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Original article

Forces achieved by different material and type of intrusion arches applied in different horizontal levels

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ABSTRACT

Background: *Intrusion is one of the most needed movements in orthodontics. It is possible to achieve this with arch wires, miniscrews, and bite-blocks.* ***Purpose:*** *This in vitro study aimed to evaluate forces achieved by different types of intrusion arches made of different materials and anchored in two different horizontal levels by either miniscrews or molar teeth.* ***Methods:*** *An upper jaw typodont was applied different types of intrusion arches: intrusion and utility arches, made of different materials (nitinol, beta III titanium, stainless steel) and different wire sizes (0.016" x 0.022" and 0.017" x 0.025") to the incisors, both anchoring from molars and miniscrews respectively. Each application was measured by a Correx gauge. Each wire was applied to both the auxiliary slot of the triple tube and the slot in the head of the miniscrew. One-way analysis of variance (ANOVA), Tukey's HSD test, and a paired two-sample t-test were used to analyze the data.* ***Results:*** *In the intrusion arches, the main effect of the material was found to be statistically significant on force values ($p = 0.034$) while the main effect of the size was not found statistically significant on force values ($p = 0.083$). In the utility arches, both the main effect of the material ($p = 0.067$) and the size ($p = 0.140$) were not found to be statistically significant on force values.* ***Conclusion:*** *Regardless of the anchorage unit level and size, nitinol was the material that applied the lowest forces among all materials. The material is the most effective factor in the force generated, while the anchorage unit level is the least.*

Keywords: *beta III titanium intrusion arch; connecticut intrusion arch; incisor display; nitinol intrusion arch; utility arch*
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INTRODUCTION

The concepts of smile aesthetics and smile design have become two of the major concerns of the contemporary orthodontic treatment approach. Facial aesthetics and, thus, smile aesthetics are the primary demand of patients who want to have orthodontic treatment. Parameters such as buccal corridors, occlusal cant, gingival display, gingival disproportions, incisor display, incisor positions, smile arc, tooth size ratios, dental angulations, torques, and midline deviations have been investigated as contributing factors to smile aesthetics in previous studies.[1–4] The display and vertical positioning of incisors in orthodontic and dentofacial orthopedic treatments are increasingly important regarding smile aesthetics.[5–7]

Intrusion mechanics are frequently used to change the vertical positions of incisors in orthodontic treatments. Treatment mechanics like utility arches, J-hook headgear, Burstone intrusion arches, Connecticut intrusion arches (CIA; in the literature, they are also abbreviated as CTA), Kalra simultaneous intrusion and retraction arches, and miniscrews are various alternatives used in incisor intrusion.[8–10] Using miniscrews for intrusion is generally preferred to eliminate the negative side effects of the other intrusion mechanics.[11]

Historically, it was suggested that classical intrusion arches should be made of stainless steel (SS) or blue Elgiloy. However, it is preferred for contemporary intrusion arches to be made of materials like nitinol, titanium molybdenum alloy (TMA), and beta titanium. Both CIA nitinol and Connecticut new arch (CNA) beta III titanium intrusion arch wires (CNA wires are nickel-free versions of CIA/CTA wires) are available in two sizes, 0.016" x 0.022" and 0.017" x 0.025". Intrusion arches are applied between the incisors and the first permanent molars in such a way that the two units are anchoring each other.[12] Miniscrew implants or

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temporary anchorage devices (TADs) are incompatible alternatives to more traditional forms of incisor intrusion with the application of light sustained forces. Better control over applied forces can reduce root resorption often associated with intrusive movements. In studies evaluating incisor intrusion with TADs, miniscrews are usually applied to the vestibule region of the incisor roots.[13]

There are many studies comparing the effects of intrusion via miniscrews and intrusion arches; however, only one study reported the miniscrew to be used directly as an anchorage level and anchorage unit for an intrusion arch.[14] Inspired and motivated by the study of Kalra and Tripathi,[14] this study aimed to evaluate forces achieved by different types of intrusion arches made of different materials and anchored in two different horizontal levels by either miniscrews or molar teeth.

MATERIALS AND METHODS

Ethical approval was not required, as there were no human or animal materials used in the study. The experiment was applied on an upper jaw typodont (3M, Unitek) with SmartClip (3M, Unitek) self-ligating brackets. The typodont had molar bands (3M, Unitek) with a sheath on the palatinal face and a triple tube on the vestibular face. A 0.016” x 0.016” sized SS (3M, Unitek) main wire was applied as the main arch in the median tube of the triple-tubed molar band.

Additionally, bracket-headed miniscrews (Quattro Standard, PSM Medical Solutions) with head holes and slot sizes 0.022” x 0.028” were applied between the roots of the second premolar and first molar on the right and left vestibular surfaces on the typodont. The applied screws were 2.0 x 7 mm in dimensions. The arches used in the study were as follows: first, prefabricated nitanium CIA nickel titanium (nitinol) arches (Ortho Organizers Inc, San Marcos, CA 92069) measuring 0.016” x 0.022” and 0.017” x 0.025” (Figure 1); second, 0.016” x 0.022” and 0.017” x 0.025” SS (3M, Unitek) intrusion arches prepared by the author by exactly copying the template of the CIA arches; third, 0.016” x 0.022” and 0.017” x 0.025” beta III titanium (3M, Unitek) intrusion arches prepared by the author by exactly copying the template of the CIA arches; fourth, 0.016” x 0.022” and 0.017” x 0.025” SS utility arch intrusion arches prepared by the author according to the descriptions of Ricketts with a 45 degree molar tip-back (Figure 2); fifth, 0.016” x 0.022” and 0.017” x 0.025” beta III titanium utility arch intrusion arches prepared by the author according to the descriptions of Ricketts with a 45 degree molar tip-back. In addition, each wire was applied to the superior auxiliary tube (0.018” x 0.025”) of the triple tube and the slot in the head of the miniscrew, and each application was measured separately. All of the arches were cinch-backed before the force was measured (Figure 3).

A new, calibrated Correx stress and tension gauge (Haag-Streit AG, Gartenstadtstrasse 10, 3098 Koeniz, Switzerland) of 0-250 g was used to measure the forces

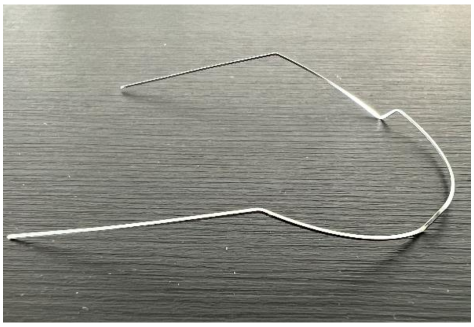

Figure 1. Nickel titanium intrusion arch.

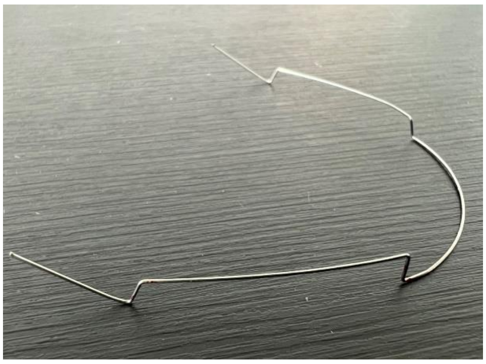

Figure 2. Utility arch with 45 degree activated molar tip-back.

Figure 3. Cinch-backed endings of arch.

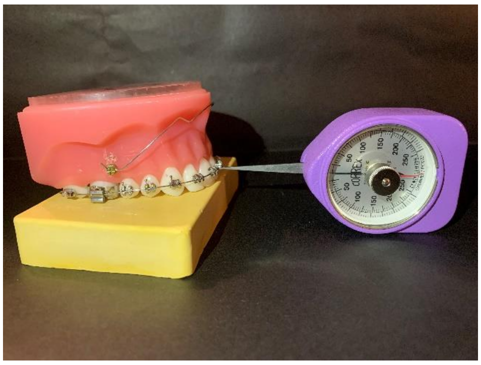

Figure 4. Tension gauge and non-activated intrusion arch—measurement setup.

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applied by the arches (Figure 4). To measure the force required to descend only to the passive point where the lateral surface of the gauge contacts the ground, without applying an extra force, the same weight (2 kg) was placed on the gauge at the same point for each measurement (Figure 5). Those values, measured separately for each wire unit, were recorded in grams (g) (Table 1).

To calculate and eliminate the method error, all measurements were repeated by the same researcher under the same conditions one week after the first measurement. The method error of the measurements was evaluated with the intraclass correlation coefficient (ICC).

Figure 5. Measurement of the force exerted by the wire taken by the measuring device.

Data were analyzed with IBM SPSS V23 (IBM, New York, USA). The conformity to the normal distribution was evaluated using the Shapiro-Wilk test. One-way analysis of variance (ANOVA) was used to compare strength values according to anchor unit level, material, and size, and multiple comparisons were performed with Tukey's HSD test. A paired two-sample *t*-test was used to compare the first and second measurement force values. The method error of the measurements was evaluated with the ICC. Analysis results were presented as mean ± standard deviation for quantitative data. The significance level was taken as $p < 0.05$.

RESULTS

A statistically significant and high correlation was obtained between the first and second measurements of the 0.016" x 0.022" sized wires (ICC = 0.992; $p < 0.001$). In addition, there was no statistically significant difference between the mean values of the first and second measurements of the 0.016" x 0.022" sized wires ($p > 0.050$). A statistically significant and very good agreement was obtained between the first and second measurements of the 0.017" x 0.025" sized wires (ICC = 0.999; $p < 0.001$). In addition, there was no statistically significant difference between the mean values of the first and second measurements of the 0.017" x 0.025" sized wires ($p > 0.050$) (Table 2).

Table 1. Measurement results of forces achieved by arches

	Forces Achieved by Different Size and Material of Arch Wires	
Anchorage Levels (Molar Level or Screw Level) Arch Wire Materials (Nitinol, Beta III Titanium, Stainless Steel)	0.016" x 0.022" (inches) Arch Wire	0.017" x 0.025" (inches) Arch Wire
Screw Level Anchored CIA Intrusion Arch	40 grams (g)	60 g
Molar Level Anchored CIA Intrusion Arch	30 g	45 g
Screw Level Anchored Beta III Titanium Intrusion Arch	75 g	105 g
Molar Level Anchored Beta III Titanium Intrusion Arch	50 g	60 g
Screw Level Anchored SS Intrusion Arch	90 g	190 g
Molar Level Anchored SS Intrusion Arch	70 g	100 g
Screw Level Anchored SS Utility Arch	80 g	180 g
Molar Level Anchored SS Utility Arch	45 g	100 g
Screw Level Anchored Beta III Titanium Utility Arch	40 g	65 g
Molar Level Anchored Beta III Titanium Utility Arch	30 g	35 g

Table 2. Examination of the method error of the measurements

Wire Size	Measurement	Mean	Standard Deviation	Test Statistics	*p*	ICC (%95 CI)	*p*
0.016" x 0.022"	First Measurement	55.0	21.9	*t* = 0.0	1.000	0.992 (0.967 - 0.998)	< 0.001
	Second Measurement	55.0	23.7				
0.017" x 0.025"	First Measurement	93.5	54.2	*t* = 0.0	1.000	0.999 (0.994 - 1.000)	< 0.001
	Second Measurement	93.5	55.4				

t: Paired two-sample *t*-test statistic; ICC: Intraclass correlation coefficient.

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In the intrusion arches, the main effect of the material was found to be statistically significant on the force values ($p = 0.034$), and the main effect of the wire size was not found to be statistically significant on the force values ($p = 0.083$). In the utility arches, both the main effects of the material and the wire size were not found to be statistically significant on the force values ($p = 0.067$ and $p = 0.140$, respectively) (Table 3).

The average force values of the nitinol, beta III titanium and SS material were 43.8, 72.5, and 112.5 g respectively. A statistically significant difference was found between the mean force values according to the materials (Table 4).

The main effect of the anchorage unit level was found to be statistically significant on force values ($p = 0.005$). The mean of the screw anchored wires' force values was 92.5 g and the mean of molar anchored wires' force values was 56 g. A statistically significant difference was found between the mean force values according to the anchorage unit level.

When the main effect of the material was evaluated, it was found to be statistically significant on the force values ($p = 0.001$). The averages of the nitinol, beta III titanium, and SS materials were 43.8, 56.9, and 106.9 g respectively.

The average of the 0.016" x 0.022" sized wires was 55 g and the average of the 0.017" x 0.025" sized wires was 93.5 g. A statistically significant difference was found between the mean force values according to the size of the wire. The average of the 0.017" x 0.025" sized wires was higher than the average of the 0.016" x 0.022" sized ones ($p = 0.004$). When the partial eta square (η^2) values are examined, the material has the most effect on the force, while the anchorage unit level factor has the least effect on the force (Tables 5 and 6).

Table 3. Comparison of force values according to material and wire size in arches

Arches	Factor	Sum of Squares	DF	Sum of Squares	F	*p*	Partial Eta Square
Intrusion Arches[1]	Material	9537.5	2	4768.75	5.323	0.034	0.571
	Wire Size	3502.083	1	3502.083	3.909	0.083	0.328
Utility Arches[2]	Material	7200	1	7200	5.465	0.067	0.522
	Wire Size	4050	1	4050	3.074	0.140	0.381

[1]: $R^2 = 0.645$, [1]Adjusted $R^2 = 0.512$; [2]: $R^2 = 0.631$, [2]Adjusted $R^2 = 0.483$; F: Analysis of variance test statistic; DF: Degrees of freedom.

Table 4. Descriptive statistics of force values by material and wire size in arches

	Intrusion Arches	Utility Arches
	Mean ± SD (Grams)	Mean ± SD (Grams)
Materials ($p < 0.050$)	($p = 0.034$)	
Nitinol	43.8 ± 12.5^{a}	---
Beta III Titanium	72.5 ± 24.0^{ab}	41.3 ± 16.5
Stainless Steel	112.5 ± 53.2^{b}	101.3 ± 57.2
Wire Sizes ($p = 0.140$)	($p = 0.083$)	($p = 0.067$)
0.016" x 0.022"	59.2 ± 22.9	48.8 ± 21.7
0.017" x 0.025"	93.3 ± 53.1	93.8 ± 64.2

a-b: There is no difference between materials with the same letter, per Tukey's HSD test.

Table 5. Comparison of force values according to anchorage unit level, material, and wire size

Factor	Sum of Squares	DF	Sum of Squares	F	*p*	Partial Eta Square
Anchorage Unit Level	6661.25	1	6661.25	10.585	0.005	0.414
Material	14651.25	2	7325.625	11.64	0.001	0.608
Wire Size	7411.25	1	7411.25	11.776	0.004	0.440

$R^2 = 0.753$, Adjusted $R^2 = 0.687$; F: Analysis of variance test statistic; DF: Degrees of freedom.

Table 6. Descriptive statistics of force values by anchorage unit, material, and wire size

		Mean ± SD
Anchorage Unit Level		($p = 0.005$)
	Screw Anchored	92.5 ± 52.8
	Molar Anchored	56.0 ± 26.6
Material		($p = 0.001$)
	Nitinol	43.8 ± 12.5[a]
	Beta III Titanium	56.9 ± 25.3[a]
	Stainless Steel	106.9 ± 51.5[b]
Wire Size		($p = 0.004$)
	0.016” x 0.022”	55.0 ± 21.9
	0.017” x 0.025”	93.5 ± 54.2

a-b: There is no difference between materials with the same letter, per Tukey’s HSD test.

DISSCUSSION

The aim of this study was to compare the forces that were created by the intrusion arches anchored by a miniscrew applied to the molar teeth region and the forces that were created by the intrusion arches applied directly to the permanent first molar teeth. Various methods for incisor intrusion have been presented by numerous authors in the literature. Utility arches, CIA and CNA intrusion arches, Burstone intrusion arches, and miniscrews are some examples of them. CIA and CNA arch wires can be found in two sizes: 0.016” x 0.022” and 0.017” x 0.025”. A wide range of materials with different physical properties are used in the production of intrusion arches. Ricketts used blue Elgiloy, which has the same hardness as stainless steel but is more formable. Burstone used beta III titanium. The CIA arches, developed at the University of Connecticut, have low formability due to their material properties of nickel-titanium. CNA is nickel-free and consists of beta III titanium.[12]

The CIA is a fabricated nitinol arch wire with a low load/deflection ratio and a V-bend in the posterior region to apply an optimal continuous intrusion force, ranging from 40 to 60 g, on the incisor teeth.[9,15] The utility arch is an alternative that can be used as an intrusion arch in controlling anterior deep overbite. It could be used for overbite reduction through incisor intrusion. A previous study stated that by using tip-back bends at the molars, the intrusion force achieved by the utility arch would be approximately 15 g on each incisor, which is considered an optimal level of force for intrusion.[10] In both the CIA intrusion arches and intrusion utility arches, a vertical intrusion force occurs on the incisors while an extrusive moment force occurs on the molars, which are the anchorage unit of the system.[10] A successful intrusion mechanic should avoid undesired extrusive movements of anchorage units.[10] In the present study, those two most frequently used intrusion arches were evaluated.

Miniscrews are presented as stable and effective anchorage units for intrusion.[10–12] However, only one study used miniscrews directly as anchorage units for intrusion arches.[14] In that study, the researchers presented an alternative method of intrusion that is a modification of the common one: an intrusion arch that prevents undesired side effects on the anchor teeth with the use of posterior miniscrews. In the study, the miniscrew anchored 0.017” x 0.025” TMA intrusion arch’s posterior arm had been directly inserted into the bracket head of the miniscrew. They described their method as an effective way to intrude maxillary incisors. Furthermore, they stated that synchronized retraction of canines with excellent anchorage control is also possible using the same miniscrew.[14] The experiment of the current study was inspired by the method of these authors. The present study compared SS, nitinol, and beta III titanium arches. Cinching back the arch was proposed to avoid the incisors’ unexpected flaring.[16] In this study, all of the arches were cinch-backed to standardize the methodology.

Ligating the intrusion arches to the main arches on the incisor zone can be applied differently with different results. The main applications are: ligation in the middle of the central teeth, ligation in the distal area of the lateral incisors, and ligation in the distal area of the canines. It has been reported that each ligation way has its own effects that occur in the form of protrusion, intrusion, or a combination of both.[17] In this study, it was performed from the midpoint of the central teeth to standardize both the method and the measurement. A Correx gauge was used to measure the forces generated by the arches. The Correx gauge is a standardized, reliable device that is often preferred for measuring orthodontic force.[18]

It was stated that the optimal force for intrusion is 10 g per incisor and 20 g per molar.[19] That is generally calculated as 40 g for four incisors in clinical intrusion applications. In the present study, the screw anchored nitinol 0.016” x 0.022” CIA intrusion arch and the screw anchored 0.016” x 0.022” beta III titanium utility arch generated a force of 40 g. Therewith, the molar anchored nitinol 0.016” x 0.022” CIA intrusion arch, the molar anchored 0.016” x 0.022” beta III titanium utility arch, and the molar anchored 0.017” x 0.025” beta III titanium utility arch generated forces of 30, 30, and 35 g, respectively. Excessive forces during intrusive movement are subject to various degrees of possible root resorption.[9] In this study, the screw anchored 0.017” x 0.025” SS intrusion arch and the screw anchored 0.017” x 0.025” SS utility arch generated forces of 190 and 180 g, respectively, which are very excessive forces. Nevertheless, the screw anchored 0.017” x 0.025” beta III titanium utility arch generated a 105 g force, which was also excessive for incisors.

In the present study, the “material” of the wire was found to be more effective than the “size” of the wire and the “anchor unit level” of the system in intrusion arcs. Since there is no other study in the literature evaluating the same intrusion mechanics supported by different horizontal levels, in this study, the forces created by two different horizontal anchor levels and the anchor unit at

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the molar level and the miniscrew level were evaluated by comparing them to each other. In the present study, the force magnitude varied according to the anchor level. The mean of the force values of the screw anchored wires was 92.5 and the mean of the strength values of the molar anchored wires was 56.0.

Unlike Elgiloy wires, which have a similar elastic modulus to SS, the elastic modulus of beta-titanium wires is 40% of that of SS. As a result, beta-titanium wires exert almost half the force compared to SS or cobalt-chrome wires at the same cross section and amount of activation. Various materials with different physical properties are used in intrusion mechanics. Ricketts used blue Elgiloy, which has the same stiffness as the SS but is more formable. Burstone used beta titanium TMA wires for excellent springback, low stiffness, and high formability. Nanda's CIA is made of nickel titanium and has low formability in routine clinical conditions. CIA intrusion arches produce optimal low, sustained force. CNA is a version of CIA and is made of beta III titanium. Compared to SS, it has the advantage of lower elastic modulus. In addition, while nitinol wires are not shaped, CNA wires are easily shaped.[16]

In this study, SS wires had the most stiffness, producing the highest forces in all combinations, while nitinol wires had the least stiffness, exerting the lowest forces. It was found that the main effect of the material was statistically significant on the force values ($p = 0.001$). The averages of the nitinol, beta III titanium, and SS material were 43.8, 56.9, and 106.9 g, respectively. A statistically significant difference was found between the mean force values according to the materials. The reason for this difference is that the average value of the SS material is higher than the average value of other materials.

The effectiveness of arch wires is determined not only by the material from which they are made, but also by geometric properties such as cross section, length, size, and diameter. For a material, the smaller the diameter of a wire, the lower its stiffness, and the greater its diameter, the greater its strength.[20] In this study, the main effect of size on strength values was found to be statistically significant ($p = 0.004$). The mean force generated by the 0.016" x 0.022" wires was 55 g, and the mean force generated by the 0.017" x 0.025" wires was 93.5 g. A statistically significant difference was found between the mean force values by size. The average of the 0.017" x 0.025" wire was higher than the average of the 0.016" x 0.022" wire.

The limitations of this study are that it was an in vitro study produced on a typodont and that the researchers did not have a digital measuring device. In conclusion, nitinol was the material that exerted the lowest forces of all materials, regardless of anchor unit level and size, followed by beta III titanium and stainless steel, respectively. In this study, it was determined that the most effective factor in the force produced was the material, and the least effective factor was the anchor unit level. Further in vivo studies evaluating different intrusion methods with different materials must be carried out.

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