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Aesthetic nickel titanium wires—how much do they deliver?

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SUMMARY The purpose of this study was to evaluate and compare the force levels of aesthetic Ni-Ti wires to regular Ni-Ti wires of the same dimension and evaluate their mechanical properties. Aesthetic and regular maxillary superelastic Ni-Ti wires (0.016 × 0.022) from four different manufacturers (G&H Wire Company, TP Orthodontics, GAC International, and Ortho Organizers) were selected and grouped I–IV. The loading and unloading values were compared using a three-point bending test. The unloading end values were also recorded to evaluate the recovery of archwires after each deflection. The unloading values were recorded at 0.5, 1.5, and 2.5 mm after loading deflections of 1, 2, and 3 mm, respectively. Cross-sectional scanning electron microscopy was used to assess the coating thickness of aesthetic wires. The results, statistically analysed, showed a significant decrease in force values for the aesthetic wires in groups I, III, and IV ($P < 0.001$) as compared to regular Ni-Ti wires of the same dimension from the same manufacturer. There was no significant difference in force values for group II wires. A statistically significant decrease in force values of epoxy-coated wires was observed in groups I, III, and IV only. This is of obvious clinical significance during wire selection. The group II coated wires, however, exhibited forces comparable to their regular Ni-ti wires with a difference that was statistically insignificant. The end values of aesthetic wires showed almost complete recovery for groups I, II, and III after 2 and 3 mm deflections.

Introduction

The growing demand for better aesthetics during orthodontic treatment has led to the development of appliances that combine both acceptable aesthetics for the patient and adequate technical performance for the clinician. Most fixed orthodontic appliance components are metallic and silver in colour. This problem was partially solved by the introduction of aesthetic transparent brackets made of ceramic or composite. However, archwires are still made of metals such as stainless steel, titanium-molybdenum alloy, and nickel titanium. Coating metallic archwires with plastic resin materials is an existing solution to this aesthetic problem. Coating improves aesthetics, but creates a modified surface, which can affect friction, corrosive properties, and the mechanical durability of the wires.

There are different opinions in the literature concerning coated archwires. An evaluation of sliding properties and adherence of coating to the archwires revealed that the plastic coating decreased friction between archwires and brackets (Husmann *et al.*, 2002). The coated wires are also found to be routinely damaged from mastication and activation of enzymes (Kusy, 1997), due to which this coating has been described as undurable (Proffit and Fields, 2002). Other authors have also experienced difficulties, claiming that the colour tends to change with time and that the coating splits during use in the mouth, exposing the underlying metal (Postlethwaite, 1992; Lim *et al.*, 1994).

Today, it has become common place for orthodontists to use nickel titanium archwires, at least in the initial stage of treatment for levelling and aligning. These wires are capable of large elastic deflections and they allow greater working ranges and therefore fewer archwire changes (Andreasen and Morrow, 1978). The demand for aesthetic appliances has resulted in manufacturers coating the Ni-Ti wires with Teflon [polytetrafluoroethene] to be used with ceramic or composite brackets. Atomized Teflon particles are used to coat the wires using clean compressed air as a transport medium. This is further heat treated in a chamber furnace (Husmann *et al.*, 2002).

When wires are subjected to deflection in the horizontal or vertical directions, it is the load–deflection properties that determine the biological nature of tooth movement. It is possible that these properties may be altered when the Ni-Ti wires are coated. The coating would obviously be at the expense of the thickness of the Ni-Ti archwire inside which has to assume a smaller diameter to compensate for the thickness of the outer coating. A comparison of load–deflection properties of coated and uncoated 0.016 in and 0.018 × 0.025 in Ni-Ti wires of a single manufacturer in conventional and self-ligating brackets using a three-point bracket bending test concluded that ultra-aesthetic wires and self-ligating brackets yielded lower forces (Elayyan *et al*., 2010).

Aesthetic wires from different manufacturers are available today. No studies have so far been conducted to evaluate the mechanical properties of these wires as compared to conventional Ni-Ti wires of the same dimension from the same manufacturer. Clinically, it is important to evaluate differences, if any, in these coated wires. The purpose of this study was to evaluate and compare the force levels of aesthetic Ni-Ti wires of four different brands to regular Ni-Ti wires of the same manufacturer and evaluate the mechanical properties of epoxy-coated Ni-Ti wires to regular Ni-Ti wires of same dimensions under the same testing conditions using a three-point bending test which has a close simulation to clinical application. The null hypothesis was that there will be no difference in load–deflection properties between coated and uncoated superelastic Ni-Ti wires of the same size. It was also decided to evaluate the thickness of the coating of the aesthetic wires using scanning electron microscopy (SEM).

Materials and methods

Aesthetic and regular maxillary superelastic Ni-Ti wires of same dimensions 0.016 × 0.022 in, from four different manufacturers (G&H Wire Company, TP Orthodontics, GAC International, and Ortho Organizers) were selected and grouped I–IV. The wires used in this study are listed in Table 1. The sample size was 10 for each group as per the sample size calculations for detecting 10 per cent differences in the values. Straight pieces of adequate length were cut from the distal ends of preformed archwires.

The load–deflection characteristics of specimens from each group were evaluated using three-point bending test previously described by Miura *et al*. (1986). Testing was performed at room temperature as the archwires were not heat activated NiTi (Elayyan *et al.*, 2008). A specially designed fixture with two supports 14 mm apart equal to the distance between upper central incisor and canine was used (Segal *et al.*, 2009). The test wire specimens were secured on brackets fixed on the poles using elastomeric ligatures (AlastiK, 3M). Testing was done using a Universal testing machine (INSTRON, model no: 5500R with BLUE HILL 2 software). The striker was attached to the upper movable head of the Instron machine. The tip of the striker was on the centre of the test-wire span (Figure 1). The wider surface of the wires faced the striker. The crosshead speed for loading and unloading was 1 mm per minute. The mid portion of the wire was deflected. The loading values for each sample were recorded at 1, 2, and 3 mm deflections and the unloading values at 0.5, 1.5, and 2.5 mm, respectively, as analysis of superelastic behaviour is said to show a nearly horizontal deactivation force/deflection slope between approximately 0.5 and 2.5 mm of deflection (Segal *et al.*, 2009).

At the end of each cycle following unloading, the residual force called 'end value' was also recorded. All the samples were tested under identical testing conditions. Cross sections of four aesthetic wires in each of the four groups were assessed using SEM (JEOL JSM 5600LV) and averages taken. The images were recorded at ×1000 magnification.

Table 1 List of archwires used in this study.

Group	Product	Manufacturer
I	Ultra Aesthetic Ni-Ti G4 Regular Ni-Ti	G&H Wire Company
II	Reflex Aesthetic Wire Reflex Regular Ni-Ti	TP Orthodontics
III	Spectra Aesthetic Ni-Ti Lowland Regular Ni-Ti	GAC International
IV	Plastic-Coated Ni-Ti O2 Regular Ni-Ti	Ortho Organizer

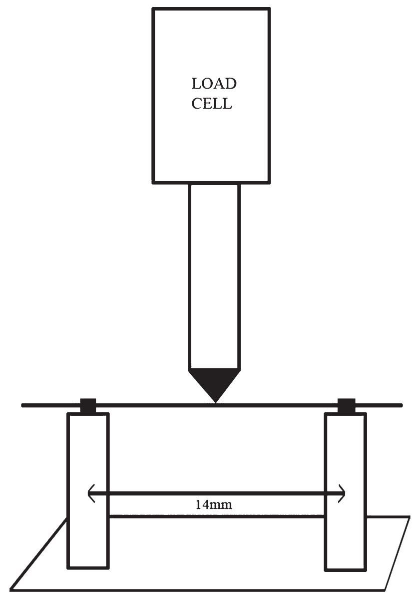

Figure 1 Schematic diagram of the three-point fixture.

Statistical analysis

Data were analysed using computer software (SPSS) version 10. Student's *t*-test was used to compare mean values between aesthetic and regular wires at different deflections in each group separately. Analysis of variance (one-way ANOVA) was performed as parametric test to compare different forces within each deflection in aesthetic and regular groups. Duncan's Multiple Range (DMR) test was used as *post hoc* analysis to elucidate individual comparisons within deflections. For all statistical evaluations, a two-tailed probability of value <0.05 was considered significant.

Results

The mean force levels for group I regular and aesthetic Ni-Ti wires are shown in Table 2 and Figure 2. Here, it can be seen that the coated wires have registered lower force values for all three deflections in both loading and unloading and the difference is highly significant ($P < 0.001$). The recovery pattern shows a statistically significant difference after 1 mm deflection only ($P < 0.01$).

Force levels for group II regular and aesthetic wires are shown in Table 3 and Figure 3. Here, there is no significant difference between the force values registered by aesthetic and regular Ni-Ti wires for 2 and 3 mm deflections in loading and 2.5 mm deflection in unloading. The difference is significant only for smaller values of unloading. Also, there is no significant difference in the recovery pattern of coated and uncoated wires of this group as evidenced by the end values.

Table 2 Comparison of different mean force (Newton) levels between regular and aesthetic Ni-Ti wires at different deflections in group I (G&H Wire Company).

Deflection	Force (mm)	Aesthetic		Regular		*t* value
		Mean	SD	Mean	SD	
Loading	1	1.05^{a}	0.04	1.56^{a}	0.05	27.007***
	2	1.82^{b}	0.03	2.45^{b}	0.04	37.807***
	3	2.40^{c}	0.04	3.26^{c}	0.09	28.205***
	F value	3044.363***		1940.154***		
Unloading	0.5	0.66^{a}	0.09	0.81^{a}	0.08	3.831**
	1.5	1.12^{b}	0.08	1.41^{b}	0.07	8.700***
	2.5	1.31^{c}	0.12	1.60^{c}	0.18	4.328***
	F value	118.736***		118.322***		
End value	1	0.19^{c}	0.14	0.01^{a}	0.01	−3.926**
	2	0.09^{a}	0.08	0.06^{a}	0.06	−1.233
	3	0.11^{ab}	0.03	0.13^{b}	0.10	0.722
	F value	2.866*		7.661**		

The letters a, b, and c indicate means with same superscript within each deflection do not differ each other (Duncan's Multiple Range Test).
$*P < 0.05$; $**P < 0.01$; $***P < 0.001$.

The force levels for group III wires are given in Table 4 and Figure 4. The mean force values for all three deflections of aesthetic wires in loading and 1.5 and 2.5 mm deflections in unloading are significantly lower than their regular counterparts ($P < 0.001$). The difference in recovery pattern is significant only for 1 mm deflection.

In group IV (Table 5, Figure 5), the mean loading forces show highly significant differences with the coated wires showing lower forces ranging between 0.98 and 2.32 N, whereas regular Ni-Ti wires show forces ranging between 1.30 and 4.21 N for the three deflections ($P < 0.001$). The unloading forces are significantly lower for 1.5 and 2.5 mm deflections of coated wires ($P < 0.001$). The regular wires show a significantly better recovery after 2 and 3 mm deflections ($P < 0.05$). The aesthetic wires at larger deflections did not recover completely, due to force degradation.

The SEM cross-sectional image of aesthetic wires show the thickness of the coating to be 0.00055 in for group I, 0.0014 in for group II and 0.0006 in for both groups III and IV (Figure 6).

Discussion

Acceptable aesthetics for the patient and optimal technical performance for the orthodontist constitute a very desirable combination. In order to obtain optimum orthodontic tooth movement, a light continuous force is required. The major challenge in designing and using an orthodontic appliance is to produce such a force system. The elastic behaviour of any material is defined in terms of its stress–strain response to an external load (Proffit and Fields, 2002) For analysis, orthodontic wires can be considered as beams, supported either at one end

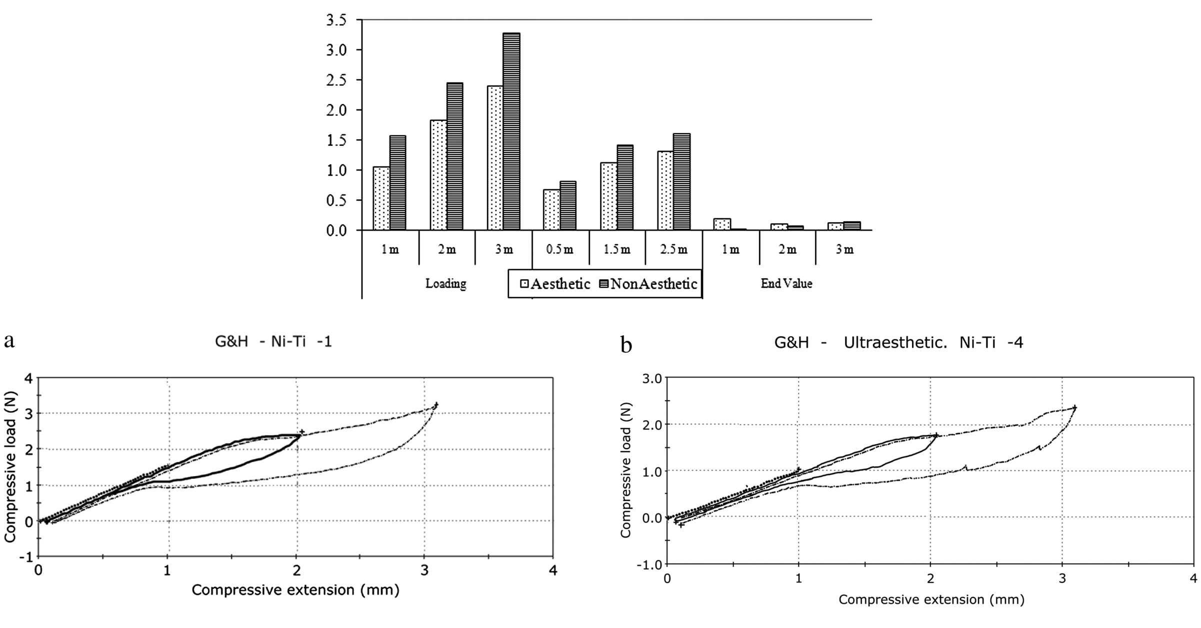

Figure 2 Mean force levels in group I regular and aesthetic Ni-Ti wires. (a) Load–deflection graph in group I regular Ni-Ti wires. (b) Load–deflection graph in group I aesthetic Ni-Ti wires.

or at both ends or in between. Force applied to such a beam can be measured as the deflection produced by the force.

The three-point bending test, devised to accurately differentiate the presence of superelasticity in wires, is claimed to 1. yield results that are reproducible, 2. differentiate wires with superelastic properties, and 3. simulate application of wire pressure on the teeth in the oral cavity (Miura *et al.*, 1986). It produces a load–deflection diagram consisting of an upper loading curve representing the force needed to engage the archwire to the bracket and a lower unloading curve, parallel to it, representing the force delivered to the teeth. The clinical implication of the resulting hysteresis is that the force delivered to the periodontal structures is lower than the force necessary to activate the wire.

Superelasticity is a remarkable property produced by stress-induced martensitic transformation. When an external force is applied, the Ni-Ti wire deforms not by slipping of lattice as is commonly seen in most metals but by martensitic transformation. In this phase, the metal is more soft and ductile. When the stress is diminished, the Ni-Ti alloy returns to the harder austenitic phase. Clinically, the superelasticity allows the archwires to exert a constant force over a large range of deactivation. It does not exhibit linear elastic behaviour but provides continuous force for long periods.

The aesthetic wires produced lower forces than the uncoated regular wires in both loading and unloading in all groups except group II. This is obviously due to the decreased size of the Ni-Ti wires occupying the inner core of the coated wires. The decrease in loading forces of coated wires is highly significant ($P < 0.001$) for all three deflections in groups I, III, and IV. The unloading forces in these three groups also show a highly significant decrease in force values for the aesthetic wires at 1.5 and 2.5 mm deflections. Reduction in size of inner Ni-Ti wire to accommodate the coating is probably the cause for reduction in force levels in these three groups. Lower unloading forces, though desirable, may not be effective if it is below the required optimum orthodontic range for tooth movement. Clinicians need to use larger size wires to get the same force value. But this implies increased friction. Inserting the wire into the slot will also be more difficult.

At 0.5 mm unloading, the value was significant ($P < 0.01$) but to a lesser extent. This is probably because laboratory

Table 3 Comparison of different mean force (Newton) levels between regular and aesthetic Ni-Ti wires at different deflections in group II (TP Ortho).

Deflection	Force (mm)	Aesthetic		Regular		*t* value
		Mean	SD	Mean	SD	
Loading	1	1.24[a]	0.07	1.68[a]	0.28	4.848***
	2	3.19[b]	0.09	3.58[b]	0.66	1.837
	3	4.24[c]	0.20	4.64[c]	0.83	1.507
	F value	1307.084***		56.499***		
Unloading	0.5	0.57[a]	0.10	0.73[a]	0.14	3.024**
	1.5	1.94[b]	0.08	2.28[b]	0.39	2.688*
	2.5	2.42[c]	0.08	2.66[c]	0.46	1.643
	F value	1207.966***		82.863***		
End value	1	0.05[a]	0.03	0.03[a]	0.03	−1.403
	2	0.05[a]	0.04	0.05[a]	0.04	−0.062
	3	0.09[a]	0.10	0.10[b]	0.06	0.281
	F value	1.265		7.295**		

The letters a, b, and c indicate means with same superscript within each deflection do not differ each other (Duncan's Multiple Range Test).
$*P < 0.05$; $**P < 0.01$; $***P < 0.001$.

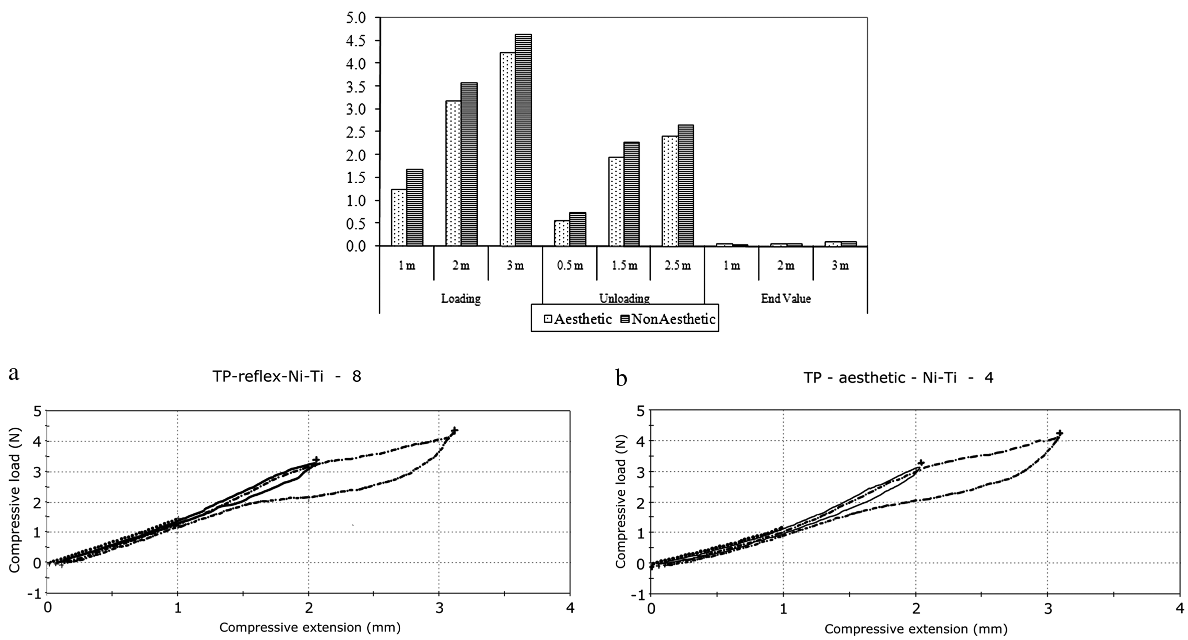

Figure 3 Mean force levels in group II regular and aesthetic Ni-Ti wires. (a) Load–deflection graph in group II regular Ni-Ti wires. (b) Load–deflection graph in group II aesthetic Ni-Ti wires.

experiments performed on austenitic superelastic wires show a lack of formation of stress-induced martensite for small deflections. Austenitic Ni-Ti presents a stiffness of 0.28 for small deflections, a value surprisingly higher than the 0.20 stiffness of a classic, work-hardened alloy (Segner and Ibe, 1995; Santoro *et al.*, 2001). According to them, superelastic wires require a deflection of at least 2 mm over a span of 14 mm for its superelastic behaviour. Austenitic alloys are therefore superelastic mainly when used for the correction of gross malalignments of teeth.

Table 4 Comparison of different mean force (Newton) levels between regular and aesthetic Ni-Ti wires at different deflections in group III (GAC).

Deflection	Force (mm)	Aesthetic		Regular		t value
		Mean	SD	Mean	SD	
Loading	1	1.06^{a}	0.05	1.54^{a}	0.09	14.657***
	2	1.79^{b}	0.06	3.46^{b}	0.06	62.691***
	3	2.36^{c}	0.10	4.60^{c}	0.16	38.126***
	F value	855.621***		1929.932***		
Unloading	0.5	0.65^{a}	0.15	0.78^{a}	0.08	2.487*
	1.5	1.20^{b}	0.07	2.22^{b}	0.08	31.231***
	2.5	1.34^{c}	0.05	2.84^{c}	0.20	23.458***
	F value	141.413***		661.342***		
End value	1	0.04^{a}	0.02	0.01^{a}	0.01	−3.529**
	2	0.08^{b}	0.02	0.06^{a}	0.07	−0.969
	3	0.07^{b}	0.04	0.06^{a}	0.08	−0.615
	F value	8.581**		1.435		

The letters a, b, and c indicate means with same superscript within each deflection do not differ each other (Duncan's Multiple Range Test).
$^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$.

Interestingly, group II wires in this study showed no significant variations in force levels between aesthetic coated wires and regular uncoated wires except at very small deflections. This is in total contrast to earlier findings (Elayyan *et al.*, 2008, 2010). The group II wires had its aesthetic coating only on the labial surface. This is probably the reason why there were no significant differences in loading and unloading forces of coated and uncoated wires of this group. An SEM analysis of the cross sections of representative wires in each group revealed that the thickness of the epoxy coating was almost similar and ranged between 0.00055 and 0.0006 in for groups I, III, and IV but was higher at 0.0014 in and one sided for group II wires. According to the manufacturers of group I wires, the coating is 0.002 in (Elayyan *et al.*, 2010). The epoxy coating in group II wires apparently did not affect their superelasticity. However, their durability may be affected. This would be of great relevance from a clinical standpoint.

There are no significant differences between coated and uncoated wires in the recovery patterns for 2 and 3 mm deflections in groups I and III and all three deflections in group II. Coating obviously did not affect force degradation significantly in these wires. Group IV aesthetic wires, however, showed significantly higher end values at 2 and 3 mm deflections ($P < 0.05$) suggestive of force degradation.

Nitinol SE has been grouped as a borderline non-superelastic group of Ni-Ti alloys with studies reporting that at 3 mm unloading, it showed force levels of 2.68 N (Bartzela *et al.*, 2007). In this study also, deflections of groups II, III, and IV fell in the range of 2.48–2.84 N at 2.5 mm deflection and group I showed 1.60 N.

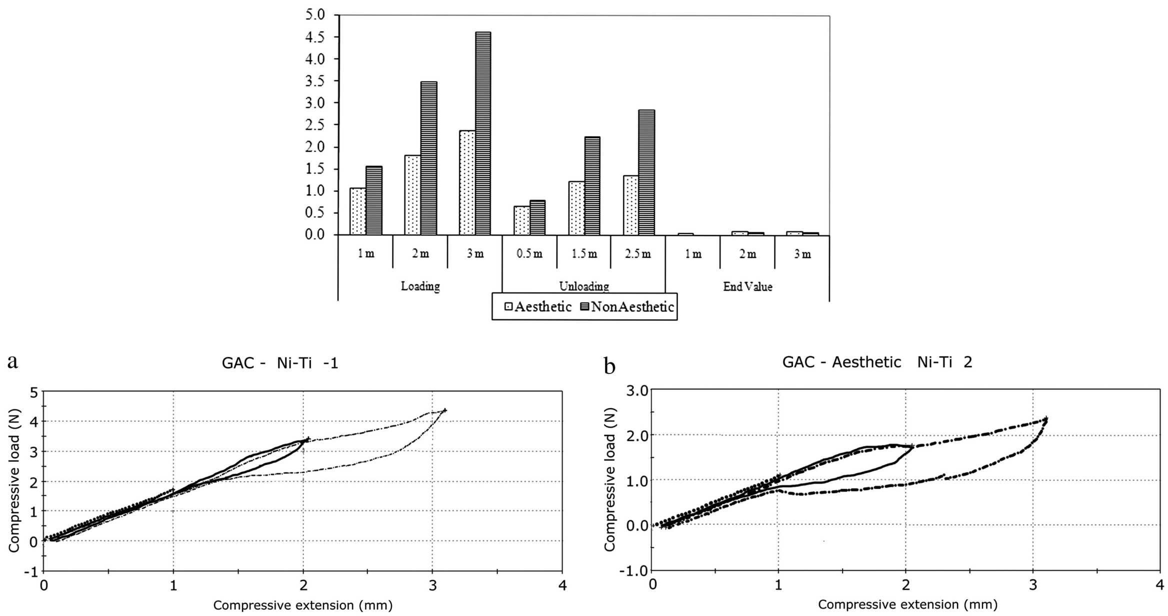

Figure 4 Mean force levels in group III regular and aesthetic Ni-Ti wires. (a) Load–deflection graph in group III regular Ni-Ti wires. (b) Load–deflection graph in group III aesthetic Ni-Ti wires.

The surface treatment in aesthetic wires contributes to a reduction in the frictional properties of the archwire. Literature findings also confirm that the friction is reduced by surface treatment, e.g. Teflon, polyethylene, or ion implantation. The best result was reported for Teflon-coated wires (Burstone and Farzin-Nia, 1995; De Franco *et al.*, 1995). Clinically, a rough surface encourages greater plaque accumulation, increased corrosion, and colour instability. This secondarily influences the clinical performance of the archwire (Bourauel *et al.*, 1998; Eliades and Athanasiou, 2002; Fischer-Brandies *et al.*, 2003). It has been reported that the surface-modified wires become rough with time in the clinical situation. Therefore, the integrity of the surface has to be evaluated over time. Aesthetic polymeric wire is a new product, which consists of a composite polymer matrix reinforced with fibres. By varying the reinforcing fibre content of the composite matrix, the elastic modulus of these wires can be adjusted to the preferred range. Work characterizing the fundamental properties of this experimental material has concluded that this product seems promising (Zufall and Kusy, 2000).

Table 5 Comparison of different mean force (Newton) levels between regular and aesthetic Ni-Ti wires at different deflections in group IV (Ortho Organizer)

Deflection	Force (mm)	Aesthetic		NonAesthetic		*t* value
		Mean	SD	Mean	SD	
Loading	1	0.98[a]	0.06	1.30[a]	0.03	15.477***
	2	1.81[b]	0.09	3.20[b]	0.05	40.9096***
	3	2.32[c]	0.12	4.21[c]	0.05	46.026***
	F value	533.804***		9367.195***		
Unloading	0.5	0.55[a]	0.07	0.60[a]	0.07	1.677
	1.5	1.12[b]	0.12	2.00[b]	0.12	16.500***
	2.5	1.30[c]	0.09	2.48[c]	0.14	22.125***
	F value	161.684***		766.714***		
End value	1	0.02[a]	0.02	0.03[a]b	0.01	1.314
	2	0.11[a]	0.09	0.02[a]	0.02	−2.592*
	3	0.27[b]	0.27	0.05[b]	0.03	−2.517*
	F value	5.719**		3.326*		

The letters a, b, and c indicate means with same superscript within each deflection do not differ each other (Duncan's Multiple Range Test).
$^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$.

This study highlights the variations in force levels while utilizing coated wires as compared to uncoated ones of the same dimensions from the same manufacturer. Optimal esthetics without compromising on the forces delivered is the ultimate choice while selecting aesthetic wires. Group II wires with coating only on the labial aspect seem to meet this requirement. Further *in vivo* studies are needed to assess the clinical efficacy of this wire as compared to newer composite wires as and when they become commercially available.

Summary and conclusions

The conclusions drawn at the end of this study are as follows:

1. The aesthetic coated archwires delivered statistically significant lower loading and unloading forces than uncoated wires of same dimensions from same

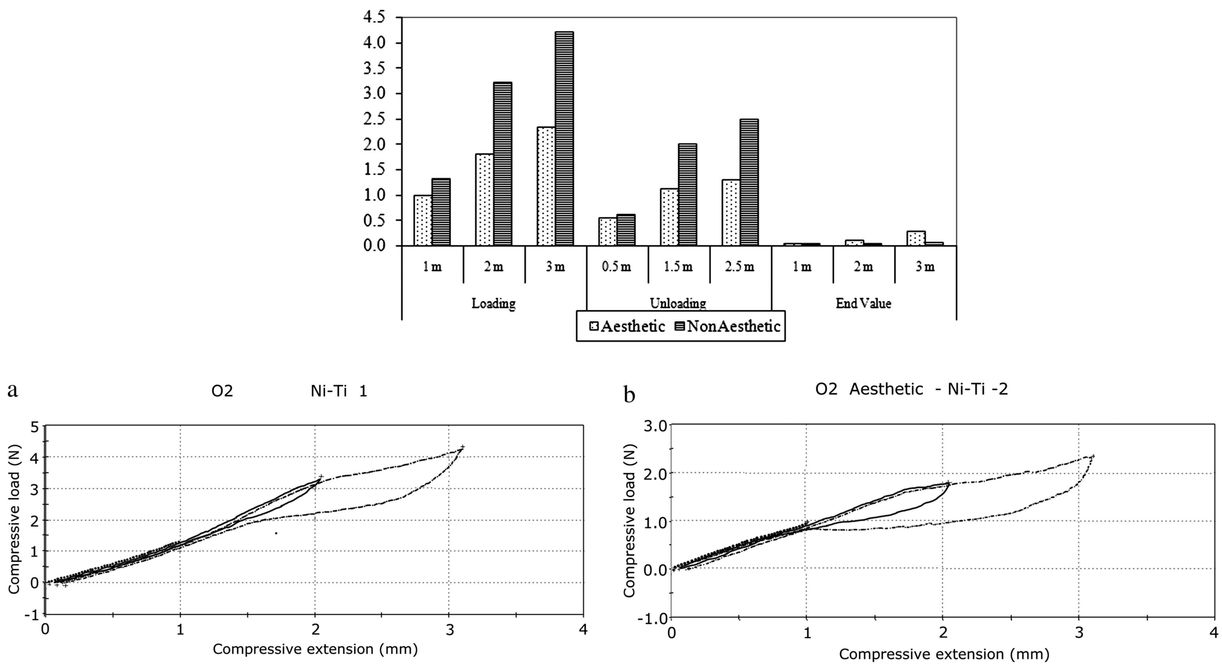

Figure 5 Mean force levels in group IV regular and aesthetic Ni-Ti wires. (a) Load–deflection graph in group IV regular Ni-Ti wires. (b) Load–deflection graph in group IV aesthetic Ni-Ti wires.

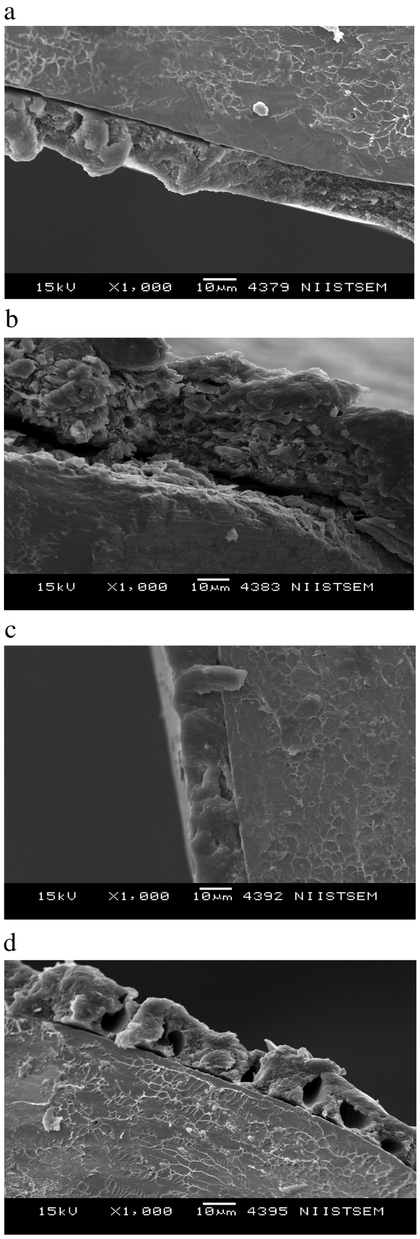

Figure 6 (a) Cross-sectional scanning electron microscopy (SEM) of aesthetic wire group I. (b) Cross-sectional SEM of aesthetic wire group II. (c) Cross-sectional SEM of aesthetic wire group III. (d) Cross-sectional SEM of aesthetic wire group IV.

manufacturer for groups I, III, and IV, thus rejecting the null hypothesis in these three cases.

2. However, in group II, there was no statistically significant difference between the mean force levels in loading and unloading exhibited by the aesthetic coated wires and regular uncoated wires.
3. The analysis of the end values of aesthetic wires showed almost complete recovery for groups I, II, and III after 2 and 3 mm deflections. Group IV aesthetic wires, however, showed significantly higher end values at 2 and 3 mm deflections suggestive of force degradation.

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