The resistance to axial dislodgement of nickel titanium compression arch wire hooks – an in vitro study

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Objective: To evaluate the level of force required to axially dislodge nickel titanium compression hooks (Trillium Compression HookTM, Hespeler Orthodontics) placed on orthodontic arch wires in vitro.

Materials and methods: Nickel titanium compression hooks were placed on arch wires with a specially designed pair of pliers. The resistance to axial dislodgement was tested on a total of 260 hooks placed in a standardised way on round (0.016", 0.018", 0.020"), square (0.020 × 0.020") and rectangular (0.016 × 0.022", 0.019 × 0.025", 0.021 × 0.025") stainless steel (Rocky Mountain Orthodontics), nickel titanium, or β-titanium (Hespeler Orthodontics) arch wires. The forces required to displace the hooks were recorded using an Instron tensile testing machine. The data were compared with the results reported in similar studies on stainless steel crimpable arch wire hooks.

Results: The forces required to dislodge the compression hooks varied between 45.0 N and 161.9 N. The hook’s resistance to dislodgement was found to be high in all tested hook/wire combinations. The lowest recorded average dislodging force was found in the 0.020" nickel titanium group and the highest average force was in the 0.016 × 0.022" β-titanium group.

Conclusion: The forces needed to dislodge the tested nickel titanium compression arch wire hooks exceed the force levels previously reported for stainless steel crimpable arch wire hooks.

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Introduction

During orthodontic and orthognathic therapy there are circumstances in which fixed appliance arch wires require the addition of an auxiliary that can be used for the application of traction. Added auxiliaries may simply consist of vertical loops, for example a tieback loop, used for space closure in the original edgewise technique. Alternatively, hooks welded or soldered to a stainless steel arch wire in desired positions may serve the same purpose, and might be preferred as they take up less interdental space between the appliance brackets. The welding of hooks is also possible on β-titanium wires but on nickel-titanium wire neither welding nor soldering is a practical option.1

An advantage of incorporated wire loops and the soldered/welded hooks is that their position on the arch wire is completely stable. An obvious disadvantage is that adding these components to the arch wire is time-consuming and cannot be carried out intraorally directly on ligated arch wires. Furthermore, there is a possibility that the heat produced during soldering or welding could negatively affect the properties of the arch wire. The use of pre-posted wires, which feature posts that are positionally stable, may be an option in some cases to overcome placement disadvantages.

In order to facilitate the addition of hooks to arch wires, the manufacturers of orthodontic materials have designed crimpable hooks, which are easy to place in desired positions on ligated orthodontic or surgical arch wires. The hooks are fixed onto the wire by the use of a pair of crimping pliers. The disadvantage of these hooks is that their positional stability is influenced by
the magnitude of the crimping force applied by the operator.²⁻⁴

Compared with loops and soldered/welded hooks, there is a risk that crimpable hooks may move axially along the arch wire during treatment when a traction force is applied. This risk may be minimised if the hooks have been firmly fixed on the wire, and if the traction force is less than the static frictional force between the crimpable hook and the arch wire.

A new type of arch wire hook introduced in 2015 is the Trillium Compression Hook™ (Hespeler Orthodontics, Cambridge, Canada, Figure 1). It is made entirely of nickel titanium and, like the crimpable hook, it may be attached to the wire intraorally or extra-orally with specially designed pliers. Unlike traditional crimpable hooks, the Trillium Compression Hook generates its own gripping force on the arch wire via the superelastic deformation of its component arms.

The aim of the present study was to evaluate the level of force required to dislodge compression hooks axially along the arch wire when placed on round, square, and rectangular wires made of stainless steel, nickel titanium, or β-titanium.

Materials and methods

The geometry of the Trillium Compression Hook is similar to traditional crimpable hooks in that both feature a hook extension attached to deflectable arms. The arch wire rests between the deflectable arms. Friction generated between the hook’s arms and the arch wire provides axial resistance to displacement of the hook.

The Trillium Compression Hooks are available in three different lengths (small – 1 mm long, medium – 2 mm long, and large – 3 mm long) and in nine sizes to match various wire designs and dimensions (Table 1). The same hook may be used for square and rectangular arch wires of equal labial-lingual dimensions, as the Trillium hook grips the labial-lingual surfaces of the wire.

The hook is placed on the arch wire using a pair of special application pliers. The hook is first loaded into the pliers, which are then positioned at the desired location on the arch wire. With a light closing pressure on the handles of the pliers, the hook is attached with an accompanying audible ‘snap’. During the procedure, the arms of the hook deflect super-elastically around to fully enclose the arch wire, whereupon the arms attempt to return to their ‘resting position’. As the space between the arms at rest position is smaller than the labial-lingual dimension of the arch wire, the deflected arms impart opposing gripping forces. The result is a high compressive force, which prevents axial dislodgement of the hook. An unusual characteristic of the nickel titanium Trillium Compression Hook is that if it is accidentally dislodged along the arch wire, it will re-grip due to the super-elastic deflection of the hook’s gripping arms, which are not dependent on an externally applied crimping force.

The resistance to axial dislodgement of a total of 260 Trillium Compression Hooks was tested on 13 hook/wire combinations. Round, square, and rectangular stainless steel (Rocky Mountain Orthodontics, CO, USA), nickel titanium, or β-titanium (Hespeler Orthodontics) wires of various dimensions were used.

Table 1. Available dimensions of compression hooks for round, square, and rectangular wires.

<table>
<thead>
<tr>
<th>Round</th>
<th>SQUARE</th>
<th>Rectangular</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.016”</td>
<td>0.016 x 0.016”</td>
<td>0.016” – 0.018 x 0.022”</td>
</tr>
<tr>
<td>0.018”</td>
<td>0.018 x 0.018”</td>
<td>0.018” – 0.019 x 0.025”</td>
</tr>
<tr>
<td>0.020”</td>
<td>0.021 x 0.021” *</td>
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</table>

*Configured to work on either 0.021 x 0.021” or 0.020 x 0.020” wires.
RESISTANCE TO DISLODGEMENT OF COMPRESSION ARCH WIRE HOOKS

in the tests (Tables IIa and IIIa). The tests were carried out on medium length hooks, installed on 15 cm lengths of straight arch wire. Before placing a hook, the arch wire was cleaned with a paper towel dipped in methanol. Following methanol evaporation, a Trillium Compression Hook of a size that matched the wire was attached with the hook pliers, at a point located 1.25 cm from one end of the wire. This end of the wire was slid into the slot of a holding apparatus, positioned on the bottom of a tank filled with circulating distilled water at a temperature of 37° ± 0.25° C. The water tank was firmly fixed in an Instron Universal tensile testing machine (Instron Corporation, MA, USA). The opposite end of the arch wire was attached to the upper crosshead of the testing machine and so orientating the wire parallel to the vertical axis of the tensile tester column (Figure 2).

After a period of two minutes to ensure the hook and wire were in thermal equilibrium with the water bath,

![Figure 2. A schematic illustration of the experimental equipment.](image)

<table>
<thead>
<tr>
<th>Type of wire</th>
<th>0.016” (1)</th>
<th>0.018” (2)</th>
<th>0.020” (3)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Mean (N)</td>
<td>SD</td>
<td>Mean (N)</td>
</tr>
<tr>
<td>Stainless steel</td>
<td>60.73 6.85</td>
<td>88.72 7.87</td>
<td>79.71 8.14</td>
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<tr>
<td>Nickel titanium</td>
<td>59.17 6.10</td>
<td>76.43 9.52</td>
<td>61.53 10.31</td>
</tr>
<tr>
<td>Diff.</td>
<td>1.56 NS</td>
<td>12.29 ***</td>
<td>18.12 ***</td>
</tr>
</tbody>
</table>

NS = not significant  *** = p < 0.001

<table>
<thead>
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<th>1 vs 2</th>
<th>1 vs 3</th>
<th>2 vs 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stainless steel</td>
<td>27.99 ***</td>
<td>-18.98 ***</td>
<td>9.01 ***</td>
</tr>
<tr>
<td>Nickel titanium</td>
<td>-17.26 ***</td>
<td>-2.36 NS</td>
<td>14.90 ***</td>
</tr>
</tbody>
</table>

NS = not significant  *** = p < 0.001

<table>
<thead>
<tr>
<th>Type of wire</th>
<th>0.016 x 0.022” (1)</th>
<th>0.019 x 0.025” (2)</th>
<th>0.020 x 0.020” (3)</th>
<th>0.021 x 0.025” (4)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Mean (N)  SD</td>
<td>Mean (N)  SD</td>
<td>Mean (N)  SD</td>
<td>Mean (N)  SD</td>
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<tr>
<td>Stainless steel</td>
<td>100.35 15.37</td>
<td>100.63 11.97</td>
<td>88.06 14.54</td>
<td>63.26 5.31</td>
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<td>Beta titanium</td>
<td>142.34 10.93</td>
<td>123.92 10.02</td>
<td>133.52 7.51</td>
<td>56.39 4.59</td>
</tr>
<tr>
<td>Diff.</td>
<td>-41.99 ***</td>
<td>23.29 ***</td>
<td>-45.46 ***</td>
<td></td>
</tr>
</tbody>
</table>

*** = p < 0.001

Table IIa. Mean force levels in newtons (N) required to cause axial dislodgement of nickel titanium compression hooks placed on 0.016” (1), 0.018” (2), and 0.020” (3) stainless steel and nickel titanium arch wires. Descriptive data and results of the one-way analysis of variance (p). Diff. = differences between the mean values in the stainless steel and nickel titanium groups data in the respective wire size groups.

Table IIb. Differences and significance levels obtained from the post-hoc pairwise comparisons of the mean values and standard deviations presented in Table IIa.

Table IIc. Mean force levels in newtons (N) required to cause axial dislodgement of nickel titanium compression hooks placed on 0.016 x 0.022” (1), 0.019 x 0.025” (2), 0.020 x 0.020” (3) stainless steel and beta titanium arch wires, and the 0.021 x 0.025” (4) stainless steel wire. Descriptive data and results of the one-way analysis of variance (p). Diff. = differences between the mean values in the stainless steel and beta titanium groups data in the respective wire size groups.
A tensile force parallel to the axis of the arch wire was applied to the hook by moving the crosshead of the tensile tester upward at a speed of 0.5 mm/minute. The force required to move the hook axially along the arch wire was recorded. This test and recording procedure was carried out on 20 samples for each hook/wire combination. These are listed in Tables IIa and IIIa.

**Statistical analysis**

The mean values and standard deviations of the dislodging forces were calculated. The recorded values of all variables were normally distributed. For each type of wire, comparisons of the mean values recorded for the different dimensions were carried out using the one-way analysis of variance (ANOVA). In case the condition of equal variances was not fulfilled, the Kruskal-Wallis one-way ANOVA by ranks was used. Statistic pairwise post-hoc comparisons of the mean force values recorded for different wire dimensions within each separate group were performed using the Holm-Sidak method.

The mean force levels recorded for each of the various dimensions of steel wires were compared with those recorded for nickel titanium and β-titanium wires of corresponding dimensions using the unpaired t-test.

All statistical analyses were performed using the SigmaStat 4.0 Software (Systat Software Inc., CA, USA). Significance was predetermined at \( \alpha = 0.05 \).

**Results**

The nickel titanium compression hooks were easy to place on the wires. After hook attachment, the wires were inspected for possible deformation or gabling, but no changes were found.

In general, the Trillium hooks exhibited a very high resistance to dislodgement (Tables IIa and IIIa). In the group of stainless steel round wires, the hooks placed on the 0.016” wires moved when exposed to an average force of 60.7 N (Range = 49.1–80.9 N). The corresponding forces recorded for hooks placed on the 0.018” and 0.020” round wires were 88.7 N (Range = 74.9–105.7 N) and 79.7 N (Range = 62.2–94.6 N), respectively (Table IIa).

The mean force needed to dislodge the hooks on the 0.016”, 0.018”, and 0.020” round nickel titanium wires was 59.2 N (Range = 48.6–70.4 N), 76.4 N (Range = 58.7–90.4 N), and 61.5 N (Range = 45.0–88.8 N), respectively (Table IIa). The average force levels recorded for the three tested hook/wire combinations within the respective stainless steel and nickel titanium groups differed significantly (\( p < 0.001 \)).

When comparing resistance to movement of the hooks placed on the round stainless steel wires with the hooks on round nickel titanium wires, no significant difference was found in the 0.016” group. However, the hooks on the 0.018” and 0.020” stainless steel wires exhibited significantly greater resistance to movement than those applied to the nickel titanium wires of corresponding dimensions (\( p < 0.001 \), Table IIa).

Table IIb shows the results of the post-hoc pairwise comparisons of the mean values presented in Table IIa. The mean forces required to dislodge the hooks placed on the round 0.016” and 0.020” nickel titanium wires did not differ significantly. All other comparisons resulted in highly significant differences (\( p < 0.001 \)).

The results of the dislodgement tests of the hooks placed on the rectangular and square wires are presented in Tables IIIa and IIIb. In the stainless steel group, the average resistance to dislodgement of hooks placed on 0.016 × 0.022” wires was 100.4 N (Range = 77.9–130.8 N). The corresponding value related to the 0.019 × 0.025” wires was 100.6 N (Range = 76.1–112.8 N). The level of resistance recorded for hooks on the two wires was significantly higher (\( p < 0.05 \), Table IIIb) than the level of resistance recorded for hooks placed on 0.020 × 0.020” wires, 88.1 N (Range = 68.5–116.4 N). In the 0.021 × 0.025” wire group, the recorded mean force level was 63.3 N.
(Range = 52.4–70.5 N). Also in this category of arch wire, the wire dimension was significantly related to the level of resistance to dislodgement of the hooks (p < 0.001).

In general, the hooks placed on the β-titanium wires exhibited considerably greater resistance to dislodgement than the corresponding hooks placed on stainless steel wires (p < 0.001, Table IIIa). The mean values recorded were 142.3 N (Range = 126.7–161.9) for the 0.016 × 0.022” wire, 123.9 N (Range = 103.8–141.4 N) for the 0.019 × 0.025” wire, and 133.5 N (Range = 120.8–144.8 N) for the 0.020 × 0.020” wire. Furthermore, in this group the hooks placed on the 0.016 × 0.022” wires exhibited a significantly greater resistance to dislodgement than the hooks placed on the 0.019 × 0.025” wires (p < 0.001) and the 0.020 × 0.020” wires (p < 0.01). The mean values recorded for hooks placed on the two latter wires also differed significantly (p < 0.01, Table IIIb).

Discussion

During the fixed appliance treatment of malocclusions, hooks are frequently required on arch wires in order to facilitate efficient force application within and between the dental arches. The most commonly-used is a crimpable hook which can be placed on the arch wire without removing the wire from the brackets bonded to the teeth.

Previous studies on the performance of crimpable arch wire hooks regarding their resistance to axial dislodgement under various conditions have been reported.3,4 The results of these studies have demonstrated that, when placing crimpable hooks, there are a number of factors that should be observed. Firstly, if excessive force is applied during crimping, there is a risk that gabling of the wire occurs.2 Secondly, the magnitude of the applied crimping force may vary between clinicians, and even the individual operator exhibits inconsistency in delivering the crimping force during attachment.3,5 Thirdly, there is a tendency that crimping forces, which are used to place hooks on arch wires outside the mouth, are greater than those applied to wires, which are ligated to the dental arches.5 Naturally, there is a risk that uncontrollable factors, as listed, may influence the clinical reliability of crimpable hooks.

The purpose of the present study was to investigate the resistance to axial dislodgement of the Trillium Compression Hooks placed on orthodontic round, square, or rectangular arch wires made of stainless steel, nickel titanium, or β-titanium.

Each test was carried out in a tensile testing machine with the sample attached to a holder fixed in a water tank containing circulating distilled water at a temperature of 37°C. In order to better simulate the oral environment, it would have been desirable to carry out the tests with the samples placed in saliva instead of water, but for practical reasons this was not possible.

Although the geometry of a crimpable hook and a compression hook is similar, the two hooks function in a very different manner. The crimpable hook depends on an externally applied force, whereas the compression hook generates its own compressive gripping force. With both types of hooks, the resistance to axial displacement is dependent on a number of factors related to the arch wire’s metallurgy, surface finish, dimensional accuracy, and geometry. The present tests showed that the mean forces required to displace the hooks differed considerably depending on the characteristics of the wire used in the tests. For example, Trillium Compression Hooks placed on the round 0.016” nickel titanium wire were displaced by a mean force of 59.2 N, whereas hooks on 0.016 × 0.022” β-titanium wires could be exposed to an average force of 142.3 N before axial movement occurred. In general, hooks placed on rectangular wires showed greater resistance to movement compared with hooks placed on round wires.

In the present study, the mean force level required to dislodge the nickel titanium compression hooks placed on 0.019 × 0.025” stainless steel wires was 100.6 N. This force far exceeded the forces recorded and reported in the literature from similar tests of crimpable hooks.2,4 A test of crimpable hooks from two different manufacturers that had been attached to 0.018 × 0.025” or 0.019 × 0.025” stainless steel wires has been described and it was determined that these hooks were displaced by forces varying between 6.2 N and 11.7 N.4 In a comparative investigation, two operators placed 20 crimpable hooks each on 0.019 × 0.025” stainless steel wires, either with the wires outside the mouth or in situ. The results showed that the mean force levels required to displace these hooks axially along the arch wires were 22.8 N and 15.7 N for the extra-orally placed hooks and 20.0 N and 14.8 N for the hooks placed intraorally.5 Even if the
resistance to axial displacement of the compression hooks showed variations depending on the hook/wire combinations tested, it may be stated that, in general, the forces needed to dislodge these hooks considerably exceeded those forces reported for crimpable stainless steel hooks.\textsuperscript{2-4}

In comparison with the stainless steel and nickel titanium wires, the force needed to displace a Trillium hook on β-titanium wires was substantially greater. This difference may be explained by the relatively high content of titanium in the beta titanium alloy that makes the surface of the wires comparatively rough,\textsuperscript{1} and this, in turn, results in higher friction between the hook and the wire compared with orthodontic wires made from other alloys.

The study of the axial resistance to the movement of hooks placed on 0.021 × 0.025” wires was carried out on wires made of stainless steel only. Hooks on wires of this dimension and quality are mainly used in the finishing stages of orthodontic treatment or in orthognathic surgery cases in which stable bases for the intra- or inter-maxillary use of elastics is required, and nickel titanium or β-titanium wires are rarely used at this stage of treatment.

The level of force applied to hooks placed on fixed arch wires varies between clinicians, and also according to the type of force delivering system used.\textsuperscript{5} The results of a previous study\textsuperscript{5} indicated that the force levels, in general, are in the region of 0.44 N – 3.54 N during movement of single or groups of teeth. A greater load on a hook might be possible if it is exposed to forces of intra- and inter-maxillary elastics at the same time. However, when comparing these forces with the mean force values that have been reported to axially dislodge crimpable hooks,\textsuperscript{2-4} it is clear that the grip of these hooks on the arch wires should be sufficient in most cases. The relatively greater standard deviations provided in the test records suggest, however, that there could be a risk of hook failures on occasions, even when normal orthodontic forces are applied. In the present study, the lowest force recorded for the displacement of a compression hook was found to be 45.0 N and occurred with a hook that was placed on a 0.020” nickel titanium wire. Consequently, the risk of compression hook failure due to orthodontic forces should be minimal. However, mastication or dental hygiene procedures, for example, under adverse conditions, could possibly expose the components of fixed orthodontic appliances to such high forces that even compression hook failures may occur.

**Conclusions**

- The tests of the resistance to dislodgement of nickel titanium compression hooks placed on arch wires resulted in values of resistance that considerably exceeded corresponding data based on similar tests of crimpable steel hooks.
- Compression hooks placed on β-titanium wires exhibited the greatest resistance to dislodgement compared with hooks placed on stainless steel or nickel titanium wires.
- The nickel titanium compression hook was easy to place on orthodontic wires.
- The placement of compression hooks did not cause unintentional deformations or gables on the arch wires.

**Conflict of interest**

None to declare.

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**References**