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Effect of Recycling on Mechanical Properties of Nickel-Titanium Closed Coil Springs – An In Vivo Study

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Abstract

Introduction: The aim of the study was to evaluate the effects of recycling on the mechanical properties of Nickel Titanium (NiTi) closed coil springs after regular clinical use.

Materials & Methods: The experimental group involved thirty NiTi closed coil springs of 9 mm length which were used for regular canine retraction for a period of 3 months. They were autoclaved and the mechanical properties were tested using Instron universal testing machine and compared with that of the control ones which consisted of thirty new Ni Ti closed coil springs of similar length and make.

Results: The mean force level of test group was 1.39N where as that for control group was 1.73N with a significant difference between both the groups. The tensile stress and energy at extension also were significantly higher for the control group.

Conclusions: The mechanical properties including the force level, tensile stress and energy at extension were significantly less for the recycled NiTi closed coil springs as compared to that of the control ones. Even though the force of the coil spring reduced considerably as compared to the control group samples, the mean force level for the test group was within the normal range required for canine retraction.

Keywords: Recycling, Ni Ti closed coil spring Force level, Mechanical properties, Tensile stress, Energy, Tensile strain, Surface topography

Introduction

Nickel-titanium alloys have gained substantial popularity for clinical application since their introduction into orthodontics in the early 1970s [1,2]. This has been attributed to their desirable mechanical properties, like high spring back, flexibility, low stiffness and high stored energy .These properties make the alloy resistant to permanent deformation so that they return to their original shape after clinical use [3].

Nickel-Titanium alloys have been used to provide light continuous forces over a considerable range of activation in various forms like arch wires, palatal expanders, open and closed coil springs owing to their two unique properties, super elasticity and shape memory [1].

The use of NiTi closed coil springs helps in space closure by individual tooth retraction or protraction, distal movement of teeth, and also traction of impacted teeth [4]. NiTi coil springs do not exhibit rapid force decay such as that seen with elastic chain or elastic modules, nor do they display the extremes in space closing forces of stainless steel coils or closing loops [5-9].

The distinct advantage of NiTi closed coil spring over polyurethane elastomeric chains is that they are highly resistant to degradation in oral environment. It has been suggested that excessive force in space closure could produce adverse effects such as loss of incisor torque control and loss of tip [10]. The low constant force of NiTi springs may be more biologically compatible than the intermittent high forces delivered by elastic chain, which has been found to degrade by up to 50% after 4 weeks of activation. The rate of space closure has been found to be quicker and more consistent with NiTi coil spring than with elastic modules, with no observable differences in final tooth position [5].

However the relatively high cost of NiTi closed coil springs and their ability to return to their original form has prompted orthodontists to recycle them [11,12]. Repeated exposure of the coil spring to various physical stresses and chemical agents in the oral environment followed by recycling which involves sterilization may induce changes in their mechanical properties and surface condition [3].

Several studies on NiTi arch wires have demonstrated physical changes caused by their clinical use and sterilization [3,12-14]. Most of the reported studies on recycling of nickel titanium products were focused on arch wires, with less attention paid to the springs. One study has been conducted on the effect of recycling on NiTi closed coil springs. But it was an invitro study done in simulated oral environment which measured only force levels of coil spring [15].

Even though it appears that the load deformation properties of arch wires and springs are similar, the deformation of arch wires is usually expressed as angular bending or linear deflection, while that of closed coil spring should be expressed as elongation [16]. Hence along with the force levels, other mechanical properties like tensile stress, tensile strain and energy at the extension similar to clinical level needs evaluation. Also the previous studies on NiTi arch wires have revealed an increased surface roughness after recycling [17-18]. Sarkar and Schwaninger demonstrated that NiTi wire has a tendency to corrode when subjected to either oral fluid or chloride solution [19]. So the purpose of the investigation is to evaluate the changes in the mechanical properties and surface characteristics of NiTi closed coil springs after clinical use and recycling.

Materials and Methods

The study consisted of 60 NiTi closed coil springs which were divided in to experimental group and control group. The experimental group involved thirty NiTi closed coil springs of 9 mm length (Rabbit force closed coil springs with eyelets ,medium force 150g) which were used for regular canine retraction for a period of 3 months and were tested for the effects of recycling on the mechanical properties and surface topography. The control group involved thirty new NiTi closed coil springs of similar length and make (9 mm length Rabbit force closed coil springs with eyelets, medium force150g).

Institutional Ethical Committee clearance was obtained. The NiTi closed coil springs from the experimental group were placed in patients undergoing orthodontic treatment during the maxillary canine retraction for a period of 3 months (Fig 1.) For standardization the coil springs received equal amount of extension (9mm to 11.7mm) and were generating constant force required for canine retraction. The treatment was carried out by a single orthodontist.

The coil springs from the experimental sample were cleaned to remove debris by ultrasonic cleansing machine followed by sterilization using autoclave at 121^0 C, 15-20 psi pressure for 15 minutes. The mechanical properties like the force level, tensile stress, tensile strain and energy at extension of both experimental and control group were measured using Instron universal testing machine (Instron model 3366). The coil springs were mounted on the crossheads of the testing machine by using a pair of hooks made of 1mm stainless steel wire. The coil springs were carefully stretched from 9mm length to 11.7mm (Fig2&3) the loading rate was fixed to 5mm/minute. The level of activation for each sample was maintained constant during the measurement which was confirmed using an electronic digital vernier caliper.

Scanning electron microscopic images were obtained at nine different areas at 1mm interval throughout the entire length of representative samples of both recycled and new nickel-titanium closed coil springs for evaluating the surface topography. Means and standard deviations were calculated for force levels, tensile stress, tensile strain and energy at extension for both control and experimental groups. Unpaired t test was used for statistical analysis.

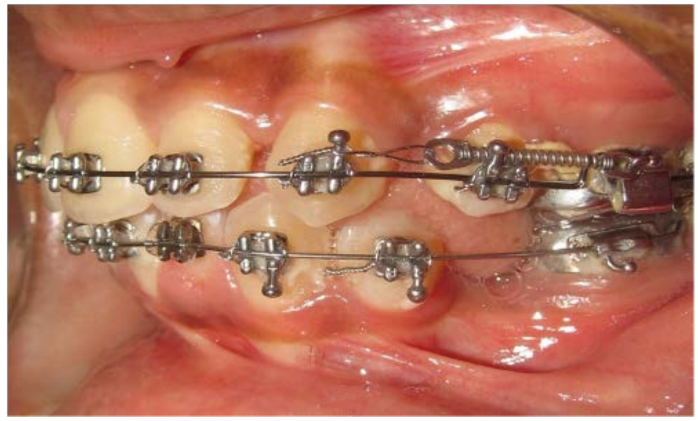

Fig. 1: Niti Coil Spring Used For Canine Retraction

Fig. 2: Coil Spring Placed In Instron Universal Testing Machine –Initial Position

Fig. 3: After Stretching For Measurement. Extension Confirmed By Digital Vernier Caliper

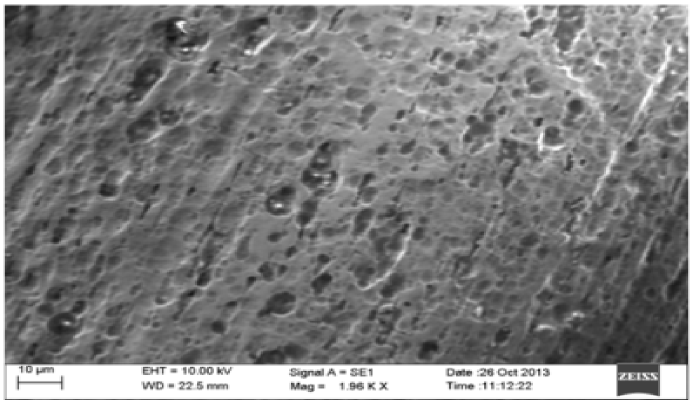

Fig. 4: Scanning Electron Microscopic Image Of Test Group

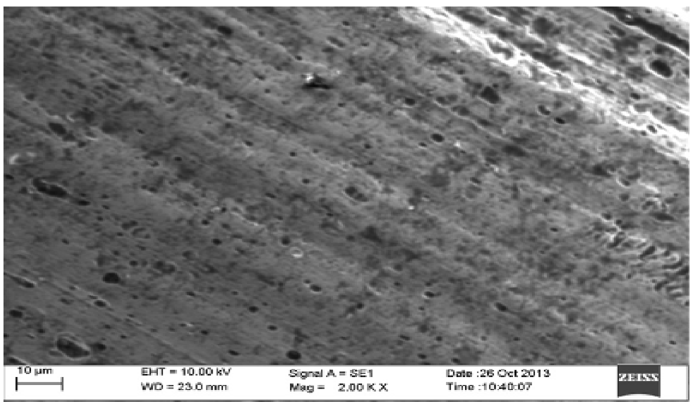

Fig. 5: Scanning Electron Microscopic Image of Control Group

Results

The mean force level of test group was 1.39N with a standard deviation of 0.11 where as that for control group was 1.73N with a standard deviation of 0.05 and the p value was <0.05 indicating a significant difference between both the groups. (Table 1) The tensile stress at extension for test group was 0.07MPa with a standard deviation of 0.006 and for control group was 0.08MPa with a standard deviation of 0.0026 which also shows a significant difference between the two groups. (Table 2) The energies at extension were 0.00249J, 0.002J for the control and test group respectively. The energy levels of control group samples were significantly higher as compared to that of test group. (Table 3)

The tensile strain at extension was also less for the test group samples, but the difference was not statistically significant. (Table 4)

Table 1: Force Level at Extension

	N	MEAN (Newton)	STANDARD DEVIATION	95% CONFIDENCE INTERVAL FOR MEAN		t value	p value
				LOWER BOUND	UPPER BOUND		
Test group	30	1.390333	0.118772	1.345983	1.434684	14.434	<0.05 significant
Control group	30	1.730667	0.050714	1.711730	1.749604		
Total	60	1.560500	0.194025	1.510378	1.610622		

Table 2: Tensile Stress at Extension

	N	MEAN (MPa)	STANDARD DEVIATION	95% CONFIDENCE INTERVAL FOR MEAN		t value	p value
				LOWER BOUND	UPPER BOUND		
Test group	30	0.070814	0.006051	0.068555	0.073074	14.370	<0.05 significant
Control group	30	0.088104	0.002608	0.087130	0.089078		
Total samples	60	0.079459	0.009866	0.076910	0.082008		

Table 3: Energy at Extension

	N	MEAN (J)	STANDARD DEVIATION	95% CONFIDENCE INTERVAL FOR MEAN		t value	p value
				LOWER BOUND	UPPER BOUND		
Test group	30	0.002013	0.000197	0.001940	0.002087	11.598	<0.05 significant
Control group	30	0.002494	0.000113	0.002452	0.002536		
Total	60	0.002254	0.000290	0.002179	0.002329		

Table 4: Tensile Strain at Extension

	N	MEAN mm/mm	STANDARD DEVIATION	95% CONFIDENCE INTERVAL FOR MEAN		t value	p value
				LOWER BOUND	UPPER BOUND		
Test group	30	0.301680	0.000893	0.301347	0.302013	0.966	0.338 Non significant
Control group	30	0.302339	0.003630	0.300984	0.303694		
Total	60	0.302010	0.002642	0.301327	0.302692		

Discussion

The desirable mechanical properties of NiTi coil springs and their relatively high cost has prompted their reuse. The properties of super elasticity and shape memory of NiTi coil spring allow the application of light and continuous forces over a long range, which lead to a more physiologic tooth movement during space closure. But NiTi arch wires are in the order of 5–40 times costlier than the other alloys.

In the recent past, the keen awareness by both public and profession about the serious diseases transmitted through cross contamination has resulted in a closer examination of the orthodontic sterilization procedure. The main objective of the cross infection control is the elimination or reduction of the number of microbes exchanged between individuals. Since many carriers of infectious diseases are unaware or unwilling to reveal their status, clinician should consider every patient as a potential carrier and adopt universal precautions. Among the available sterilization systems steam autoclaving is the standard and the most common form used [20].

While considering the reuse, the effect of sterilization and recycling on the properties of the coil spring has to be considered. The combined effects of repeated exposure of the NiTi coil spring to mechanical stresses and elements of oral environment followed by sterilization could result in alteration of its properties. So this study was done to assess the effect of clinical use followed by sterilization on the mechanical properties of NiTi closed coil spring.

Most of the previous studies which were done to study the effect of recycling in NiTi products involved the use of arch wires. According to Kapila et al Nitinol wires subjected to one or two recycles demonstrated statistically significant differences during loading than the control wires [21]. Shiva Alavi et al also shows that steam sterilization caused decrease in the applied force values of super elastic NiTi alloy arch wires in both loading and unloading phases [22]. While the other studies on NiTi arch wires on the effect of sterilization by Mathew et al and Lee et al showed that there was no statistically significant difference in mechanical properties before and after sterilization [12,13].

Spring wires differ from arch wires in that the springs are subjected to winding during its manufacturing procedure [23]. For this reason, the load exerted by the NiTi coil spring would be expected to be less predictable than those from NiTi arch wires and the results obtained from studies on arch wires could not be fully extended to coil springs. NiTi coil springs could also be reused if adequate force levels are maintained after clinical use and sterilization.

The previous study about the effect of recycling on unloading forces of NiTi closed coil spring was done in simulated oral environment [15]. In actual clinical situation various other factors like the changes in temperature and chemical environment due to intake of different fluids and food substances and even the mechanical stresses due to oral functions could alter the properties of coil spring.

Since NiTi coil springs are having the disadvantage of collecting debris [24],after removing the coil springs from the patient’s mouth, they were cleaned using ultrasonic cleansing machine and sterilized by autoclaving.

While measuring the mechanical properties in universal testing machine, the coil springs were carefully stretched to increase their length from 9mm to 11.7mm which was giving the constant force required for canine retraction when used clinically and the amount of extension was kept constant by using a pair of hooks made of 1mm stainless steel wire and confirmed by digital vernier caliper. The loading rate was fixed to 5mm/minute as done in the study by Momeni Danaei et al [15].

The results showed that the mean force level for control group was 1.73N, but that of the test group was 1.39N, which is significantly less. Also the tensile stress, energy and tensile strain at extension were less for the test group as compared to that of the control group. Except the tensile strain at extension, all the other values were statistically significant.

Since the coil spring is already subjected to some torsional and tensile stress while winding during the manufacturing process, there could be changes in the load deformation properties of coil spring compared to the NiTi wires [25]. In addition to this the oral temperature changes and mechanical microdeflections caused by tongue play or mastication could also cause changes in the mechanical properties [26]. The relative concentration of the austenitic and martensitic phases in the alloy would determine the resultant stiffness of the coil spring and the amount of force delivered [27]. Theoretically a consistent presence of martensitic phase in the NiTi alloy, either thermally generated or stress-induced, is responsible for the lowering of the force delivery. The coil springs with high resilience (increased stored energy) aid in delivering clinically desirable low continuous forces with an increased working range [28]. It was seen in the present study that there is a reduction in the energy of the recycled coil spring which reduces its the elasticity. This could probably explain the reduction in the force delivery after recycling.

Several studies revealed that the Ni-Ti wires were having more surface indentations and pitting after recycling; which indicated surface corrosion and decreased performance of Nitinol [17,18,29]. The representative samples from the experimental group of coil springs showed an increased surface roughness as compared to the control group in the scanning electron microscopic images (Fig 4&5). However since the surface topography is evaluated qualitatively only for representative samples from the test and control group, proper conclusions can not be drawn and further studies are recommended.

Momeni Danaei et al concluded that recycling of the Ni-Ti closed coil springs could decrease their force levels but this was not clinically significant [15].

The reason for altered mechanical properties in case of NiTi coil spring could be due to the surface roughness produced by pitting and surface corrosion occurring during clinical use and sterilization leading to deterioration of the mechanical properties of NiTi alloys These changes in mechanical properties would become clinically significant in case of NiTi coil spring because of their small cross sectional diameter which also makes it prone to more micromechanical distortion during the clinical use.

The variation in the force levels among NiTi coil springs in the experimental group could be due to the effect of the temperature changes and the mechanical stress in the oral cavity. Oral cavity has one of the most inhospitable environments in the human body. Therefore, orthodontic archwires, coils or brackets are subjected to larger temperature variations ranging from ice cold temperatures (5ºC) to that of hot coffee and soup (70ºC). Eduardo Espinar-Escalona et al showed that the increase in temperature of 18 ^{0}C induced an increase in the NiTi coil spring force of 30%. However, when the temperature returns to 37 ^{0}C the distraction force recovers to the initial level. After cooling down the spring to 15 ^{0}C, the force decreased by 46% [30]. Tripolt et al also showed that Superelastic coil springs are extremely temperature sensitive and thus produce a large force variation at different mouth temperatures [31].

The mean force level for experimental group was 1.39N which is 141.74 g. According to Quinn and Yoshikawa the force for canine retraction could vary from 100g to 200g [32]. So even though the force of the coil spring reduced considerably when compared to that of the control group, it is not clinically significant. Since the study sample was in clinical use only for three months, the result of the study should be interpreted with caution. Hence studies involving usage of coil springs for longer period are recommended.

Summary and Conclusion

This investigation evaluated the changes in the mechanical properties of NiTi closed coil springs after clinical use and recycling.

The results show that

- The mechanical properties including the force level, tensile stress and energy at extension were significantly less for the recycled NiTi coil springs as compared to that of the control ones.
- Even though the force of the coil spring reduced considerably as compared to the control group samples, the mean force level for the test group was within the normal range required for canine retraction.

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