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Original Article

The effects of aging process and preactivation on mechanical properties of nickel-titanium closed coil springs

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ABSTRACT

Background: The most favorable feature of nickel-titanium (Ni-Ti) alloys in orthodontics is producing constant forces in a wide deformation range. Ni-Ti closed coils produce compressive strength and can be used for several purposes such as space closure. The aim of this study was to evaluate the effects of the aging process (temperature changes and prolonged strain) on Ni-Ti closed coils and to assess the effects of preactivation on forces generated by these coils.

Materials and Methods: A total of 60 Ni-Ti closed coils (G&H Wire Co., Indiana, USA) were divided into four groups (n = 15). Two groups were kept in room temperature and two were incubated in 37°C in normal saline for 45 days. All the samples were extended to 30% of their original length. One group of the incubated coils and one group of room temperature coils were preactivated the same amount of 30%. The incubated groups also received 1000 thermocycles on days 22 and 45. The unloading forces were measured by a universal testing machine on days 0, 22 and 45. The data were analyzed using SPSS. Significance was set at 0.05.

Results: The unloading forces of the Ni-Ti closed coils was not affected by prolonged heat and moisture either in preactivated groups ($P = 0.8$) or the nonpreactivated groups ($P = 0.6$). Furthermore, preactivation had no significant effect on the unloading forces of Ni-Ti closed coils ($P = 0.7$).

Conclusion: Within the limitations of this study, both aging process and preactivation do not affect on mechanical properties of nickel-titanium closed coil springs. Preactivation had no effect on the forces generated by Ni-Ti closed coils.

Key Words: Closed coil springs, mechanical properties, nickel-titanium

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INTRODUCTION

Tooth movement requires force application. This force is produced by orthodontic appliances.[1] Continuous forces lead to the most efficient tooth movement. Nickel-titanium (Ni-Ti) alloys can generate relatively continuous forces.[2] After the introduction of Ni-Ti alloys to dentistry in 1970, it has been widely used.[3] Producing constant forces in a wide deformation range is the most favorable feature of Ni-Ti alloys, which is due to the two-phase structure of the alloy; the martensite and the austenite phases.[2]

For the best use, the alloy must be in the austenite phase when placed in room temperature.[2] Various orthodontic appliances are produced from Ni-Ti alloys such as closed or open coil springs.[4] Open coils generate expansive forces, while closed coils generate compressive forces.[4] Ni-Ti coil springs, unlike elastomeric chains, do not undergo rapid force degradation and unlike stainless steel coils do not generate extremely high forces.[5] Temperature and strain could lead to phase change in Ni-Ti alloys.[6] Therefore, the temperature changes, which occur in the oral cavity may affect the forces generated by the coils.[6] Several studies have

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showed that prolonged strain and heat could reduce the predictability of forces produced by coils.[1,5,7] It has been reported that preactivation can prolong the continuity of the forces produced by elastomeric chains.[8-10] The aim of this study was to evaluate the effects of the aging process (temperature changes and prolonged strain) on Ni-Ti closed coils and also to assess the effects of preactivation on the forces generated by these coils.

MATERIALS AND METHODS

In this experimental *in vitro* study, sixty 9 mm medium Ni-Ti closed coils (G&H Wire Co., Indiana, USA) were divided equally in to four groups (*n* = 15). In the 1st group, the samples were stretched to 12 mm (3 mm activation) using a universal testing machine (walter + bai, Switzerland). After that, the samples were returned to their original length by the testing machine, with the crosshead speed of 0.5 mm/s. The forces were recorded at every 0.5 mm. Holding jigs were designed; it was comprised of stainless steel rods, which were placed at 12 mm distances [Figure 1]. The samples were carefully placed on the holding jig after every test to maintain their 12 mm length during the study. These measurements were repeated in T1 = day 22 and T2 = day 45. In the 2nd group the process was similar to the 1st group except that after the measurement, the samples that were placed on the holding jig were inserted in normal saline (Samen, Mashhad, Iran) then transferred to an incubator (Behdad, Tehran, Iran) and kept in 37°C. Before repeating the tests in T1 and T2 the 2nd group samples underwent 1000 thermocycling cycles from 5°C to 55°C. The 3rd and 4th group samples were preactivated by the amount of 30% (3 mm) using the gauge provided by the manufacturer (G&H Wire Co., Indiana, USA). In the 3rd group, the process was similar to the 1st group and after the measurements, the samples were carefully placed on the holding jig and kept in room temperature and then the measurements were repeated in T1 and T2. In the 4th group, after the initial measurements the samples were placed on the holding jig and kept in normal saline inside the incubator. Before repeating the measurements in T1 and T2 the samples underwent 1000 thermo cycling cycles between 5°C and 55°C. Finally, the data was analyzed by the repeated measure two-way ANOVA using the SPSS software version 13 (SPSS, Chicago, IL, USA). The significance was set at 0.05.

Figure 1: The designed holding jig.

RESULTS

Statistical analysis showed that the mean forces produced in all groups were slightly higher than the target force stated by the manufacturer (120 gf). The mean forces are shown in Table 1 and Figure 2. Comparing the nonpreactivated groups showed that there was no significant difference between the forces in the dry and incubated groups in different time periods ($P = 0.6$). In the preactivated groups, there was no significant difference between the forces in the dry and incubated groups in different time periods ($P = 0.8$). Regarding preactivation, the mean forces of preactivated coils (dry and incubated) had no significant difference with the mean forces produced by nonpreactivated coils (dry and incubated) ($P = 0.7$). In the incubated groups, the mean forces slightly decreased from T0 to T2, but it was not

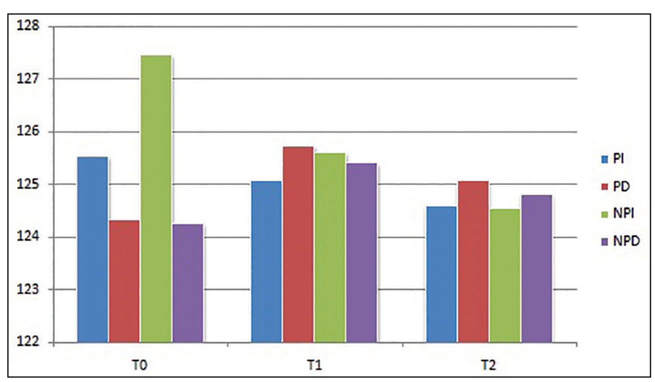

Figure 2: The mean values of unloading forces in different groups. PI = Prestretched and incubated, PD = Prestretched in dry condition, NPI = Nonprestretched and incubated, NPD = Nonprestretched in dry condition (the mean values of unloading forces are presented in gf.), T0 = Tested on day 1, T1 = Tested on day 22, T2 = Tested on day 45.

Table 1: The mean values of unloading forces in different groups (gf)

Time	Groups	*n*	Mean	Standard deviation	Standard error	95% confidence interval for mean		Minimum	Maximum
						Lower bound	Upper bound		
T0	PI	15	125.5333	4.50185	1.16237	123.0403	128.0264	117.00	131.00
	PD	15	124.3333	4.38613	1.13249	121.9044	126.7623	116.00	131.00
	NPI	15	127.4667	3.39888	0.87759	125.5844	129.3489	119.00	132.00
	NPD	15	124.2667	4.94927	1.27790	121.5259	127.0075	114.00	131.00
	Total	60	125.4000	4.43102	0.57204	124.2553	126.5447	114.00	132.00
T1	PI	15	125.0667	4.11386	1.06219	122.7885	127.3448	119.00	131.00
	PD	15	125.7333	4.66701	1.20502	123.1488	128.3178	114.00	132.00
	NPI	15	125.6000	4.99714	1.29026	122.8327	128.3673	117.00	133.00
	NPD	15	125.4000	3.73784	0.96511	123.3301	127.4699	117.00	130.00
	Total	60	125.4500	4.29988	0.55511	124.3392	126.5608	114.00	133.00
T2	PI	15	124.6000	1.88225	0.48599	123.5576	125.6424	122.00	129.00
	PD	15	125.0667	2.71153	0.70011	123.5651	126.5683	119.00	129.00
	NPI	15	124.5333	2.85023	0.73593	122.9549	126.1117	121.00	130.00
	NPD	15	124.8000	3.18927	0.82347	123.0338	126.5662	118.00	129.00
	Total	60	124.7500	2.64014	0.34084	124.0680	125.4320	118.00	130.00

PI: Prestretched and incubated; PD: Prestretched in dry condition; NPI: Nonprestretched and incubated; NPD: Nonprestretched in dry condition (the mean values of unloading forces are presented in gf); T0: Tested on day 1; T1: Tested on day 22; T2: Tested on day 45.

statistically significant ($P = 0.6$), but in the dry groups, the mean forces slightly increased, but this also was not statistically significant ($P = 0.4$).

DISCUSSION

In this study, we evaluated the effects of aging and preactivation on the forces produced by Ni-Ti closed coils. We measured the forces in the days 0, 22 and 45, while two groups were kept in room temperature and two groups were incubated in 37°C. We found that the mean forces produced by the coils, in all time periods, were slightly higher than the target force stated by the manufacturer. Vidoni *et al.*,[1] Bezrouk *et al.*[4] and Maganzini *et al.*[6] also reported that the mean forces produced by Ni-Ti coils were higher than the target force of the manufacturer. This difference could be due to different method of measurement between these studies and the manufacturer. In this study and the studies mentioned, the force measurements were performed by the highly accurate universal testing machine.

The results of this study showed that the forces produced by coils in room temperature had no significant difference with the forces produced by coils kept in the incubator, which means that prolonged moisture and heat did not affect the forces produced by Ni-Ti closed coils. Vidoni *et al.*[1] and Wichelhaus *et al.*[3] showed that the presence of moisture and heat doesn't affect the forces produced by Ni-Ti coils. On the other hand, Tripolt *et al.*[7] stated that heat increases the forces produced by Ni-Ti coils, but in the oral environment the magnitude of this force change is not significant. Bourke *et al.*[8] showed that Ni-Ti closed coils could maintain their force levels during oral environment changes. It seems that in normal conditions, phase change does not occur in Ni-Ti alloys present in the oral cavity. Wichelhaus *et al.*[3] have reported that some manufacturers preactivate the Ni-Ti coils, which results in a longer plateau in the stress-strain charts of the coils. Our study showed that preactivation doesn't affect the forces produced by Ni-Ti closed coil in either dry or incubated environments. Regarding the change in forces produced by Ni-Ti closed coils, our study showed that the incubated coil (either preactivated or nonpreactivated) forces decreased over time, but the coils kept in room temperature (preactivated or nonpreactivated) showed increased forces over time. However, none of these changes were statistically significant. Nattrass *et al.*[11] have reported an increase in forces produced by Ni-Ti coils over time whilst, Angolkar *et al.*[12] showed a decrease in Ni-Ti coil forces over time. Vidoni *et al.*[1] reported that nitinol coils had no significant force change overtime (after 45 days) but Ni-Ti coils had a slight force decrease after 45 days which was statistically significant but didn't have clinical significance.

In the studies of Nattrass *et al.*[11] and Angolkar *et al.*[12] thermocycling was not performed, which could explain the different results. In Vidoni *et al.*[1] study, the coils were stretched 50% of their initial length, whilst in our study, the coils were stretched

30% and a different brand of coil was used in their study, which could be the cause of different results.

CONCLUSION

1. Aging process does not affect the forces produced by Ni-Ti closed coil spring.
2. Preactivation has no statistically significant effect on the forces generated by Ni-Ti closed coils.

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