Force Characteristics of Nickel Titanium Closed Coil Springs (3M, GAC, RMO)

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ABSTRACT

Introduction: The aim of this study was to compare the characteristics of deflection load of three kinds of nickel titanium closed coil springs.

Methods and Materials: This research was an experimental study. Research sample contains three kinds of NiTi closed coiled springs (heavy, medium, light) from GAC, 3M, and RMO factories. 10 springs with 9 mm length for each group (totally 90 springs) were subjected to tensile test. They were pulled to 12 mm extension by Dartec machine and then were released. Our variables were maximum force at 12 mm extension, force at the start of the plateau, deflection at the start of plateau, mean force of plateau, plateau slope, force at the end of plateau, deflection at the end of plateau. For tensile test, we used DARTEC universal machine. The data were analyzed by ANOVA and Duncan tests.

Results: In comparision among identical coils from different factories, the deflection at the end of plateau hadn't significant difference ($P=0.107$) but the other parameters had significant differences ($P<0.001$). Among heavy coils, the maximum force of coil had statistically significant difference between 3M and GAC heavy coils. In medium coils, the maximum force of three kinds of springs had significant differences with each other ($P<0.001$). In comparision among light springs, maximum force of coils had significant differences with each other. Mean force of plateau among the identical types of different manufacturer and among the different types of one factory had significant differences ($P<0.001$).

Discussion: Only light type of RMO coil springs had a favorable force for tooth movements. In GAC and 3M springs, the medium type is recommended for canine retraction.

Key words: NiTi, Closed Coil Springs, Force Characteristics.

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Introduction

Among orthodontic alloys, nickel titanium alloy had attracted many considerations because of two unique properties (shape memory and low modulus of elasticity). Manufactures produce NiTi springs for dental movements and they believe that the ideal force is produced by these coils[1]. With attention to this fact that the production method has many influences on coil's quality, thus the comparision of mechanical properties between three types of NiTi coils that are conventionally used in orthodontic clinics has many benefits for us. Most of the reported studies of nickel titanium products have focused on arch wires with less attention paid to springs.

Miura, in 1988, introduced a NiTi coil spring with super elastic property and a constant force in unloading phase. He said that by increasing the diameter of the NiTi wire and constancy of its lumen diameter, the

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amount of force is increased but super elasticity range of the coil is decreased. With constancy of wire's diameter and increasing the size of the lumen, the force is decreased and super elasticity is increased. With elevation of temperature transition phase in these coil springs, the force in super elastic section will be decreased [2].

Angloker, in 1992, said that force decay occurres in all of coils and the most force decay occurs in the first 24 hours. This force decay is higher in steel and chrome cobalt springs than NiTi coils. The mean of coil's force decay is between 8.7 to 20 percent and this is very lower than elastics and elastic modules force degradation [3].

Han, in 1993, studies on nickel titanium alloys and attempted to determine whether their mechanical properties are affected by prolonged exposure to a static, simulated oral environment. Nickel titanium springs suffered no degradation of their spring properties where as polyurethane elastics lost a large portion of their force-generating capacity [4].

Barwart, in 1996, studied the influence of temperature on the coils' forces. He concluded that super elasticity occur in specific temperature and thermal changes in mouth can change the coils' forces [5].

Manhartsberger in 1996, investigated into GAC springs (open and closed type). The closed coil springs were subjected to a tensile and the open coil ones to a compression test. He founded that the force delivery given by the producer could be achieved only within certain limits [6].

Tripolt, in 1999, examined three kinds of GAC coils (light, medium, heavy) between 15^{o} to 60^{o} of temperature. Although the force changes with variable temperatures are considerable but these changes is lower in oral cavity because of lower thermal changes were not significant. Force changes were not significant for medium and heavy coils in 30^{o} to 40^{o} [7].

Schneevoigt, in 1999, studied about the force / compression characteristics of 32 commercially available NiTi compression springs from seven distributors in order to support the orthodontist, to select an appropriate spring. He concluded that springs made of super elastic NiTi alloys cover a broad field of application with nearly constant force levels [8].

The aim of this research was the evaluation the characteristics of deflection load of NiTi closed coils of three factories.

Methods and Materials

This research is an experimental (descriptive-analytic) study. Our samples were three kinds of nickel titanium closed coil springs (light, medium, heavy) from GAC, RMO, 3M factories with identical lengths (9 mm). The number of samples were 10 in each group (totally 90 samples). Measurements were done with DARTEC universal test machine. Additional apparatus for attaching the springs to DARTEC were made.

Two columns were made with a hook (0.016 inch steel) on each of them for attaching to non removable and removable arms of the DARTEC machine. They were used for attaching coil springs to Dartec machine.

The distance between hook before the beginning of experiment was 9 mm, equal to the length of inactive coils. of variability of nickel titanium alloy's force in various environmental temperatures, we must do our experiments in a constant temperature (approximately near to the mouth temperature). For this aim, a digital thermometer with special probe (SUNS UT30 C) and precision of 1 degree of centigrade was used. The heat source was a 150 watts lamp with controlled distance.Initially we connected nickel titanium coil on DARTEC arms and the two arms were separated from each other with speed of 1mm per minute and the coils were pulled to extension of 12 mm. We recorded the spring's force at each 5 mm and then the coils were released with speed of 1 mm per minute and the force was recorded at each 0.5 mm.

We recorded variables such as the maximum force at 12mm (MAX F), start of plateau load (SPL), start of plateau deflection (SPD), mean force at the plateau (Mean P), slope of plateau (Slope), end of plateau load (EPL), and the end of plateau deflection (EPD).

Acquired data was transferred to computer by work shop soft ware. The deflection load diagram of each coil was traced by Excel software and then curve fitting was done. The parameters for each diagram were calculated and then were analyzed using ANOVA and Duncan tests with signification level of 0.001.

Results

Informations about the characteristics of RMO, GAC, and 3M coils are presented in tables 1, 2 and 3. The diagrams (1 to 3) indicate the comparision of heavy, medium, and light coils of three factories.

With ANOVA test, we founded the different among end of plateau deflections of heavy coils from different manufactures was not significant (P=0.107). All of other parameters had statistically significant differences (P<0.001).

One by one comparision of coils from different distributors were done with Duncan tests (tables 1, 2 and 3).

To compare heavy, medium, and light coils of one factory with together, different kinds of coils of each factory were compared with ANOVA tests. On this basis, the plateau slope in GAC coils didn't have significant differences (P=0.08). Other parameters had significant differences (P<0.001).

Then we used Duncan test and the following parameters showed no significant differences:

a) The deflection at the start of plateau between medium and heavy GAC coils,

b) The deflection at the start of plateau between heavy and light GAC coils,

c) The deflection at the start of plateau between light and medium RMO coils,

d) The plateau slope between medium and light GAC coils,

e) The plateau slope between medium and heavy GAC coils, and

f) The plateau slope between light and heavy GAC coils.

Other parameters had statistically significant differences.

Table 1: Comparision of different heavy closed coil springs (with significance level of 0.001)

	MAXF Mean (SD)	*SPL Mean (SD)*	*SPD(mm) Mean (SD)*	*EPL Mean (SD)*	*EPD(mm) Mean (SD)*	*Slope Mean (SD)*	*Mean P Mean (SD)*
RMO	578.4(2.55)	455.22(2.53)	7.4(0.17)	321.19(2.90)	1.82(0.78)	24.01(0.57)	388.20(2.70)
GAC	296.38(1.09)	129.64(1.28)	6.74(0.12)	101.11(1.29)	2.15(0.12)	5.98(0.51)	115.54(1.26)
3M	295.79(1.67)	145.03(1.23)	6.67(0.99)	132.54(0.42)	2.71(0.952)	3.11(0.22)	138.78(0.79)
Pvalue	P<0.001	P<0.001	P<0.001	P<0.001	P=0.107	P<0.001	P<0.001

Table 2: Comparision of different medium closed coil springs (with significance level of 0.001)

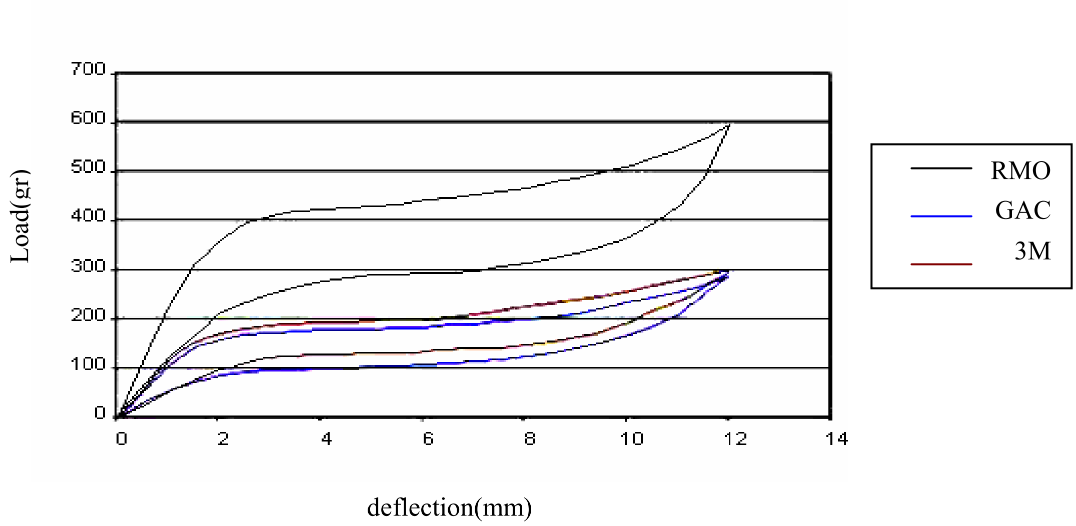
	MAXF Mean (SD)	*SPL Mean (SD)*	*SPD(mm) Mean (SD)*	*EPL Mean (SD)*	*EPD(mm) Mean (SD)*	*Slope Mean (SD)*	*Mean P Mean (SD)*
RMO	206.5(1.25)	94.8(1.68)	7.19(0.13)	63.92(1.49)	2.13(0.20)	6.08(0.14)	79.37(1.58)
GAC	219.25(1.41)	108.46(1.84)	6.81(0.87)	78.18(0.69)	1.80(0.69)	6.02(0.78)	93.32(0.75)
3M	197.37(1.4)	105.85(1.59)	6.41(0.87)	65.85(2.07)	2.4(0.15)	9.92(0.25)	85.85(1.81)

P-value	P<0.001	P<0.001	P<0.001	P<0.001	P<0.001	P<0.001	P<0.001

I, II, III: Duncan sub-groups
* p-value=0.059

Table 3: Comparision of different light closed coil springs (with significance level of 0.001)

	MAXF Mean (SD)	*SPL Mean (SD)*	*SPD(mm) Mean (SD)*	*EPL Mean (SD)*	*EPD(mm) Mean (SD)*	*Slope Mean (SD)*	*Mean P Mean (SD)*
RMO	396.36(1.55)	269.61(1.66)	7.16(0.17)	146.37(1.38)	2.30(0.21)	25.34(0.42)	207.99(1.51)
GAC	252.16(1.34)	118.24(0.81)	6.71(0.73)	91.27(0.88)	2.27(0.13)	6.04(0.96)	104.75(0.78)
3M	236.65(1.40)	113.50(1.40)	6.68(0.14)	82.95(0.76)	2.14(0.16)	6.44(0.19)	98.22(1.077)
P-value	P<0.001	P<0.001	P<0.001	P<0.001	P<0.001	P<0.001	P<0.001



Fiture 1: Comparision of different heavyNiTI closed coils.

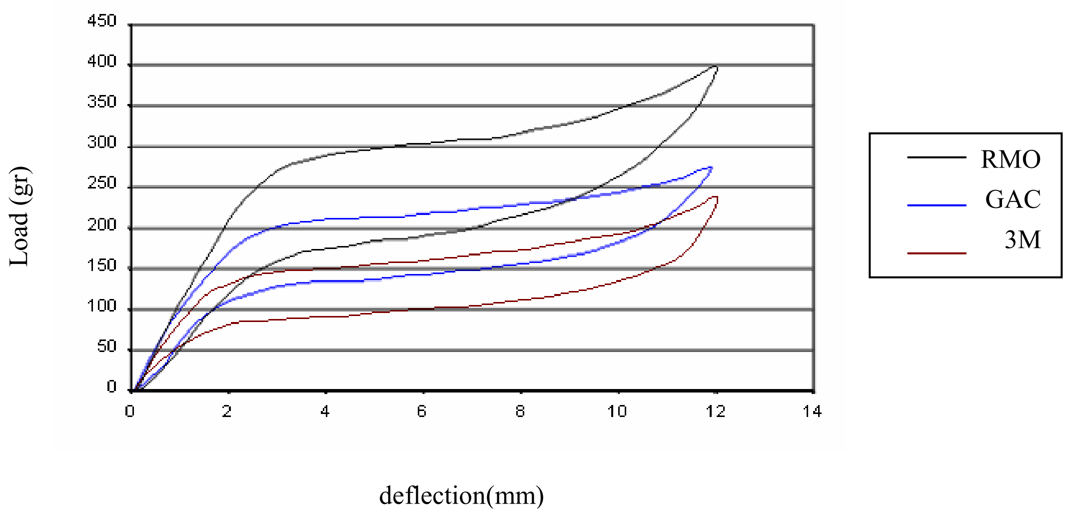


Figure 2: Comparision of different medium NITI closed coils.

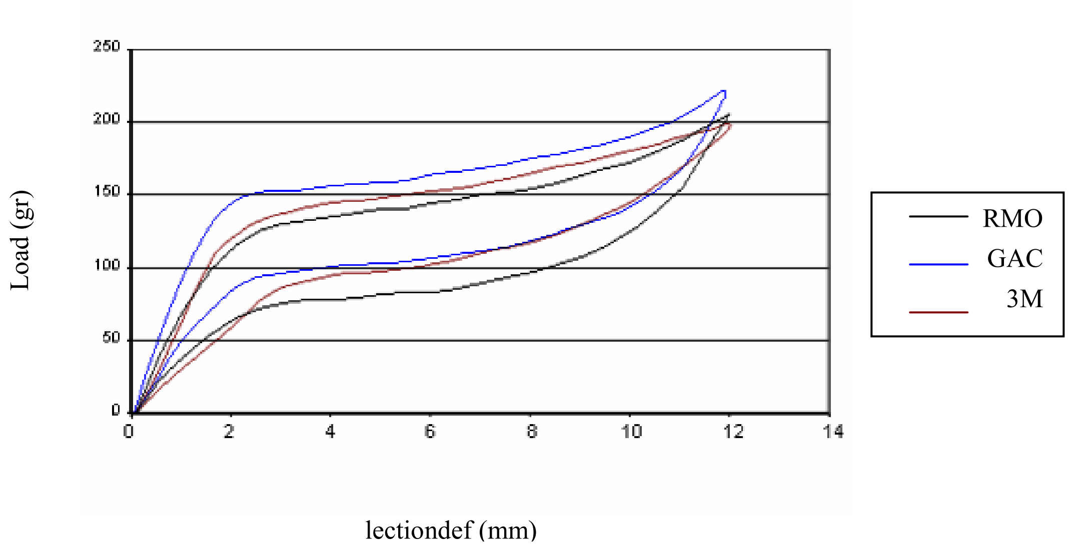


Figure 3: Comparision of different light NiTi closed coils.

Discussion

In studying light, medium, and heavy NiTi closed coil springs from 3M, GAC and RMO factories we founded that the maximum loading force of 3M and GAC heavy coil springs at 12 mm extension are approximately similar and it is very lower than what for RMO coils; however it is higher than the force, recommended by story and smith for canine retraction. They recommended 150 to 200gr force for canine movements [9]. Maximum load of heavy RMO coil is very high for distalization of canine tooth. We recommend it only when we need high forces. These findings about GAC heavy coil springs are similar to Manhartsberger findings [6].

Maximum load of RMO medium coil springs (396gr) at 12 mm extension are higher than 3M and GAC coils and it is not safe for canine movements. Applied force by 3M and GAC medium coils are similar to each other and we can use it for canine movements. The load of GAC medium coil springs are similar to findings of Manhartsberger [6].

Although the maximum load of light coils of three kinds at 12 mm extension had statistically significant differences($P<0.001$), but their forces were approximately similar. The load of GAC light coils is in recommended range for canine movements. The start of plateau load of heavy RMO springs is nearly three times of 3M and GAC heavy coils and it is very high for canine movement. The force delivered by 3M and GAC heavy coils at the start of plateau had statistically significant differences ($P<0.001$), but they are similar in clinical aspects and they are safe for canine movements. The force produced at the start of plateau by medium RMO coil springs (269gr) is more than double force of 3M and GAC springs and it is a little higher than the Reitan's recommendation force for canine movement [9].

The applied force at this point by medium 3M and GAC coils is near to each other and they are suitable for canine movement.

The start of plateau force for light 3M and GAC coil springs are identical to each other and it is a little higher than the force of

RMO light spring. This force is lower than the required force for canine movement and Burstone recommend this level of force for retraction of anterior teeth [10].

The start of plateau deflection in heavy coils starts faster than two other heavy coil springs. But the RMO force has many differences with 3M and GAC coils. Medium coils of three manufacturers didn't have apparent difference with each other. The applied force of RMO medium spring is higher than two other springs and the start of plateau deflection in RMO light springs is higher than GAC and this point in 3M spring is lower than the others.

The end of plateau load in RMO heavy spring is approximately $2\frac{1}{2}$ times the load of 3M and a little higher than three times the load of GAC springs. The load of 3M and GAC heavy springs are in the recommended range and it is more applicable than RMO springs.

The end of plateau load in medium springs of three manufacturers are approximately in acceptable range for a tooth movement, and in RMO springs is higher than in 3M and GAC. We must consider force degradation in plateau and, because of higher slope of RMO springs, force degradation in this spring is more than two other manufactures; thus, we must not rely on this force at this point.

The end of plateau load in GAC light spring is more than 3M and RMO. There is not any clinical difference among three manufacturers. Force degradation in 3M light spring is more than in other types because of more plateau slope. The mean plateau force in RMO springs is lower than mean plateau force in two other manufactures.

The mean of applied force by heavy RMO spring is more than two other identical springs and it's force consistency is lower than two others. Thus two important characteristic of suitable force (magnitude and consistency of force) are not in this type of spring.

Two types of heavy springs (3M and GAC) are more applicable than RMO springs in clinical usage and among them, GAC spring is better than 3M.

The mean of plateau force in moderate RMO spring is twice the force of 3M and GAC springs and based on Reitan and Burstone's recommendation, its force is acceptable for retraction of canine tooth [10]. But because of its plateau slope, its consistency is not suitable. The force applied by 3M and GAC medium springs are more suitable than RMO and among them, GAC spring is better than the others, because of more suitable force level along unloading diagram.

The mean force of plateau level in light springs is lower than $2\frac{1}{2}$ required force for canine retraction and it is recommended for retraction of incisor teeth. Force degradation in plateau phase in RMO light spring is lower than 3M but there is not any difference between light GAC and 3M springs.

Among light, medium, and heavy RMO springs, the light type had more consistent and suitable force than heavy and moderate springs.

Among different types of GAC springs and with attention to maximum loading force, plateau slope, the mean force of plateau, and story and smith's idea that recommended 150 to 200gr force for canine movement, the medium type of this spring is suitable for canines and the heavy spring for molar or multiple tooth movement and the light spring is good for incisor movement [9].

Among 3M springs and according to story and smith's idea, the medium type is the first choice for canine movement and the heavy type is suitable for posterior tooth movements [9]. The light 3M spring is good for incisor movements.

Among RMO springs, the heavy type had a high force level and its indication for routine movements is under question. Moderate and light springs are better for clinical application.

Although the mean force of plateau of moderate spring is suitable for canine movement, but maximum loading force and plateau slope in this spring are higher and we don't recommend this spring for clinical use.

Force characteristic of light springs are better than medium and heavy types and they can be used for incisor movements. With attention to plateau slope of heavy and moderate types, their application is under question. But the light type of RMO springs can be compared with light types of 3M and GAC springs.

We agreed with Manhartsberger, Han, and schneevoigt in this important character of NiTi coil springs that they deliver a good clinical behavior and this alloy is a preferred material for many orthodontic applications [4, 6, 8], but we must consider the optimal force level that we need for different tooth movements.

References

1. *Proffit WR, Fields HW. Contemporary orthodontics. 3rd ed. New York: Mosby; 2000. p. 240-50,326-40.*
2. *Miura F, Mogi M, Ohura Y, Karibe M. The super-elastic Japanese NiTi alloy wire for use in orthodontics. Part III. Studies on the Japanese NiTi alloy coil springs. Am J Orthod Dentofacial Orthop. 1988 Aug; 94(2):89-96.*
3. *Angolkar PV, Arnold JV, Nanda RS, Duncanson MG Jr. Force degradation of closed coil springs: an in vitro evaluation. Am J Orthod Dentofacial Orthop. 1992 Aug;102(2):127-33.*
4. *Han S, Quick DC. Nickel-titanium spring properties in a simulated oral environment. Angle Orthod. 1993 Spring;63(1):67-72*
5. *Barwart O. The effect of temperature change on the load value of Japanese NiTi coil springs in the superelastic range. Am J Orthod Dentofacial Orthop. 1996 Nov; 110 (5): 553-8.*
6. *Manhartsberger, C. Seidenbusch, W. Force delivery of NiTi coil springs Am J Orthod Dentofacial Orthop 1996; 109: 8–21.*
7. *Tripolt H, Burstone ch, Bantleon P, Mansehiebel W. Force characteristics of nickel titanium tension coil springs. Am J Orthod Dentofacial Orthop. 1999 May;115(5):498-507.*
8. *Schneeviogt R, Haase A, Eckardt V, Harzer W, Bourauel C. Laboratory analysis of superelastic NiTi compression springs. Med Eng Phys. 1999 Mar;21(2):119-25.*
9. *Webb R, Caputo AA, Chaconas SJ. Orthodontic force production by closed coil springs. Am J Orthod. 1978 Oct;74(4):405-9.*
10. *Smith RJ, Burstone CJ. Mechanics of tooth movement. Am J Orthod. 1984 Apr; 85(4): 294-307.*