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RESEARCH ARTICLE

In vitro study of the stretching time-associated force magnitude generated by NiTi and stainless-steel closed coil springs

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ABSTRACT

Closed coil spring is an additional tool in a fixed-orthodontic treatment. NiTi is an orthodontic alloy that has shape memory and elasticity features, while stainless steel has properties of malleability, low friction between wire-bracket, as well as easy soldering and welding. Various properties of closed coil springs have been widely studied, but research on the stretching time remains unclear. This study aimed to determine the effect and differences in the stretching time for 7 days, 14 days, 21 days, and 28 days on the force magnitude of NiTi and stainless-steel (SS) closed coil spring. A 7 x 5 x 1 cm acrylic blocks with 1 cm acrylic posts were employed, and 25 mm closed coil springs were attached to the acrylic posts using modified T-sticks. The springs were immersed in an artificial saliva with pH of 6.75 for 7, 14, 21, and 28 days in an incubator at 37 °C. The container was removed from the incubator and the force was measured using a universal testing machine. Kolmogorov-Smirnoff test was carried out to analyze parametric data, while independent T-test was used to determine the difference between each group. There was a significant effect of stretching time on the force magnitude of the SS closed coil spring in all the groups ($p < 0.05$). There was no significant effect of stretching time on the force of the NiTi closed coil spring on days 7, 14, and 21 ($p > 0.05$) but there was a significant effect on day 28 ($p < 0.05$). A significant effect between the ratio of the SS and NiTi closed coil spring ($p < 0.05$) was confirmed. Longer stretching time indicated a force loss in the SS closed-coil spring, while the NiTi spring had a more stable force which implies a formidable treatment-time for orthodontic treatment.

Keywords: closed coil spring; NiTi closed coil spring; SS closed coil spring; force magnitude; stretching time

INTRODUCTION

Malocclusion is the most common problem experienced by adolescents and adults. This condition can affect oral health in general and in particular, such as the occurrence of inflammation and swelling of the gums, caries, and tooth loss.[1] The prevalence of malocclusion in developed countries is quite high, around 56% according to a report from WHO, in which the highest was reported in African countries at 81%, Europe at 72%, America at 53%, and Asia at 48%.[2] Indonesia is one of the countries with the largest prevalence of malocclusion, and according to the 2018 National Basic Health Research (Riskesdas) report, the prevalence of malocclusion was very high at around 80%; it was the third dental and oral health problem after caries and periodontal diseases. Therefore, orthodontic treatment is very necessary to treat these problems.[3]

Malocclusion treatment using orthodontic appliances aims to obtain optimal and supportive dental occlusion with physiological adaptation, normal function, dentofacial repair, and good aesthetics feature.[4] The tools used for orthodontic treatment are removable appliances, fixed appliances, and functional appliances, in which their uses are adjusted to the indications of each treatment.[5] Optimal orthodontic tooth movement requires light and continuous force, while fixed orthodontic treatment, which requires tooth extraction, requires a technique to move the tooth into the extraction space such as closed-coil spring. This spring is an additional tool in fixed orthodontic treatment that can be used in tooth movement, such as the closure of extraction space, retraction

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of canines, mesialization of molars, retraction of individual teeth, closure of the anterior region, and retraction of impacted teeth.[6] Closed coil spring provides optimal force without damaging the health of the periodontal tissue and is constant for long-term maintenance. Although the early closed coil springs were made with stainless steel (SS) and cobalt-chromium nickel alloys which offer elasticity feature and resistance to corrosion, they have considerably high load-deflection rate which leads to force degradation.[7-10] Drastic reduction in force when using SS-closed-coil springs has also been reported by 20-21% every week, indicating non-adaptive functions.[9] Therefore, using springs with lower load-deflection rate would improve orthodontic treatment.

The introduction of nickel-titanium-based (NiTi) closed-coil springs has demonstrated promising techniques due to their low and constant forces upon deactivation,[8] and easy forming, low friction between the wire and the bracket, as well as easy soldering and welding.[6] As the distance for the closure of the extraction space of the first premolar in fixed orthodontic treatment with an elastomeric chain ideally 4 circles is 25 mm,[11] the retraction techniques commonly use elastomeric chains, elastomeric modules, active ligatures, and closed coil springs.[12,13] For instance, during canine retraction and space closure that are the most time-consuming phases, NiTi springs can result in minimum pain and improve safety due to their optimal force between 150-250 grams with space-closure force around 2 mm per month.[14,15] The low load-deflection rate in NiTi also suggests its ability to prevent force degradation, implying a shorter treatment time around 3 weeks, despite the fact that it is costly.[7,16,17] However, NiTi closed-coil spring seems to experience a reduced force after 4 weeks, thus increasing the total treatment time,[18] and another study has also found that NiTI closed coil spring also experiences force-loss around 13% after almost a month of use.[19] A recent study has also reported that neither the NiTi nor elastomeric chains generate significant force in the rate of tipping and rotation; even elastomeric chains even cause more pain.[20] Thus, it can be said that studies are still limited on the use of NiTi closed-coil springs and its relationship with force degradation, length of treatment time, on how to reduce total treatment time, improve patient cooperation, and minimize possible negative side effects. The purpose of this study was to determine the effect of stretching for 7, 14, 21, and 28 days on the force magnitude of NiTi and SS closed coil springs.

MATERIALS AND METHODS

This research started by preparing an acrylic block with a dimension of 7 cm x 5 cm x 1 cm. The block was perforated with a length of 0.5 cm, measured from a distance of 10 mm on the left and right sides of the acrylic block. After that, an acrylic post with a diameter of 0.5 cm was inserted into the acrylic block in a way that no movement could be guaranteed. One acrylic block had 5 pairs of acrylic posts that were 10 mm apart from each other, and they were placed vertically with a height of 10 mm to avoid deviation of the acrylic posts after the closed coil springs were installed, as it is displayed in Figure 1.

The right and left closed coil springs were first inserted on the modified T-stick with a distance of 25 mm. Due to its wire at the end, the closed coil springs were inserted into the acrylic post lastly. The eyelets and SS closed coil springs were placed 5 pieces on 5 acrylic posts in 1 acrylic block. The effects of SS closed coil spring were determined by observing the control group and groups whose coil spring immersion times were 7 days, 14 days, 21 days, and 28 days. Each day, the treatment group was placed in a container containing artificial saliva with a normal pH of 6.75 and a temperature of 37 °C in an incubator. Figure 2 and 3 show the result of observation of samples immersed in artificial saliva.

The SS closed coil spring in the control group was measured using the Universal Testing Machine. Firstly, the SS closed coil spring was removed from the incubator and placed in a thermal bag to avoid changes in its temperature and measured using a room thermometer. Then the closed coil spring was removed with a modified

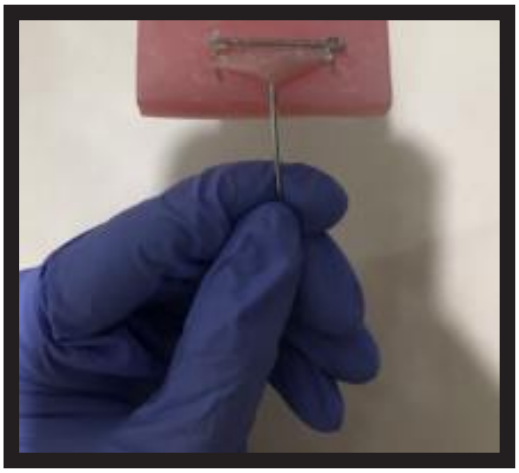

Figure 1. Installation of *closed coil springs* to acrylic posts with T sticks spaced 25 to avoid deviation

Figure 2. The stretched samples with two separate bollards on acrylic blocks

Figure 3. Acrylic block and *closed coil spring* immersed in a *stainless steel* filled with artificial saliva

T stick and placed on the Universal Testing Machine to measure the stretching force. The force was measured in grams/gm (1 N = 101971 gm = 3.59694 oz).

RESULTS

Table 1 shows the strength and magnitude of the samples. The repeated measures ANOVA test obtained a significance of $p = 0.000$ ($p < 0.05$), showing that stretching time had an effect on the force of the SS closed coil spring in the control group on the 7th day. On the 14-day group, the repeated measures ANOVA test obtained a significance of $p = 0.000$ ($p < 0.05$), indicating that stretching time had an effect on the force magnitude of the SS closed coil spring in the control group on the 14th day. Similarly, the repeated measures ANOVA test also showed a significance of $p = 0.000$ ($p < 0.05$), indicating that stretching time had an effect on the force magnitude of the SS closed coil spring in the control group on the 21st day. Finally, the repeated measures ANOVA test obtained a significance of $p = 0.000$ ($p < 0.05$), indicating that stretching time had an effect on the force magnitude of the SS closed coil spring in the control group on the 28th day.

Table 2 shows the effects of treatment. The repeated measures ANOVA test obtained a significance of $p = 0.000$ ($p < 0.05$), indicating that stretching time had an effect on the force magnitude of the SS closed coil spring on the 7th and 14th days. A similar analysis result was also found between the 7-day group and the 21- and 28-day groups. The repeated measures ANOVA test obtained a significance of $p = 0.000$ ($p <0.05$), indicating that stretching time had an effect on the force magnitude of the SS closed coil spring when measured on the 14th and 28th days.

In Table 3, the repeated measures ANOVA test results showed a significance of $p=0.06$ ($p > 0.05$), indicating that stretching time did not have an effect on the NiTi closed coil spring in the control group after the 7-day treatment. Similar results were also found in the NiTi closed coil spring after 14 days in the control group, namely

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p=0.07 (p > 0.05), meaning that stretching time had no effect on the force magnitude. Also, the repeated measures ANOVA test obtained p=0.08 (p > 0.05), indicating that stretching time had no effect on the force magnitude of the NiTi closed coil spring in the control group after treated for 21 days. In contrast, the repeated measures ANOVA test obtained a significance of p=0.00 (p < 0.05), indicating that stretching time influenced the force magnitude of the NiTi closed coil spring in the control group after the 28-day treatment.

In addition, based on Table 1, the repeated measures ANOVA test commonly showed similar results on the force magnitude of the NiTi closed coil spring in the 7-day group and 14-day group with p = 0.06 (p > 0.05), in the 7-day group and the 21-day group with p = 0.07 (p > 0.05), in the 14-day group and the 21-day group with p = 0.07 (p > 0.05). In contrast, the 7-day group and the 28-day group as well as the 14-day group and the 28-day group showed significant effects of stretching time on the force magnitude of the NiTi closed coil spring with p = 0.000 and p = 0.000 (p < 0.05), respectively.

In Table 4, the force magnitude of the SS and NiTi closed coil springs was analyzed by an independent t-test. The results of the independent t-test showed a significance of p=0.001 (p < 0.05), indicating that stretching time had an effect on the force magnitude of both the SS and NiTi closed coil springs in the 7-day groups. Similarly, the results of the independent t-test showed a significance of p = 0.000 (p < 0.05), indicating that stretching time also influenced the force magnitude of both the SS

Table 1. Comparison of strength and magnitude in control group and treatment days

	Control	Treatment
Strength of closed coil spring ss		
Day 0	295.45 ± 3.98	
Day 7		261.13 ± 9.47
Day 14		207.4 ± 5.06
Day 21		154.54 ± 3
Day 28		104.3 ± 2.4
Magnitude of the closed coil spring ss		
Day 0	158.07 ± 2.7	
Day 7		153.86 ± 1.01
Day 14		152.1 ± 1.3
Day 21		149.4 ± 1.57
Day 28		143.7 ± 2

Table 2. Effect of stretching time on the magnitude of the *closed coil spring* SS between the groups 7 days, 14 days, 21 days, 28 days and control

p value	14 days	21 days	28 days	Control
7 days	0.000*	0.000*	0.000*	0.000 *
14 days	-	0.000*	0.000*	-
21 days	-	-	0.000*	-
Control	0.000*	0.000*	0.000*	-

*= significant

Table 3. The effect of stretching time on the magnitude of the *closed coil spring* NiTi in the treatment group 7 days, 14 days, 21 days, 28 days and control

p value	14 days	21 days	28 days	Control
7 days	0.06	0.07	0.000*	0.06
14 days	-	0.07	0.000*	-
21 days	-	-	0.001*	-
Control	0.07	0.08	0.000*	-

*= significant

Table 4. The effect of stretching time on the magnitude of the force between *closed coil spring* SS and NiTi in the treatment group 7 days, 14 days, 21 days, 28 days and control

P Value	7 days SS	14 days SS	21 days SS	28 days SS	Control SS
7 days NiTi	0.001*	-	-	-	-
14 days NiTi	-	0.000*	-	-	-
21 days NiTi	-	-	0.000*	-	-
28 days NiTi	-	-	-	0.000*	-
Control NiTi	-	-	-	-	0.000*

*= significant

and NiTi closed coil springs in the 14-day groups. In addition, the results of the independent t-test showed a significance of p = 0.000 (p < 0.05), indicating that stretching time affected the force magnitude of both the SS and NiTi closed coil springs in the 21-day groups. The results of the independent t-test showed a significance of p = 0.000 (p < 0.05), indicating that stretching time had an effect on the force magnitude of both the SS and NiTi closed coil springs in the 28-day groups. Finally, the results of the independent t-test showed a significance of p = 0.000 (p < 0.05), indicating that stretching time had an effect on the force magnitude of both the SS and NiTi closed coil springs in the control group.

DISCUSSION

The results of the observation in the SS group are in line with the results of a study conducted by Padmaraj which examined the force magnitude of the SS closed coil spring stretched at a distance of 25 mm of which the treatment groups were divided into 7 days, 14 days, 21 days, and 28 days; the results of which showed that the force of the SS closed coil springs in each treatment group and the control group had significant differences. The force of the SS closed coil spring was high at the initial activation, but decreased by 20-21% every week. The most significant decrease in the force of the SS closed coil spring occurred in the 4th week. In addition, the results of this study are also in line with the results of a study by Agarwal DK which showed that the force of the SS closed coil spring had a significant difference when the closed coil spring was activated and deactivated.[8,21] There was a linear increase in the force of the SS closed coil spring at the beginning of activation (100% - 200%), but a drastic decrease occurred at deactivation (100%).[8] The results of this study, i.e., the mean force of the closed coil spring during deactivation was 104.3 ± 2.4 gm, are not in line with the results of a study by Manhartsberger which showed that the mean force magnitude of the SS closed coil spring at the time of deactivation was 709.92 grams. This is due to the closed coil springs were of different brands (Hi-T II, Unitek Corporation) and length of the wire (15 mm) used.[6,21]

The results of the observation of the NiTi group are in line with the results of a study by Padmaraj V which examined the force magnitude of the NiTi closed coil spring with a length of 25 mm which was tested periodically, namely 7 days, 14 days, 21 days, and 28 days. The results of the study found a significant decrease in the force of the NiTi closed coil spring on day 28.[9] The results of this study are also in line with the results of a study by Quinn and Yoshikawa who periodically measured the force magnitude of the NiTi closed coil spring in week 1 to week 6. The results indicated that the force magnitude of the NiTi closed coil spring decreased significantly to its lowest point in week 4, so patients with NiTi closed coil springs should be checked 4 weeks after the installation.[2] The results of this study, i.e., the mean force of the closed coil springs are in line with the results of a study by

Manhartsberger, showing the mean force of the closed coil spring of 159.12 ± 27.54 gm.[8]

The results of this study indicated that there was a significant difference in the effect of stretching time on the force magnitude of the SS and NiTi closed coil springs in the control group, the 7-day treatment group, the 14-day treatment group, the 21-day treatment group, and the 28-day treatment group with p value < 0.05. The results of this study are in line with the results of a study by Manhartsberger which showed that the mean force magnitude (at deactivation) of the NiTi closed coil spring was 121.38 grams and that of the SS closed coil spring was 709.92 grams. The results of this study are in line with the results of a study by Agarwal DK which showed that the SS closed coil spring showed significantly greater force than NiTi. The study by Agarwal DK showed a significant decrease in the force of the SS closed coil spring between the control group, the 7-day group, the 14-day group, the 21-day group, and the 28-day group, but there was no significant decrease in the force of the closed coil spring between the control group, the 7-day group, the 14-day group, and the 21-day group.[8] According to Melsen, this is because the force generated by SS closed coil spring is more linear and greater than that by NiTi closed coil spring , but NiTi has superelasticity and shape memory.[22] According to research by Padmaraj V, the SS closed coil spring which stretched 100% compared to its initial length showed a significant decrease in force, while the closed coil spring, which had a force of 100-150 gm and stretched 500% of its initial length or equivalent to 5 times its initial length, did not show a significant decrease in force.[8,23]

The force generated by a NiTi closed coil spring (5 oz equivalent) is more stable than the force generated by SS closed coil spring. It is recommended to conduct further research with artificial saliva of which the pH is alkaline or normal. It is also necessary to conduct further research on the relationship between the stretching time and distance of the closed coil springs with different diameters and lengths.

CONCLUSION

Based on the statistical analysis, stretching time had an effect on the force magnitude of the SS closed coil spring after being used for a month; significant effect was observed through an analysis carried out every week. In contrast, no effect was found in the NiTi samples. Thus, a force degradation was found to be significant in the SS coil-spring because the longer the stretching time, the higher the force degradation of closed coil spring. As there was a significant difference in the effect of stretching time for 7 days, 14 days, 21 days, and 28 days on the SS and NiTi closed coil spring groups, the NiTi with 1.39N (1N = 3.59 oz) appears to be more stable than the SS coil-spring, which indicates an effective length of orthodontic treatment time.

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