O_3 coated CuNiTi archwire and Al_2O_3 coated L&H NiTi archwire was statistically significant (Table 3).

In Group C, TiO_2 coated CuNiTi archwires (5.8940 ± 1.79466 *N*) showed the highest frictional force followed by TiO_2 coated NiTi archwires (5.6267 ± 1.25191 *N*). TiO_2 coated L&H NiTi archwire (4.3240 ± 0.99798 *N*) showed the least frictional force (Table 1). *Post hoc* intergroup comparison showed that the difference in the frictional resistance values only between TiO_2 coated L&H NiTi archwire with that of both NiTi and CuNiTi was statistically significant (Table 4).

Table 2: *Post hoc* comparison of uncoated archwires

(I) Group	*(J) Group*	*Mean difference (I–J)*	*Std. error*	*Sig.*	*95% Confidence interval*	
					Lower bound	*Upper bound*
Uncoated NiTi	Uncoated CuNiTi	−0.10533	0.38886	0.787	−0.8786	0.6679
	Uncoated L&H NiTi	1.85867*	0.38886	0.000	1.0854	2.6319
Uncoated CuNiTi	Uncoated NiTi	0.10533	0.38886	0.787	−0.6679	0.8786
	Uncoated L&H NiTi	1.96400*	0.38886	0.000	1.1907	2.7373
Uncoated L&H NiTi	Uncoated NiTi	−1.85867*	0.38886	0.000	−2.6319	−1.0854
	Uncoated CuNiTi	−1.96400*	0.38886	0.000	−2.7373	−1.1907

*The mean difference is significant at the 0.05 level

Table 3: ANOVA and *post hoc* comparison between Al_2O_3 coated archwires

ANOVA

	Sum of squares	*DF*	*Mean square*	*F*	*Sig.*
Between groups	550.892	5	110.178	57.135	0.000
Within groups	161.984	84	1.928		
Total	712.875	89			

Post-hoc tests

(I) Group	*(J) Group*	*Mean difference (I–J)*	*Std. error*	*Sig.*	*95% Confidence interval*	
					Lower bound	*Upper bound*
NiTi aluminum oxide coated	CuNiTi aluminum oxide coated	−0.93200	0.50707	0.070	−1.9404	0.0764
	L&H NiTi aluminum oxide coated	0.54267	0.50707	0.288	−0.4657	1.5510
CuNiTi aluminum oxide coated	NiTi aluminum oxide coated	0.93200	0.50707	0.070	-0.0764	1.9404
	L&H NiTi aluminum oxide coated	1.47467*	0.50707	0.005	0.4663	2.4830
L&H NiTi aluminum oxide coated	NiTi aluminum oxide coated	−0.54267	0.50707	0.288	−1.5510	0.4657
	CuNiTi aluminum oxide coated	−1.47467*	0.50707	0.005	−2.4830	0.4663

*The mean difference is significant at the 0.05 level

Table 4: ANOVA and *post hoc* comparison between TiO_2 coated archwires

ANOVA

	Sum of squares	*DF*	*Mean square*	*F*	*Sig.*
Between groups	568.001	5	113.600	82.434	0.000
Within groups	115.758	84	1.378		
Total	683.759	89			

Post hoc tests

(I) Group	*(J) Group*	*Mean difference (I–J)*	*Std. error*	*Sig.*	*95% Confidence Interval*	
					Lower bound	*Upper bound*
NiTi titanium oxide coated	CuNiTi titanium oxide coated	−0.26733	0.42865	0.535	−1.1198	0.5851
	L&H NiTi titanium oxide coated	1.30267*	0.42865	0.003	0.4502	2.1551
CuNiTi titanium oxide coated	NiTi titanium oxide coated	0.26733	0.42865	0.535	−0.5851	1.1198
	L&H NiTi titanium oxide coated	1.57000*	0.42865	0.000	0.7176	2.4224
L&H NiTi titanium oxide coated	NiTi titanium oxide coated	−1.30267*	0.42865	0.003	−2.1551	−0.4502
	CuNiTi titanium oxide coated	−1.57000*	0.42865	0.000	−2.4224	−0.7176

*The mean difference is significant at the 0.05 level

In group D, ZrO_2 coated CuNiTi archwires (5.4027 ± 1.52733 *N*) showed the highest frictional force followed by ZrO_2 coated NiTi archwires (4.9953 ± 1.44417 *N*). ZrO_2 coated L&H NiTi archwires (3.1253 ± 0.45822 *N*) showed the least frictional force (Table 1). *Post hoc* intergroup comparison showed that the difference in the frictional resistance values between ZrO_2 coated NiTi archwire and ZrO_2 coated CuNiTi archwire were not statistically significant and the rest of the comparisons were statistically significant (Table 5).

When comparing the uncoated NiTi archwires with the three archwires nanocoated with Al_2O_3, TiO_2 and ZrO_2, the uncoated NiTi archwire showed the highest frictional force (7.0060 ± 0.83355 *N*) followed by Al_2O_3 coated NiTi archwire (5.6793 ± 1.08464 *N*) and then the TiO_2 coated NiTi archwires (5.6267 ± 1.25191 *N*). ZrO_2 coated NiTi archwire (4.9953 ± 1.44417 *N*) showed the least frictional force during the testing (Table 1). *Post hoc* intergroup comparison showed that the difference in the frictional resistance values between

Table 5: ANOVA and *Post hoc* comparison between ZrO_2 coated archwires

ANOVA					
	Sum of squares	*DF*	*Mean square*	*F*	*Sig.*
Between groups	606.516	5	121.303	79.154	0.000
Within groups	128.730	84	1.533		
Total	735.247	89			

Post hoc tests

(I) Group	*(J) Group*	*Mean difference (I–J)*	*Std. error*	*Sig.*	*95% Confidence interval Lower bound*	*95% Confidence interval Upper bound*
NiTi Zirconium oxide coated	CuNiTi zirconium oxide coated	−0.40733	0.45203	0.370	−1.3063	0.4916
	L&H NiTi zirconium oxide coated	−1.87000*	0.45203	0.000	0.9711	2.7689
CuNiTi Zirconium oxide coated	NiTi zirconium oxide coated	0.40733	0.45203	0.370	−0.4916	1.3063
	L&H NiTi zirconium oxide coated	2.27733*	0.45203	0.000	1.3784	3.1763
L&H NiTi Zirconium oxide coated	NiTi zirconium oxide coated	−1.87000*	0.45203	0.000	−2.7689	−0.9711
	CuNiTi zirconium oxide coated	−2.27733*	0.45203	0.000	−3.1763	−1.3784

*The mean difference is significant at the 0.05 level

Table 6: ANOVA and *post hoc* comparison between NiTi archwires

ANOVA					
	Sum of Squares	*DF*	*Mean Square*	*F*	*Sig.*
Between groups	1080.300	7	154.329	108.331	0.000
Within groups	159.555	112	1.425		
Total	1239.855	119			

Post hoc

(I) Group	*(J) Group*	*Mean difference (I–J)*	*Std. Error*	*Sig.*	*95% Confidence interval Lower bound*	*95% Confidence interval Upper bound*
NiTi	NiTi aluminum oxide coated	1.32667*	0.43583	0.003	0.4631	2.1902
	NiTi titanium oxide coated	1.37933*	0.43583	0.002	0.5158	2.2429
	NiTi zirconium oxide coated	2.01067*	0.43583	0.000	1.1471	2.8742
NiTi aluminum oxide coated	NiTi uncoated	−1.32667*	0.43583	0.003	−2.1902	−0.4631
	NiTi titanium oxide coated	0.05267	0.43583	0.904	−0.8109	0.9162
	NiTi zirconium oxide coated	0.68400	0.43583	0.119	−0.1795	1.5475
NiTi titanium oxide coated	NiTi uncoated	−1.37933*	0.43583	0.002	−2.2429	−0.5158
	NiTi aluminum oxide coated	0.05267	0.43583	0.904	−0.9162	0.8109
	NiTi zirconium oxide coated	0.63133	0.43583	0.150	−0.2322	1.4949
NiTi zirconium oxide coated	NiTi uncoated	−2.01067*	0.43583	0.000	−2.8742	−1.1471
	NiTi aluminum oxide coated	−0.68400	0.43583	0.119	−1.5475	0.1795
	NiTi titanium oxide coated	−0.63133	0.43583	0.150	−1.4949	0.2322

*The mean difference is significant at the 0.05 level

uncoated archwire and each of the three nanocoated archwires was statistically significant. However, the difference among the three nanocoated groups was not statistically significant (Table 6).

Among the CuNiTi archwires, the uncoated CuNiTi archwires (7.1113 ± 1.29031 N) showed the highest frictional force followed by Aluminum oxide coated CuNiTi archwires (6.6113 ± 1.64546 *N*) and Titanium oxide coated CuNiTi archwires (5.8940 ± 1.79466 *N*). Zirconium oxide coated CuNiTi archwires exhibited the least frictional force (5.4027 ± 1.52733 *N*) (Table 1). *Post hoc* intergroup comparison showed that the difference in the frictional resistance values between Aluminum oxide coated CuNiTi archwires and uncoated CuNiTi archwires, the difference between Aluminum oxide coated CuNiTi archwires and Titanium oxide coated CuNiTi archwires and the difference between Zirconium oxide coated CuNiTi archwires and Titanium oxide coated CuNiTi archwires were not statistically significant (Table 7). The difference between uncoated and TiO_2 nanocoated, uncoated and ZrO_2 nanocoated, Al_2O_3 nanocoated and TiO_2 nanocoated, and Al_2O_3 nanocoated and ZrO_2 nanocoated groups was statistically significant (Table 4).

Among the L&H NiTi archwires, the uncoated L&H NiTi archwire (5.1473 ± 1.37272 *N*) showed the highest frictional force followed by Aluminum oxide coated L&H NiTi archwires (5.1367 ± 1.99256 *N*) followed by Titanium oxide coated L&H NiTi archwires (4.3240 ± 0.99798 *N*). Zirconium oxide coated L&H NiTi archwire (3.1253 ± 0.45822 *N*) showed the least frictional force (Table 1). *Post hoc* intergroup comparison showed that the difference in

Table 7: ANOVA and *post hoc* comparison between CuNiTi archwires

ANOVA					
	Sum of squares	*DF*	*Mean square*	*F*	*Sig.*
Between groups	945.933	7	135.133	79.006	0.000
Within groups	191.566	112	1.710		
Total	1137.499	119			

Post hoc tests						
					95% Confidence interval	
(I) Group	*(J) Group*	*Mean difference (I–J)*	*Std. error*	*Sig.*	*Lower bound*	*Upper bound*
Uncoated CuNiTi	CuNiTi aluminum oxide coated	0.50000	0.47755	0.297	−0.4462	1.4462
	CuNiTi titanium oxide coated	1.21733*	0.47755	0.012	0.2711	2.1635
	CuNiTi zirconium oxide coated	1.70867*	0.47755	0.001	0.7625	2.6549
CuNiTi aluminum oxide coated	CuNiTi uncoated	−0.50000	0.47755	0.297	−1.4462	0.4462
	CuNiTi titanium oxide coated	0.71733	0.47755	0.136	−0.2289	1.6635
	CuNiTi zirconium oxide coated	1.20867*	0.47755	0.013	0.2625	2.1549
CuNiTi titanium oxide coated	CuNiTi uncoated	−1.21733*	0.47755	0.012	−2.1635	−0.2711
	CuNiTi aluminum oxide coated	−0.71733	0.47755	0.136	−1.6635	0.2289
	CuNiTi airconium oxide coated	0.49133	0.47755	0.306	−0.4549	1.4375
CuNiTi zirconium oxide coated	CuNiTi uncoated	−1.70867*	0.47755	0.001	−2.6549	−0.7625
	CuNiTi aluminum oxide coated	−1.20867*	0.47755	0.013	−2.1549	−0.2625
	CuNiTi Titanium oxide coated	0.49133	0.47755	0.306	−1.4375	0.4549

*The mean difference is significant at the 0.05 level

the frictional resistance values between Zirconium oxide coated L&H NiTi archwire and the other three groups were statistically significant (Table 8).

The results show that L&H NiTi had the least friction among the uncoated archwires followed by NiTi and highest with CuNiTi archwires. L&H NiTi archwires consistently showed lesser frictional resistance with all the three metal oxide nanocoatings. All the nanocoated archwires significantly reduced friction compared to uncoated wires. Among the three metal oxides; ZrO_2 had the least frictional resistance followed by TiO_2 and Al_2O_3. Least frictional resistance among all the groups was seen with ZrO_2 nanocoated L&H NiTi and the highest was seen with uncoated CuNiTi wires.

Discussion

The characteristics of orthodontic archwires include low surface friction, high formability, low stiffness, increased spring back, high resiliency, and improved biocompatibility.[6] Most of these properties are seen with the superelastic archwires which are made of Nickel Titanium alloys. However, one disadvantage of these wires is their increased frictional resistance. Reduced frictional resistance is an essential consideration in orthodontics, as they directly influence treatment efficacy. Increased friction will cause binding, prolonged treatment, and anchorage loss.[7] Thus, one of the primary objectives of various orthodontic manufacturers is to reduce friction in archwires to enable efficient orthodontic treatment.

To overcome this limitation of the archwire, many surface modification procedures were implemented and evaluated.[8,9] Nanotechnology has extended its perks toward orthodontics by introduction of coating the nanoparticles over the orthodontic archwire thereby reducing the friction.[3] In light of the continuous effort to improve orthodontic treatment modalities, research into the effects of coatings of nanoparticles on the archwires becomes crucial. Most of these studies have used stainless steel archwires for this purpose.[3,10]

The relatively new low hysteresis NiTi wires promises excellent force properties.[1] But studies in literature evaluating the frictional resistance of superelastic archwires are limited. Even though a number of nanoparticles have been used for coating, comparative studies between different nanoparticles have not been carried out. Presently there are no studies evaluating friction on the nanocoated low hysteresis NiTi archwires. Therefore, the aim of this study was to compare the frictional resistance of three types of superelastic archwires namely; NiTi, CuNiTi and L&H NiTi using nanocoating of three metal oxides; Aluminum oxide (Al_2O_3), Titanium dioxide (TiO_2), and Zirconium oxide (ZrO_2) when compared to the uncoated group. This study can provide valuable insights into the impact of metal oxide nanocoatings on the frictional properties of superelastic orthodontic archwires.

The nanocoating was performed in the present study using a combination of dip coating along with ultra-sonification followed by electrophoresis method. A pilot study using this method done by Naveen et al. in stainless steel archwires had shown consistent results.[11] A customized jig was used which is ideal to test friction in superelastic archwires. The offset bracket in the jig mimics the oral conditions better, since superelastic archwires are used when minor irregularities are present between the teeth.

Among the uncoated archwires, L&H NiTi archwires showed the lowest frictional force followed by NiTi archwires. Uncoated CuNiTi archwires showed the highest frictional force. This was in accordance with the study by Jaber LC et al.[12] According to the authors, the increased flexibility of the low hysteresis wires could have led to decreased binding thereby reducing friction. Initial binding can drastically affect the static friction.

With regard to NiTi archwires, the comparison of uncoated NiTi archwires with the three archwires nanocoated with Al_2O_3, TiO_2 and ZrO_2, the uncoated NiTi archwire showed that the highest

Table 8: ANOVA and *post hoc* comparison between L&H NiTi archwires

ANOVA

	Sum of squares	*DF*	*Mean square*	*F*	*Sig.*
Between groups	609.912	7	87.130	64.793	0.000
Within groups	150.613	112	1.345		
Total	760.525	119			

Post hoc tests

(I) Group	*(J) Group*	*Mean difference (I–J)*	*Std. error*	*Sig.*	*95% Confidence interval Lower bound*	*95% Confidence interval Upper bound*
L&H NiTi Uncoated	L&H NiTi Aluminum oxide coated	0.01067	0.42344	0.980	−0.8283	0.8497
	L&H NiTi titanium oxide coated	0.82333	0.42344	0.054	−0.0157	1.6623
	L&H NiTi zirconium oxide coated	2.02200*	0.42344	0.000	1.1830	2.8610
L&H NiTi aluminum oxide coated	L&H NiTi uncoated	−0.01067	0.42344	0.980	−0.8497	0.8283
	L&H NiTi titanium oxide coated	0.81267	0.42344	0.058	−0.0263	1.6517
	L&H NiTi airconium oxide coated	2.01133*	0.42344	0.000	1.1723	2.8503
L&H NiTi titanium oxide coated	L&H NiTi uncoated	−0.82333	0.42344	0.054	−1.6623	0.0157
	L&H NiTi aluminum oxide coated	−0.81267	0.42344	0.058	−1.6517	0.0263
	L&H NiTi zirconium oxide coated	1.19867*	0.42344	0.006	0.3597	2.0377
L&H NiTi zirconium oxide coated	L&H NiTi uncoated	−2.02200*	0.42344	0.000	−2.8610	−1.1830
	L&H NiTi aluminum oxide coated	−2.01133*	0.42344	0.000	−2.8503	−1.1723
	L&H NiTi titanium oxide coated	−1.19867*	0.42344	0.006	−2.0377	−0.3597

*The mean difference is significant at the 0.05 level

frictional force followed by Al_2O_3 coated NiTi archwire and then the TiO_2 coated NiTi archwire. ZrO_2 coated NiTi archwire showed the least frictional force during the testing. A study by Golshah et al. showed that zirconium oxide nanocoating was only observed on TMA wires and not on NiTi and stainless steel archwires. The surface roughness of coated NiTi and SS wires had no significant difference from that of non-coated wires.[13] The failure to observe the nanocoating on NiTi archwires maybe because of the difference in the coating methods between the present study and the study mentioned above.

The results for the CuNiTi and L&H NiTi coated archwires were very similar to the NiTi archwires wherein the lowest friction was seen with ZrO_2 coated wires. ZrO_2 coating has consistently showed better reduction in frictional resistance than the other two metal oxides. But on the whole, all three metal oxides were quite efficient in this aspect. In a study done by Zeidan et al., ZnO coating of orthodontic brackets was studied and the results showed significant reduction in friction.[14] However, the disadvantage of coating brackets is that the coating might wear off after a few weeks and will not have the intended benefits beyond a certain period. Nanocoating of wires on the other hand, need not have a prolonged effect since they will be changed every appointment.

When it comes to the comparison among the Al_2O_3 nanocoated archwires, Al_2O_3 coated CuNiTi archwire showed the highest frictional force followed by Al_2O_3 coated NiTi archwire. Al_2O_3 coated L&H NiTi archwire showed the least frictional force. This behavior was similar to uncoated archwires where the highest friction was seen with CuNiTi. A study by Gravina et al. had shown that CuNiTi had higher friction than NiTi.[15] This is due to copper content of the alloy which may have influenced the surface characteristics.[16] The results of TiO_2 and ZrO_2 were similar to Al_2O_3 nanocoated wires.

The purpose of the present study was twofold. One was to examine the frictional properties of the L&H NiTi wires when compared to NiTi and CuNiTi wires. These newer archwires are supposed to have better mechanical properties like high spring back, lower activation force thereby reducing the pain for the patient.[17] Since the hysteresis is reduced there is also a more controlled force delivery.[2]

The second purpose of the study was to evaluate the effect of metal oxide nanoparticle coatings on superelastic wires. Previous studies on metal oxides in orthodontics were have concentrated on stainless steel archwires for the nanocoating.[11,18–20] The rationale was that only these wires were used during space closure. But friction plays a major role even during alignment and leveling and any efforts to reduce this will help in improving treatment efficiency during the initial stages. A study by Jeyaram et al. studies the effect of thin film coating of Al_2O_3 and ZnO on NiTi archwires showed a reduction in friction.[21] Very few studies are available in the literature about the effect of nanocoating of low hysteresis wires.

The results from this study proved that L&H NiTi has low friction and all three metal oxides were effective in reducing frictional resistance significantly. ZrO_2 performed the best out of the three metal oxides. The consistent indication of superior mechanical performance of ZrO_2-coated wires across all wire types, as evidenced by the lowest frictional forces, underscores the potential efficacy of ZrO_2 nanocoatings in reducing archwire friction and, consequently, improving orthodontic treatment efficiency and patient comfort.

These results emphasize the promising application of nanotechnology in enhancing the mechanical properties of orthodontic materials, constituting a significant step toward addressing the challenges associated with frictional resistance in orthodontic archwires. By demonstrating the efficacy of metal oxide nanocoatings in reducing friction, the study provides a compelling rationale for further exploration of nanotechnology-based interventions to improve orthodontic treatment outcomes.

While this study provides compelling evidence for the benefits of nanocoatings on superelastic orthodontic archwires, the limitation is that it may not accurately mimic *in vivo* conditions. The tenacity of the coating was also not studied which could determine the longevity of the advantages.

Future *in vivo* studies should be conducted to evaluate the performance of these coated archwires under real-life conditions, including their interaction with saliva, food particles, and varying oral pH levels. Additionally, investigating the potential antibacterial properties of these nanocoatings could provide further benefits in reducing oral infections and maintaining oral hygiene during orthodontic treatment. Exploring other nanomaterials and coating techniques may also yield even greater improvements in the performance of orthodontic archwires.

Furthermore, the evaluation of the biocompatibility of these nanocoatings is crucial for ensuring patient safety. This aspect is particularly important for long-term orthodontic treatments where the materials are in constant contact with oral tissues.

Conclusion

Within the limitations of the study, it can be concluded that L&H NiTi had the least friction among the uncoated archwires followed by NiTi and highest with CuNiTi archwires. Low hysteresis NiTi archwires consistently showed lesser frictional resistance with all the three metal oxide nanocoatings. All the nanocoated archwires significantly reduced friction compared to uncoated wires. Among the three metal oxides; ZrO_2 had the least frictional resistance followed by TiO_2 and Al_2O_3. Least frictional resistance among all the groups was seen with ZrO_2 nanocoated L&H NiTi and the highest was seen with uncoated CuNiTi wires.

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