Properties of the Epoxy-coated NiTi Open Coil Springs

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This study was aimed to determine the load-deflection ratio (stiffness) of the aesthetic nickel titanium orthodontic coil springs and to compare their stiffness with those of the uncoated springs. A total number of 40 open coil-springs (regular and epoxy coated) from two different manufacturer were purchased. From each manufacturer ten regular 7 inch length and ten epoxy coated open coil springs of the same shape and dimension were tested. The springs were subjected to compression tests, using an Instron Universal Testing Machine. The maximum stiffness value was recorded and included in the statistical analysis. The effect of coating did not show statistically significant different stiffness values in the case of Ortho Technology coil springs. The Azdent coated coil spring have showed statistically significant lower stiffness values than the rest of the tested coil springs. Coating might affect the stiffness of an orthodontic coil spring.

Keywords: Epoxy-coated nickel-titanium, coil springs, orthodontics, mechanical properties

Coil springs, introduced for orthodontic tooth movement in 1931, can be divided into two categories: open coil and closed coil springs [1]. They are used for space closure, protraction and retraction of teeth and applying force on the impacted teeth [2]. Variables which affect the force levels produced by coil springs are: the alloy, the diameter of the arch wire, lumen size, pitch angle of the coils and the length of the spring. Different materials have been used to manufacture closed and open coil springs: stainless steel, chrome-cobalt alloy. Today nickel titanium alloy is the material of choice [3.

Open coil springs are important auxiliaries in the orthodontic treatment, especially when the management of space opening is required. The maximum force an open coil spring is able to deliver is influenced by numerous factors. The mechanical properties of the coil springs were intensively studied in different works [2-7, 19-21] . Han et.al [19] compared the Ni-Ti closed coil springs with stainless steel and polyurethane elastics in a simulated oral environment. The results showed degradation of physical properties of SS springs and elastics, but Ni-Ti remained relatively stable. Miura et al.[22] also studied the differences between the Japanese Ni-Ti open and closed coil springs and SS springs. Springs of various lumen sizes, wire sizes, and different pitch were used in their study. It was observed that when the lumen of coil springs remained constant, the load value of super elastic activity increased as wire diameter increases. The Ni-Ti springs demonstrated a super elastic effect, with a constant load for a large range of deflection.

The use of aesthetic materials has grown in popularity over recent years [4]. The aesthetic appearance of the arch wire-bracket system is rated by patients, especially adults, as a significant factor [5]. Many companies produce aesthetic appliances, including arch wires, coil springs and ligatures. Materials used in the coating process are plastic resin materials such as Teflon or epoxy resin [6]. The epoxy coating is manufactured using a depositary process that coats the base arch wire with an epoxy resin approximately 0.002 inch thick, so a powerful adhesion is achieved between the coating and the wire [7]. There are different opinions in the literature concerning aesthetic coated arch wires [8-18]. An evaluation of sliding properties and adherence of the coating to the arch wires revealed that the plastic coating decreased friction between arch wires and brackets [8]. Also, several studies showed that loading and unloading forces obtained via bending tests are significantly lower compared to the regular, uncoated arch wires, resulting in a lower clinical efficacy [9-11].

No information is available in the orthodontic literature regarding the mechanical properties and surface characteristics of the coated open Ni-Ti coil springs. This study was aimed to determine the load-deflection ratio (stiffness) of the aesthetic Ni-Ti coil springs. It was also aimed to compare their stiffness with those of the uncoated Ni-Ti springs.

Experimental part

A total number of 40 open NiTi coil-springs (regular and epoy coated) from two different manufacturer (OT Ortho Technology, Tampa, Florida, USA™ and Azdent, China) were purchased. From each manufacturer ten regular 7 inch length (True Flex Ni-Ti and Azdent) and ten epoxy coated (Tooth tone Ni-Ti and Azdent esthetic) open coil springs of the same shape and dimension (0.012x0.030 inch) were tested. All springs used were from the same lot number.

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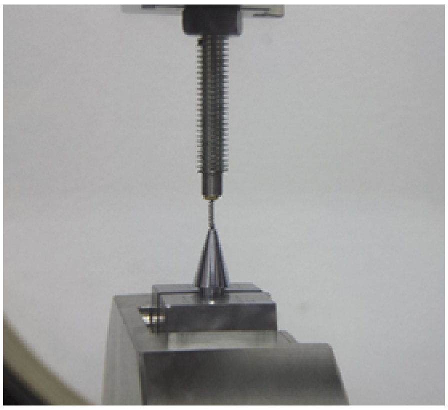

Fig. 1. Uncoated OT coil spring, under compression

intraoral use of the coil-springs. If used with round base arch wires, the coil springs could determine undesirable biomechanical side effects, such as rotation and tipping of the limited teeth. Special, custom-made jigs were used to compress the coil springs. The arch wires were fixed at the upper end and it could slide freely at the lower end. Each Ni-Ti spring was compressed 4 mm (until the coils came in contact with each other) at a deflection speed of 1mm/min. The spring stiffness defined as the ratio between the force and corresponding deflection was determined as the slope of the load – deflection curves presented in figure 2. All the wires were tested under identical testing conditions.

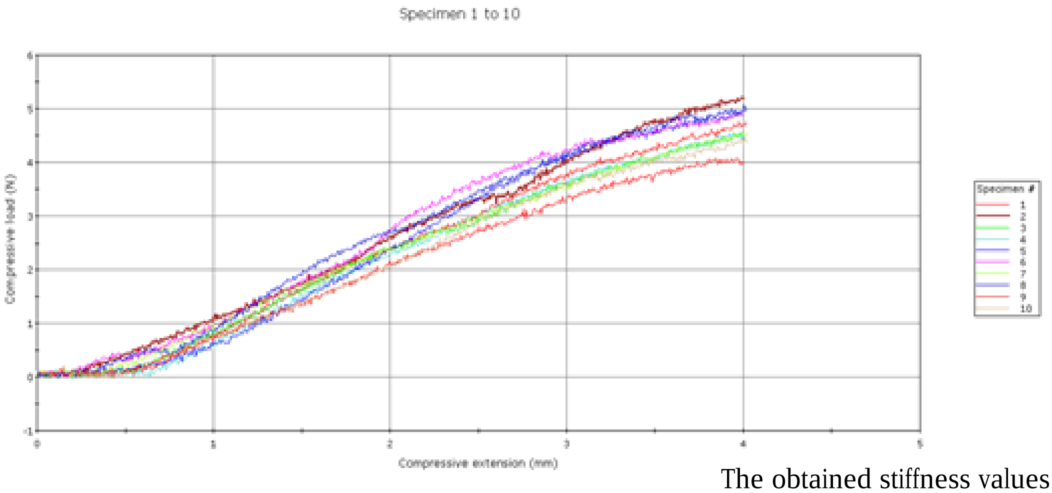

Fig. 2. Compression test of OT aesthetic Ni-Ti coil springs on the 0.016x0.022 inch arch wire

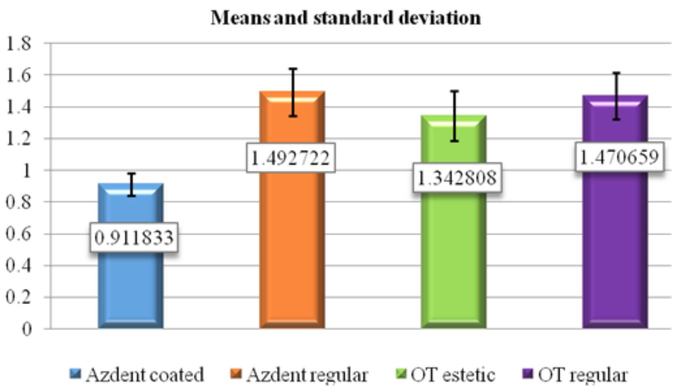

Fig. 3. Mean stiffness based on the spring type and standard deviation

The coil springs were subjected to compression tests. An Instron Universal Testing Machine type 3366, 10kN was used to perform the tests (fig. 1). The measured values were recorded for each specimen by the testing machine software Instron Bluehill 2. The collected data was exported in spreadsheet file format (Microsoft Excel).

In order to determine the coil springs stiffness, the coil springs were cut in pieces of 10 mm length. The specimens were slid over a 0.016 x 0.022 inch rectangular Stainless steel wire (True Force SS Euro, OT Ortho Technology, Tampa, Florida, USA™) which allowed a 0.008 inch clearance between the arch wire and the 0.030 inch lumen coil spring. The decision to use rectangular arch wire, instead of round one, was taken in order to imitate the

The obtained stiffness values of each open coil spring were statistically analyzed. Descriptive analysis was made to determine the mean and standard deviation values. For statistical analysis *t- test* was performed in order to compare the results. Statistically significant differences ($p<.05$) were evaluated for all measurements. Statistical analysis was performed using Microsoft Excel.

Results and discussions

The mean stiffness and the standard deviation, obtained after the compression tests for both the regular and coated coil springs are shown in the diagram in figure 3. As illustrated in figure 3, mean stiffness ranged from 0.911N/mm for the coated Azdent coil springs to a value of 1.492 N/mm for the Azdent regular coil spring. It can be seen that, compared to the regular coil spring from the same manufacturer, the coated Azdent coil springs have showed statistically significant lower stiffness values ($p < 0.001$), (table 1).

The coated OT coil springs did not showed significantly different stiffness compared with the regular OT coil springs. Table 1 shows the *p* value obtained after the statistical analysis of the results.

There are various ways of describing the physical properties of orthodontic coil springs. In the case of stiffness, it is defined as the ratio of unit stress to unit strain, usually expressed as N/mm. For a coil spring in compression, the stiffness is the ratio between the cross-sectional area multiplied with the (tensile) elastic modulus (or Young's modulus) and the length of the element.

In our study, the determined property of the coil springs was the stiffness. Because the aesthetic coated coil

Table 1

THE p-VALUES OF DIFFERENT COMPARED GROUPS

p =	Azdent coated	OT regular	OT esthetic	Azdent regular
Azdent coated	-	**<0,0001**	**<0,0001**	**<0,0001**
OT regular		-	0,1228	0,7436
OT esthetic			-	0,0782
Azdent regular				-

springs have not sufficiently been tested yet, we also considered useful a study that evaluates the stiffness capability by these springs compared to the regular non-coated ones. Especially the findings about aesthetic arch wires showed lower performances, decreased force levels and different stiffness values during mechanical testing [17,18, 23-25]. Elayyan et al. [17] found that epoxy resin coated arch wires produced lower frictional force compared to uncoated wires of the same nominal sizes. Husmann et al. [15] showed that the coating of the springs decrease frictional force and it influences the stiffness of the arch wire. In our study the stiffness of the coated Azdent coil springs was significantly lower compared to the other groups (Azdent regular, OT esthetic and OT coated).

Jacob et.al. [20] investigated the load deflection rate of open and closed coil springs. Their study showed that increased in the wire diameter increased the force level in open coil springs. But in our study, the length of the springs (10 mm), the composition of the wire used for fabrication of the spring (NiTi) and the dimensions of the springs (0.012x0.030 inch) were the same in all the four category. When all the other variables (length, structure, dimension of the lumen and compression of the coil springs) are identical, stiffness can be an indicator of the force produced during compression. We obtained greater stiffness (1.47 N/mm compared to 1.34 N/mm), which might indicate greater force, of the same coil spring when the surface of the coil spring was coated, although the values were not statistically significant.

Statistically, significant lower stiffness values were obtained in the compression test of the coated coil springs from Azdent. The findings can be explained by a different manufacturing procedure of the coil springs that might affect their mechanical properties.

Comparing our results regarding the regular OT spring with those found in the literature, we can state that in the case of Ni-Ti open coil springs stiffness was within the range of 0.91183-1.49272 N/mm equivalent to 3.64732-5.97088 N force. Fraunhofer et al. 21] tested in compression the 0.010x0.035 inch open coil springs. The wires length was 15 mm and compression was made up to 7 mm. The mean unloading forces of the coil springs were 61.7 g, approximately 6.17 N. Calculating the obtained force by multiplying the stiffness with the extent of the compression (4 mm) we obtained slightly lower force values for the tested springs, 5.88 N for the OT regular and 5.97 N for the Azdent regular.

The present findings indicate that aesthetic coating might affect the stiffness of the coil springs in some commercially available coil springs.

Conclusions

Both the coated and the regular, uncoated open Ni-Ti coil springs from the same manufacturer (OT Ortho Technology, Tampa, Florida, USA™) showed no statistically differences the force-deflection ratio (stiffness).

The coated springs from Azdent presented statistically significant differences of the maximum stiffness when compared with the regular springs from the same manufacturer.

The coated springs from the two different manufacturers presented statistically significant differences of the maximum stiffness. This might indicate differences in the manufacturing process of the coated springs used by the manufacturers.

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