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Force degradation of nickel-titanium closed coil springs: an in vitro

Degradação de força de molas fechadas de níquel-titânio: um estudo in vitro

Fuerza de degradación de resortes cerrados de níquel-titanio: un estudio in vitro

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Abstract

Objective: evaluation of the forces resulting from the initial stretching of closed Nickel-titanium springs and the degradation of these forces after 28 days of stretching. Methodology: The sample comprised 80 Morelli Nickel-titanium closed coil springs, divided into 4 groups of 20 according to their length, 7, 9, 12 and 15mm. In each group, 10 spring coils suffered distension in 50 and 100% of its original length and were maintained in devices to simulate the distension. The resulting forces were measured with a tensiometer and compared with the force described by the manufacturer on the spring packaging (200 grams force). Measurements were performed in 2 time-points; right after the initial strain (T1) and after 28 days (T2), when the devices were kept in artificial saliva at a temperature of 37°C. For the statistical analysis, the Mann-Whitney test was applied to compare the forces in T1 with the manufacturer's value and the paired t test to compare the forces between T1 and T2. In all statistical tests, a significance level of 5% was adopted. Result: In T1 the springs of 9, 12 and 15mm stretched by 50% showed significantly lower values and the springs of 7 and 15mm stretched by 100% showed significantly higher values, both compared with the manufacturer's recommendation. All groups of springs showed significant degradation of forces between T1 and T2, with percentage rates of force degradation from 7.1 to 21.9%. Conclusion: It is necessary to measure the forces of the springs during orthodontic treatment, aiming to establish an optimal force for tooth movement and thus optimizing the total treatment time.

Keywords: Orthodontics; Movement; Spring coil; Nickel-titanium.

Resumo

Objetivo: Avaliação das forças resultantes da distensão inicial de molas fechadas de Níquel-titânio e a degradação dessas forças após 28 dias de distensão. Metodologia: Foram utilizadas 80 molas de níquel titânio da marca Morelli divididas em 4 grupos de 20 de acordo com o comprimento, 7, 9, 12 e 15mm, sendo que 10 molas de cada grupo foram mantidas em dispositivos simulando a distensão em 50 e 100% do seu comprimento original. As forças resultantes foram medidas com tensiômetro e comparadas com a força descrita pelo fabricante na embalagem das molas (200 gramas força). As mensurações foram realizadas logo após a distensão inicial (T1) e após 28 dias de distensão (T2). Os dispositivos foram mantidos em saliva artificial a uma temperatura de 37°C. Para a análise estatística foi utilizado teste t independente para comparação das forças em T1 com o valor do fabricante e o teste t pareado para comparação das forças entre T1 e T2. Em todos testes estatísticos foi adotado nível de significância de 5%. Resultado: Em T1, as molas de 9, 12 e 15mm distendidas em 50%

apresentaram valores significantemente menores e as molas de 7 e 15mm distendidas em 100% apresentaram valores significante maiores, ambos comparados com o valor do fabricante. Todas os grupos de molas apresentaram degradação significante das forças entre T1 e T2. Conclusão: Faz-se necessário fazer a mensuração das forças das molas durante o tratamento ortodôntico, visando estabelecer uma força ótima para a movimentação dentária e otimizando assim o tempo total de tratamento.
Palavras-chave: Ortodontia; Movimentação; Mola; Níquel titânio.

Resumen

El objectivo de este articulo científico fue evaluar los valores de las fuerzas resultantes de los resortes de ojalillo en niquel-titanio y también evaluar la degradación de estas fuerzas después de 28 días de distención. Se utilizaran 80 resortes de ojalillo en níquel-titanio de la casa comercial Morelli divididos en 4 grupos de 20 según las longitudes 7, 9, 12 e 15 mm y 10 resortes de cada grupo fueron mantenidos en aparatos que simulan la distensión en 50% y 100% de su longitud original. Se medieron las fuerzas resultantes con tensiómetro (gramos) y se compararon con la fuerza descrita por el fabricante en el empaque de los resortes (200 gramos fuerza). Las mediciones se realizaron en 2 etapas; imediantamente después de la tesión inicial y después de 28 días de tensión. Los aparatos fueron mantenidos en saliva artificial a uma temperatura de 37° C. Para el análisis estadístico se utilizó prueba t independente para comparación de las fuerzas en T1 con el valor de la casa comercial y la prueba T emparejada para comparación de las fuerzas entre T1 y T2. En todas las pruebas estadísticas se adoptó um nivel de significancia de 5. De acuerdo a los resultados en T1, los resortes de 9, 12 y 15mm extendidos en 50% mostraron valores significativamente más bajos y los resortes de 7 y 15 mm extendidos en 100% mostraron valores significativamente más grandes, ambos en comparación con el valor de la casa comercial. Todos los grupos de resortes mostraron degradación significante de las fuerzas entre T1 y T2. En conclusión, es necesario hacer la medición de las fuerzas de los resortes durante el tratamento de ortodoncia, con el objetivo de estabelecer uma fuerza optima para el movimiento dentario y optimizando la duración total del tratamiento.
Palabras clave: Ortodoncia; Movimentación; Resortes; Niquel-titanio.

1. Introduction

The closure of remaining spaces after extraction or tooth loss by sliding mechanics is one of the most common types of orthodontic movement. Several devices may be used for that purpose, such as closed nickel-titanium (NiTi) or stainless steel coil springs, elastomeric chains and archwires with space closure loops. The development of NiTi alloy allowed the introduction of favorable mechanical properties for orthodontic movement, such as superelasticity and memory shape. Thus, it became possible to use light and constant forces, to move the teeth faster with less discomfort and less adverse effects (Miura, et al., 1998 ; von Fraunhofer, Bonds & Johnson, 1993 ; Normam, Worthington & Chadwick, 2016).

Any orthodontic movement, such as anterior retraction for extraction space closure or distal movement, as well as mesialization of molars to the edentulous space, requires biologically compatible forces maintained during the period between sessions. Several authors have compared the use of forces between NiTi coil springs and elastomeric chains for space closure (Samuels, Rudge & Mair, 1998 ; Nattrass, Ireland & Sherriff,1998; Mohammed et al .,2018 ; Santos, et al ., 2007; Nightingale & Jones ,2003; Angolkar, et al.,1992). Most NiTi coil springs present good results concerning force degradation and deformation over time, being a good option for this type of orthodontic mechanics.

However, *in vitro* studies evaluating the forces released by NiTi coil springs simulating the oral environment have demonstrated contradictory results. Some indicate a reduction in forces (Santos,et al., 2007 ; Manhartsberger & Seidenbusch,1996) other indicated increases (Nattrass, Ireland & Sherriff,1998), and others only reported no differences in forces over time (Han & Quick, 1993 ; Vidoni, et al., 2010).

Thus, due to the lack of consensus about the forces released by NiTi coil springs and to investigate if the force parameters indicated on packages are reliable, this study compared the degradation of forces delivered by NiTi coil springs of different lengths and degree of extension.

2. Methodology:

2.1 Meaningful difference between groups

Based on a similar study (Santos et al, 2007), a meaningful difference of 17 gf with a SD of 9gf was adopted for force degradation of a 12mm Morelli coil spring after one day distended 100% of the original length.

2.2 Sample size calculation

The sample calculation was based in a similar study (Santos et al, 2007) where authors selected 40 coil springs divided into 4 groups of 10 each. Then, we also distributed our sample in 10 coil springs in each group.

2.3 Sample preparation and handling

This *in vitro* study comprised 80 Morelli Nickel-titanium closed coil springs, divided into 4 groups of 20 according to their length (7mm, 9mm, 12mm and 15mm) and subdivided according to the amount of distension in 50 and 100% of its original length. So, each group was composed by 10 coil springs.

A device was designed for the study, composed of a metallic base with vertical pins sequentially arranged in two rows at a 20-mm distance (Figure 1).

Figure 1. Metallic device designed for the study with sequential vertical pins.

Source: Authors.

The pins were used as support for insertion of coil springs, which were extended by 50 and 100% of their original length. The measurements were obtained using an accurate tensiometer manufactured by Zeusan (Figure 2).

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Figure 2. Tensiometer measuring the forces of the extended coils springs.

Source: Authors.

The resulting forces were measured (grams) and compared to the force described by the manufacturer on the packages of coil springs (200 grams-force) (Figure 3). The measurements were obtained at two periods: soon after initial extension (T1) and after 28 days of extension (T2).

Figure 3. Manufacturer packages for checking the described forces of the coil springs.

Source: Authors.

The greater end of the coil spring (which would be supported on the miniscrew) was inserted at one side of the pin row, and the smaller end (supported om the molar tube) was extended until the size determined for the study, measured with a ruler, using a ligature connected to the opposite pin row. After fixation, each group of coil springs (7, 9, 12 and 15mm) was divided into 10 springs each, extended by 50 and 100% of the original size.

Following, the support with the static devices and extended NiTi coil springs was submerged in a container with artificial saliva and stored in an oven at a controlled temperature of 37°C, simulating a similar environment as the oral cavity. The coil springs remained in this condition for a period of 28 days, which was sufficient to simulate the time between orthodontic sessions. After this period, the coil springs were removed from the support and the same methodology was used for another measurement (T2), to investigate if there was degradation of forces of the coil springs in the conditions and time to which they were submitted.

2.4 Allocation sequence, randomization and blinding

A previously calibrated researcher (CV) prepared the samples, allocated them into groups in a random manner. Each package of coil springs has 5 coils, 4 packages of the same length were open (n=20) and allocated into 2 groups of 10 coils, distended 50 and 100% of original length. Another researcher (LF) blindly measured the coil springs force, and the statistical analysis was performed by another researcher (JFSJ) who assessed the outcomes.

2.5 Statistical analysis

The study power was analyzed and revealed a value of α=1.0 for comparisons between groups, intervals and groups x intervals.

The data distribution was evaluated by the Shapiro-Wilk test. Since the data did not present normal distribution on the initial measurements, the Mann-Whitney test was applied to compare the values measured for each extension in each group of coil springs and the values suggested by the manufacturer. The paired t test was applied to compare the initial (T1) and final (T2) force for each group of coil spring in their extensions. A significance level of 5% was considered for the analyses.

The statistical tests were run on the software SigmaPlot (SigmaPlot, San Jose, CA, USA) version 13.0.

3. Results

The force values applied by the coil springs, obtained at T1, were compared with the values provided by the manufacturer and described below.

For coil springs with 7, 9, 12 and 15mm and extension of 50%, the results are described in Table 1. When the coil springs were extended by 50% of their original length, only the coil spring with 7mm (195 grams) presented values compatible with those indicated by the manufacturer. The remaining 3 groups of coil springs (9, 12 and 15mm) presented statistically lower results than the advocated values.

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Table 1. Force values (grams) for each type of coil springs extended by 50% of their original length at T1 (initial force) in mean and median values. The comparison of T1 force with manufacturer was performed with median values (Mann-Whitney test)

Coil Springs	T1 Force (mean)	T1 Force (median)	25%	75%	Manufacturer force	P value
7mm	195.50	195.00	190.00	206.25	200.00	0.229
9mm	178.00	180.00	163.70	190.00	200.00	0.001*
12mm	161.50	160.00	155.00	166.25	200.00	0.001*
15mm	162.50	162.50	150.00	171.25	200.00	0.001*

* Statistically significant values $p \leq 0.05$. Source: Authors.

For coil springs with 7, 9, 12 and 15mm and extension of 100%, the results are described in Table 2. In this extension, only coil springs with 7 and 15mm presented statistically higher values.

Table 2. Force values (grams) for each type of coil springs extended by 100% of their original length at T1 (initial force) in mean and median values. The comparison of T1 force with manufacturer was performed with median values (Mann-Whitney test)

Coil Springs	T1 Force (mean)	T1 Force (median)	25%	75%	Manufacturer force	P value
7mm	226.50	230.00	192.50	261.25	200.00	0.043*
9mm	195.50	197.50	190.00	200.00	200,00	0.069
12mm	193.00	192.50	183.75	206.25	200.00	0.230
15mm	215.50	217.50	210.00	220.00	200.00	0.001*

* Statistically significant values $p \leq 0.05$. Source: Authors.

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To observe if there was degradation of coil spring forces, the values at T1 and T2 were compared and are described in Table 3.

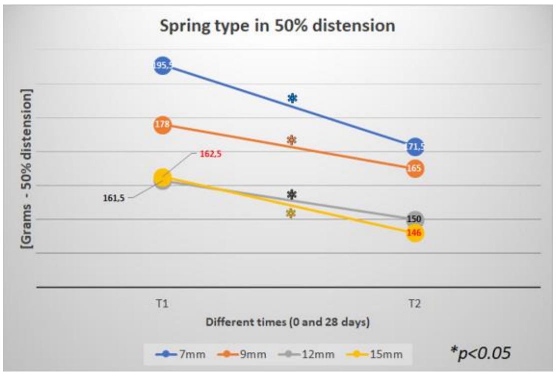
Table 3. Comparison of mean forces (grams) at T1 and T2 for each type of coil springs extended by 50% of their original length (Paired T-test)

Coil Springs	T1 Force (mean)	T2 Force (mean)	P value
7mm	195.50	171.50	0.001*
9mm	178.00	165.00	0.000*
12mm	161.50	150.00	0.003*
15mm	162.50	146.00	0.002*

* Statistically significant values $p \leq 0.05$. Source: Authors.

For coil springs with 7, 9, 12 and 15mm with extension of 50%, the results demonstrated that all presented statistically significant differences of force degradation after a period of 28 days. Figure 4 showed the force degradation between periods (T1-T2).

Figure 4. Graphic showing force degradation between periods T1 – T2 in 50% distension coil springs



Source: Authors.

The same was observed for coil springs with 7, 9, 12 and 15mm extended by 100% (Table 4).

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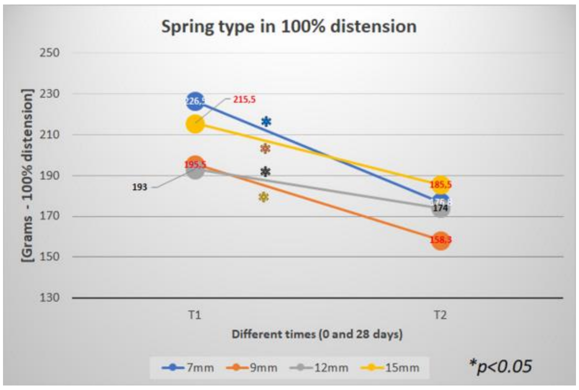
Table 4. Comparison of mean forces (grams) at T1 and T2 for each type of coil springs extended by 100% of their original length (Paired T-test).

Coil Springs	T1 Force (mean)	T2 Force (mean)	P value
7mm	226.50	176.80	0.005*
9mm	195.50	158.30	0.000*
12mm	193.00	174.00	0.005*
15mm	215.50	185.50	0.000*

* Statistically significant values $p \leq 0.05$. Source: Authors.

It was observed that all springs presented statistically significant values of force degradation after a period of 28 days. Figure 5 showed the force degradation between periods (T1-T2).

Figure 5. Graphic showing force degradation between periods T1 – T2 in 100% distension coil springs.



Source: Authors.

Table 5 indicates the percentage of force degradation of each spring after T2. It is observed that coil springs extended by 50% of the original size presented lower degree of force loss than those extended by 100%.

Table 5. Percentage of force degradation (T2 – T1) of each coil spring types extended in 50% and 100% of their initial length.

Coil Springs	Extension 50%	Extension 100%
7mm	12.3%	21.9%
9mm	7.3%	19.0%
12mm	7.1%	9.8%
15mm	10.1%	13.9%

Source: Authors.

4.Discussion

A better understanding of forces released by NiTi coil springs is extremely important, since these devices have been largely used in recent years. Thus, this study aimed to elucidate and aid orthodontists in selecting the best commercially available material, aiming at a consistent and healthy tooth movement.

The comparison of extension forces applied by the coil springs at T1 with the values described by the manufacturer revealed that, in general, the description of packages is different from the real force, in both extensions of 50% or 100% of the original size. When extended by 50%, only 7-mm coil springs showed similar strength to the 200gr suggested by the manufacturer. When extended by 100%, the 9-mm and 12-mm coil springs showed values close to the 200gr described on the package. This result demonstrates the lack of standardization of forces applied by the springs, and their initial size does not directly influence the concordance of these values.

This lack of standardization of force values with those recommended by manufacturers corroborates the results of other authors, who reported values of 223.18 grams for Morelli coil springs extended twice their length (Santos, et al., 2007) ; as well as 9-mm NiTi springs from different brands extended further 12mm, generating forces that ranged from 147 to 474 grams (Maganzini, Wong & Ahmed, 2010). These authors concluded that the information provided by manufacturers on the package and the standardization of coil spring forces is very confusing and misleading.

Concerning the stability of forces yielded by NiTi coil springs, the present study observed that there was degradation in the coil spring forces extended by 50% or 100% of their length. The values at T2 were significantly lower than at T1, measured at the study onset. This information agrees with other study in which force reductions of 8 to 20% were reported after 28 days comparing stainless steel, CoCrNi and NiTi coil springs (Angolkar et al., 1992). The same was observed in other *in vitro* and *in vivo* study in which the coil springs (GAC Sentalloy) lost approximately 12% of the initial strength in 4 weeks, with an additional loss of 7% between 4 and 8 weeks, when the strength levels apparently stabilized (Cox et., 2014). It should be highlighted that these authors found similar results of force degradation, regardless of whether the coil springs were tested in laboratories or used in patients. Other authors also found values of 18% of force degradation (Schneevoigt, et al.,1999), but contrasting results were found in another study, which reported that closed NiTi coil springs were not affected by extension in an environment simulating the oral cavity and did not present deformation of their initial size (Han & Quick, 1993). In our study we found a degradation rate of force ranging from 7.1 to 12.3% for the extension of 50% and from 9.8 to 21.9 for the 100% extension after 28 days (Table 5). Although all coil springs presented a significant decrease in force values between T1 and T2, the percentage of the force degradation was more pronounced in the 7mm spring extended by 100% of their original length.

Several studies have compared the effectiveness of closed NiTi springs with elastomeric chains. In a systematic review, the authors reported that closing spaces with closed NiTi coil springs is faster than with elastomeric chains, and that the ideal force to close these spaces with coil springs is 150 to 200 grams, similar to the values indicated by the manufacturer on the packages in the present study (Mohammed, et al.,2018). The rate of space closure is 0.21mm/week for chain elastics and 0.26mm/week for NiTi springs (Nightingale & Jones, 2003) yet other authors stated that the space closure rate with NiTi springs is around 1mm per month (Cox, et al.,2014 ; Geng, et al., 2019). Conversely, the degradation of forces on elastics varies from 37.4% to 71.6% according to the commercial brand and is much greater than the means of NiTi springs (Santos, et al., 2007) . This factor may be explained by the negative influence of the oral environment on the elastomeric chains, thus substances as water, Coca-Cola, spices and the oral temperature affect the degradation of elastics strength, unlike the coil springs, which were only affected by temperature. All this information validates the use of closed NiTi springs instead of elastic ligatures, because they are better for orthodontic movement, despite the degradation of forces (Nattrass, Ireland &

Sherriff, 1998). The degradation force rate of NiTi coil springs is lower than the rate of elastomeric chains, but one may consider that elastomeric chains are usually changed after 28 days but the coil springs may stayed for longer periods and maybe after 6 months the values of force delivered may not be acceptable.

Bezrouk et al (2014), suggested pre-activation of the coil springs prior to their use, extending the spring beyond the necessary measure. According to their *in vitro* study, this pre-activation would promote mechanical stabilization of the coil springs, and thus the degree of force degradation after use would be insignificant. Wichelhaus et al (2010), agree with the need for pre-activation of coil springs and state that the oral environment seems to have a minor influence on the properties of springs.

This study evaluated only coil springs manufactured by Morelli, but future studies might include a larger number of brands available on the market. A limitation of our study refers to the evaluation time (28 days), simulating the interval between appointments. It is advisable to check the coil springs degradation force in a 6 months period to simulate clinical procedures, yet these coil springs are usually changed over a longer period of time. However, despite the evaluation time similar to that of change of elastics, the present results indicate a significant degradation of force, regardless of the coil spring size and degree of extension. These data caution the professionals to adopt a force measurement instrument in all clinical appointments, to optimize the orthodontic movement and treatment time.

5. Conclusion

Based on our in vitro study the forces released by NiTi coil springs presented a significant reduction over time and they are different from the force recommended by manufacturer. Because of that It is necessary to meas ure the force generated when the coil spring is extended to check the force delivered, as well as at each session, to assure that the force degradation is not impairing the tooth movement and activating when needed.

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