MECHANICAL PROPERTIES OF ORTHODONTIC NICKEL-TITANIUM OPEN COIL SPRINGS

Thesis Submitted to the Department of Orthodontics, Faculty of Oral and Dental Medicine, Cairo University
for partial fulfillment of the requirements for
the master Degree in Orthodontics.

By
Alaa Fraeg Othman Hasanain

BDS Thamar University- Republic of Yemen
(2003)

Faculty of Oral and Dental Medicine
Cairo University
(2012)
بسم الله الرحمن الرحيم

(قال رب اشرح لي صدرى (52) ويسر لي أمرى (26) واحلل عقدة من
لسانى (27) يفقهوا قولي (28))

صدق الله العظيم

(سورة طه 25-28)
Supervisors

Dr. Ahmed Abd El-Salam Eid
Professor of Orthodontics
Faculty of Oral and Dental Medicine
Cairo University

Dr. Fouad Aly EL-Sharaby
Lecturer of Orthodontics
Faculty of Oral and Dental Medicine
Cairo University
I dedicate this work to my country, which I miss.

&

To my wonderful family for their sacrifices, encouragement and understanding.
# Contents

Acknowledgement .......................................................... I

List of figures ................................................................. II

List of tables .................................................................. IV

Introduction ....................................................................... 1

Review of literature ......................................................... 4

Aim of the study .............................................................. 18

Materials and methods .................................................... 19

Results ............................................................................. 29

Discussion ................................................................. 77

Summary and conclusion .................................................. 83

References ........................................................................ 85

Arabic summary .............................................................
### List of Figure

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A spring segment was cut to a length of 10mm.</td>
</tr>
<tr>
<td>2</td>
<td>Springs in compression racks before being compressed.</td>
</tr>
<tr>
<td>3</td>
<td>The universal testing machine (LLOYD instruments, Fareham, England) used in the study.</td>
</tr>
<tr>
<td>4</td>
<td>The spring mounted on an orthodontic guiding 0.018&quot; stainless steel wire.</td>
</tr>
<tr>
<td>5</td>
<td>Springs in compression racks after compression to 50% of their original length.</td>
</tr>
<tr>
<td>6</td>
<td>a. Personal computer where data automatically recorded.</td>
</tr>
<tr>
<td>6</td>
<td>b. Screen shot for the software.</td>
</tr>
<tr>
<td>7</td>
<td>Bar chart representing mean of maximum force values of different group at T1.</td>
</tr>
<tr>
<td>8</td>
<td>Bar chart representing mean of maximum force values of different groups at T2.</td>
</tr>
<tr>
<td>9</td>
<td>Bar chart representing mean of maximum force values of different groups at T3.</td>
</tr>
<tr>
<td>10</td>
<td>Bar chart representing mean of maximum force values of different groups at T4.</td>
</tr>
<tr>
<td>11</td>
<td>Line chart representing change by time in mean of maximum force value (force degradation) of each spring.</td>
</tr>
<tr>
<td>12</td>
<td>Bar chart representing mean of average force during deactivation of different groups at T1.</td>
</tr>
<tr>
<td>13</td>
<td>Bar chart representing mean of average force during deactivation of different groups at T2.</td>
</tr>
</tbody>
</table>
14 Bar chart representing mean of average force during deactivation of different groups at T3.

15 Bar chart representing mean of average force during deactivation of different groups at T4.

16 Line chart representing change by time in mean of average force during deactivation of each group.

17 Bar chart representing mean of load-deflection ratio of different groups at T1.

18 Bar chart representing mean of load-deflection ratio of different groups at T2.

19 Bar chart representing mean of load-deflection ratio of different groups at T3.

20 Bar chart representing mean of load-deflection ratio of different groups at T4.

21 Bar chart representing change by time in mean load-deflection ratio of each group.
List of tables

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>NiTi springs used in the study.</td>
<td>21</td>
</tr>
<tr>
<td>2</td>
<td>Comparison of Mean and Standard deviation (SD) of maximum force values in the sixteen groups at T1.</td>
<td>31</td>
</tr>
<tr>
<td>3</td>
<td>Comparison of Mean and Standard deviation (SD) of maximum force values in the sixteen groups at T2.</td>
<td>33</td>
</tr>
<tr>
<td>4</td>
<td>Comparison of Mean and Standard deviation (SD) of maximum force values in the sixteen groups at T3.</td>
<td>35</td>
</tr>
<tr>
<td>5</td>
<td>Comparison of Mean and Standard deviation (SD) of maximum force values in the sixteen groups at T4.</td>
<td>37</td>
</tr>
<tr>
<td>6</td>
<td>Comparison of Mean and standard deviation (SD) of maximum force value of each group at different time periods.</td>
<td>43</td>
</tr>
<tr>
<td>7</td>
<td>Comparison of Mean and Standard deviation (SD) of average force during deactivation in the sixteen groups at T1.</td>
<td>47</td>
</tr>
<tr>
<td>8</td>
<td>Comparison of Mean and Standard deviation (SD) of average force during deactivation in the sixteen groups at T2.</td>
<td>59</td>
</tr>
<tr>
<td>9</td>
<td>Comparison of Mean and Standard deviation (SD) of average force during deactivation in the sixteen groups at T3.</td>
<td>51</td>
</tr>
<tr>
<td>10</td>
<td>Comparison of Mean and Standard deviation (SD) of average force during deactivation in the sixteen groups at T4.</td>
<td>53</td>
</tr>
<tr>
<td>11</td>
<td>Comparison of Mean and Standard deviation (SD) of average force during deactivation of each group at different periods.</td>
<td>60</td>
</tr>
<tr>
<td>12</td>
<td>Comparison of Mean and Standard deviation (SD) of load-deflection ratio in the sixteen groups at T1.</td>
<td>63</td>
</tr>
</tbody>
</table>

IV
13 Comparison of Mean and Standard deviation (SD) of load-deflection ratio in the sixteen groups at T2.

14 Comparison of Mean and Standard deviation (SD) of load-deflection ratio in the sixteen groups at T3.

15 Comparison of Mean and Standard deviation (SD) of load-deflection ratio in the sixteen groups at T4.

16 Comparison of Mean and Standard deviation (SD) of load-deflection ratio of each group at different period.
Acknowledgement

I would like to express my deep appreciation and gratitude to Dr. Ahmed Abd El-Salam Eid Professor of Orthodontics, Faculty of Oral and Dental Medicine, Cairo University, for his generous expert supervision, endless encouragement, spiritual support, and for making all the facilities possible to carry this work forward.

I am very deeply obliged and grateful to Dr. Fouad Aly El- Sharaby Lecturer of Orthodontics, Faculty of Oral and Dental Medicine, Cairo University, for his kind suggestions, enthusiasm, support during my difficult moments and scientific supervision. I owe him a great deal in making this thesis comes to light.

Also special thanks for Dr. Khaled Keera who helped me in statistics of this study.

My deep thanks are also extended to my colleagues, staff members of the Orthodontic Department, Faculty of Oral and Dental Medicine Cairo University.
Introduction

Nickel Titanium alloys were introduced to the orthodontic specialty in the early 1970s, and marketed as "Nitinol®". The name Nitinol is an acronym derived from the elements which comprises the alloy (Ni, nickel; Ti, titanium; NOL, Naval Ordnance Laboratory). It is very useful in clinical orthodontics for its exceptional springness.

The unique mechanical properties exhibited by nickel titanium include superelasticity and shape memory. Both of these properties are related to the phase transitions of nickel titanium allows between its martensitic (flexible at low temperature) and austenitic (stiff at high temperature) forms.

Nickel titanium alloys used in orthodontics can be in the form of springs (open or closed) or archwires. Spring wires differ from archwires in that springs are necessarily subjected to an additional manufacturing procedure - that of winding – which might affect their mechanical properties. Moreover, the forces applied to springs include torsional, tensional, and bending forces. Despite that, it might appear that load-deformation properties of archwires and springs are similar however; deformation of archwires is usually expressed as angular bending or linear deflection while deformation of springs is expressed as elongation or compression.

* Unitek Corp.
Nickel-titanium (NiTi) coil springs can produce light continuous forces over a large range of activation. They have significantly limited the use of stainless steel coil springs as force-generating modules in orthodontics, since the latter can only produce initial forces of high magnitude that quickly dissipate even with small deactivations.

The open coil spring is a wound spring which is activated by compression to exert a net "pushing" force in two directions away from its center. There are many uses of the open coil springs in orthodontics.

The force produced by an open-coil spring can be affected by its, wire type, wire size, lumen size and the winding pitch (pitch is the distance between individual coils in the spring). With a constant lumen size; an increase in wire size produced an increase in force at a given activation and with a constant wire size; an increase in lumen size produced a decrease in force at a given activation. As the pitch decreases, the amount of wire incorporated into the spring is increased. Therefore, small pitch generally produces lower forces.

Orthodontic suppliers offer numerous nickel titanium open coil springs that could be used. However, an examination of numerous orthodontic supply catalogs can be confusing, because suppliers label their nickel titanium open coil springs with descriptive terms, including “Ultra Light, Light, Medium, Heavy, and Extra Heavy” . Others list the “constant force values” that their coils provide, such as “100 grams, 150 grams, and 200 grams”. Some suppliers identify coils by coil lumen diameter, such as 0.010", 0.011", and 0.012".
For such reason, working with the open coil springs, the clinician cannot be sure of the exact amount of force that the used coil exerts. Since orthodontics is iterative in nature, it would be of great benefit to the orthodontist to be familiar with such parameter. Consequently, he can predict the forces being applied to the teeth leading to a better control of the course and time of treatment.

Previous studies showed that labeling forces of nickel titanium springs could be confusing and misleading. Consequently, the purpose of this study was to compare the forces generated by different nickel titanium open coil springs supplied by five different companies which were available in the Egyptian market.
Review of literature

Going through the literature, we found that there was a marked absence of information about the open coil springs.

In (1919) Byrnes soldered pleated gold band material between two attachments so that spaces could be opened or expansion obtained by opening or closing the pleats, which was the earliest references to anything similar to a coil.

In (1931) the Arnold coil spring became very popular. An article was written by Arnold, in which a description was given for the method of using the coil compressed against the buccal attachment and arch wire.

In (1934) Arnold advocated the use of coils on a lingual arch wire for expansion and observed that coils 0.010 inch in diameter, made of precious metal, with a 0.040 inch lumen, were equivalent to a 0.007 inch or 0.008 inch wire of steel.

In the same year (1934), Johnson stated that he used 4 ounces of pressure on a molar coil spring (0.009 inch on 0.030 inch lumen) by compressing the spring 1/32 inch, against 5 or 6 ounces of elastic pressure from the use of intermaxillary elastics.

From these two separate studies, Arnold and Johnson made the observation that precious metal open coil springs did not produce as much force for a given activation as did comparable springs made of steel wire.
In (1941) Johnson explained some of the factors concerning coil springs in regard to the force applied. He gave us five very fine points to be considered in regard to the open coil spring. These were, briefly: Precious metal springs were only about one-half as efficient as steel made from 8-18 steel alloy, The smaller the diameter of spring wire used, the weaker it was, if wrapped on the same lumen or core, The same diameter spring wire was stronger on a smaller gauge arch wire than on a larger gauge arch wire, The longer the spring, the weaker the force, if compressed the same amount, a spring that fits a wire too snugly will bind and loose some of its efficiency in friction.

In (1942) Oppenheim stated that “Since we are quite in the dark as to whether an individual has a high tissue resistance or is very susceptible to damage, I consider it unjustified and wrong to use indiscriminately the same measured amounts of force for all persons, even disregarding their ages. I repeat again: We have only one reliable criterion for the correctness of the forces applied in any given individual, i.e., the firmness and sensitivity of the teeth.”

In (1944) Oppenheim did some work on mature monkeys (Maraca rhesus), involving three experiments, in two of which coil springs were used. For each, a plain arch of precious metal, 0.030 inch thick, was inserted into buccal tubes soldered to caps on the molars and premolars and tied to the banded incisors with steel ligatures. Coil springs furnished the continuous force in the first and third experiments. The coil springs of stainless steel wire were 0.010 inch in diameter and 1 cm. long, with the individual coils separated from each other by a distance of 1 mm. They were compressed between the mesial ends of the tubes and spurs on the
arches to different lengths-in one experiment, to one-half their original length and, in the other, to two-thirds their original length. The force necessary for such a compression was 180 grams in the first case and 120 grams in the latter case. In the treatment of patients, the only criteria we have as to the appropriateness of the force are the firmness and lack of soreness of the teeth. Therefore, in order to judge within general limits the relationships between the amount of force and the changes brought about by this force, we have to measure it.

Up to this time, the only articles written that had given definite findings on the amount of force, in either grams or ounces, were by Johnson and Oppenheim. Both gave us information as to the length of spring and amount of compression.

In (1947) Nagamoto explained how to make the single and double contraction coil spring. This was a pull type spring or closed coil, just the opposite of the open coil, but for all practical purposes, the results were identical, and it was a very fine spring.

In (1951) Bell examined the amount of force applied in the use of elastics and coil springs in orthodontic therapy. He summarized his findings with this statement: “If the greatest amount of force is desired, the largest size wire wound on the smallest, arbor practical should be selected, being cautious to avoid friction loss.” Bell compressed his coils one-half their length before testing to make them consistent. He used 20, 30, and 40 millimeter length springs and found displacement on the 40 millimeter length to be more responsive to a given amount of force but, as the length of spring was shortened, the force per millimeter was increased, although the displacement was less.
In (1955) Born discussed some characteristics of open coil springs. He activated a variety of springs of different wire and lumen sizes and several sizes of arch wire to varying compressed lengths with the materials used at that time, he then tabulated the forces produced for comparison purposes. He concluded that the usefulness of coil springs can be extended by increasing the length of the spring, thus providing a gentle continuous corrective force. With the longer spring, the pressure can be regulated more accurately because a given change in pressure is obtained with a greater adjustment in length. The frequency of adjustment can also be reduced substantially when a longer spring is used.

A theoretical approach to the mechanics of coil springs was presented by Kobayashi and Muramatsu (1972). They found a “preliminary tensile stress” portion of force production where the deformation against a load did not start until 70 grams of force was added. They also found the force extension curve to be a straight line until it reached 500 grams of load, at which time the deformation against the load markedly increased because of inelastic deformation.

There is a dearth of information in the literature since the 1950s concerning the characteristics of open coil springs. Investigations on closed coil springs have been reported by Webb et al and Chaconas et al (1978). These works showed the effects of wire size, lumen size, and wire type on force production of closed coil springs.
In (1978) Webb et al analysed closed coils spring from various manufactures, and found that the Force production was affected as follows: Keeping the lumen size constant, an increase in wire size produced an increase in force. Keeping the wire size constant, an increase in lumen size produced a decrease in force. For a given wire size, force varied with different wire types.

This study has shown that the current recommendations for the use of closed coil springs produce forces of greater magnitude than is necessary for orthodontic tooth movement. The clinician should take care to select the proper closed coil spring for specific clinical situations.

In (1984) Chaconas et al investigated the effects of wire size, lumen size, and wire type on the production of force by open coil springs. It was found that with a constant lumen size, an increase in wire size produced an increase in force at a given activation. With a constant wire size, an increase in lumen size produced a decrease in force at a given activation. The effect of the arch wire size and shape was not significantly different for the coil springs with the smaller lumen sizes. For the larger lumen sizes, the springs used with the rectangular arch wire manifested a greater linear range than those used with the smaller round arch wire. Finally, the difference between the load-deflection characteristics of the coil springs from different manufacturers was attributed mainly to the difference in the pitch of the coils (distance between coils).
In (1988) Miura et al compared the mechanical properties of Japanese nickel-titanium and stainless steel coil springs, in both closed and open types. They found that Japanese nickel-titanium coil springs exhibited superior spring-back and super elastic properties. They found that when the lumen of the coil spring remained constant, the load value of super-elastic activity increases as the wire diameter increased. They added that when the diameter of the wire remains constant, the load value of super-elastic activity increases as the lumen of the coil becomes smaller. Moreover, when the martensite transformation temperature elevated, the load value of super-elastic activity was reduced. Finally, when the pitch of coils of the open coil spring was changed from fine to coarse, the load value of superelastic activity could still remain the same and the range of super-elastic activity increased.

In (1990) Boshart et al investigated load-deflection rate for a variety of open and closed coil springs. Ten millimeter lengths of open and closed coil stainless steel and cobalt-chromium-nickel (Co-Cr-Ni) alloys in combinations of 0.008, 0.009 and 0.010 inch wire sizes, and 0.030 and 0.032 inch luemen sizes were tested. Other groups included heat treated Co-Cr-Ni springs and springs of 15 and 20 millimeter lengths. Forces and activations were measured by a tension load cell with an INSTRON universal testing instrument. Stiffness increased dramatically with wire size and pitch angle of the coils. Stiffness decreased slightly with increased lumen size. Co-Cr-Ni closed coil springs were slightly stiffer than stainless steel, whereas stainless steel open coil springs were much stiffer than Co-Cr-Ni. Heat treatment
increased the stiffness of Co-Cr-Ni coil springs. They concluded that the length of the spring had a great effect on the load-deflection rate. A shorter spring was stiffer than a longer spring by an amount directly proportional to the ratio of the length of the longer spring to that of the shorter spring.

In (1992) Angloker et al studied the force degradation of closed coil springs made of stainless steel (SS), Cobalt-Chromium-Nickel (Co-Cr-Ni) and Nickel-Titanium (Niti) alloys, when they were extended to generate an initial force value in the range of 150 to 160 gm. The specimens were divided into two groups. Group I included SS, Co-Cr-Ni, and two Nickel-Titanium spring types (Niti 1 and Niti 2), 0.010 × 0.030 inch with an initial length of 12mm. Group II was comprised of SS, Co-Cr-Ni, and (Niti 3) 0.010 ×0.036 inch springs, with an initial length of 6mm. All springs showed a force loss over time. The major force loss for most springs was found to occur in the first 24 hours. The SS and Co-Cr-Ni springs showed relatively higher force decay in group I (0.010 × 0.030 inch) compared with Niti 1 and Niti 2. The Niti 3 springs of group II (0.010 × 0.036 inch) showed higher force degradation than the SS and Co-Cr-Ni springs of this group. The least force decay was found in the Niti 1 springs. In general, the total force loss after 28 days was in the range of 8% to 20% for all springs tested. This was considered to be relatively less compared with force loss shown by latex elastics and synthetic elastic modules.