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Original Article

Analysis of Intrusion Forces in Stainless Steel and Nickel-Titanium Orthodontic Archwires: An Experimental Study

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Orthodontics involves alignment of improperly positioned teeth mostly with fixed appliances. Round archwires are commonly used for intrusion of anterior teeth. The aim of this study was to measure the magnitude of force required to deflect the archwire for 2 mm between central and lateral incisors. To mimic the real oral domain, an experimental set-up with maxilla and mandible with metallic teeth was constructed. Orthodontic brackets (0.018" x 0.025") were bonded on the metal tooth and 0.016" Stainless steel (SS) and Nickel Titanium (NiTi) archwires were used with SS ligature. The archwire is deflected for 2 mm and a three point bending test was performed to measure the force magnitude using a six-axis spine tester. The forces from NiTi and SS archwires were 10.3 N and 11.4 N respectively in the maxilla, and 13.2 N and 15.3 N respectively in the mandible. As the deflection increases the loading forces also increase and is higher in SS than NiTi. Clinicians can thus select their wire deflection for the amount of force needed for intrusion planning.

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Introduction

Deep bite is a common manifestation in most malocclusion and is treated by intrusion of anterior teeth which is displacement of a tooth apically into the alveolar bone. This is acheived with the components of fixed appliances such as orthodontic bracket, archwire and ligature. SS and NiTi archwires are widely used in orthodontic treatment due to its biocompatibility, formability, resilience, stiffness etc [1]. An experimental study quantified the load-deflection characteristics of 0.0163 straight SS, NiTi, glass fiber-reinforced polymer composite (GFRPC) archwires in four ceramic brackets [2]. They concluded that NiTi archwires generated low force with conventional ceramic brackets but did not consider SS brackets and dental arch. Another study measured the loading and unloading deflection of 0.016" round and 0.016" x 0.022" rectangular coated and regular archwires of three manufacturers with four self-ligating brackets. The coated wires produced less force than the regular wires [3].

In a three-point bend test which compared the mechanical properties of 0.016" NiTi archwires from different manufacturers, for a 2 mm deflection, the maximum force of 102 grams was generated by the archwires [4]. Previously, the force levels were measured in both conventional and heat activated NiTi wires in self-ligating and conventional brackets with elastic and steel ligature. They suggested that ligatures have an impact in force due to elasticity loss and it is difficult to quantify the archwire force when elastic ligatures are used [5]. Quainto et al. performed a deactivation force using a three-point bend test considering only two brackets, reported that conventional SS wires produced highest force compared to superelastic NiTi and heat activated NiTi [6]. Ahmed et al. stated that, the friction between archwire and bracket may affect the deactivation force [7]. Another study showed that there was more variation in force-deflection properties of the archwire which leads to indeterminate orthodontic treatment [8].

All these studies were performed with two and four brackets, and

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with single composition wires only. But, for clinical simulation it is vital to perform with full arch form. So, we have conducted an archwire force measurement experimentation including the archform of maxillary and mandible to deflect a commonly used 0.016” SS and NiTi archwires upto 2 mm deflection for intrusion in the anterior teeth.

Materials and Methods

The mesial-distal, gingival-occlusal and height of the crowns of maxillary and mandibular teeth were obtained from the existing literature. A 3D model of the same were developed using modeling software (Solidworks, Dassault Systemes, Velizy-Villacoublay, France). The tooth was modelled as a cylinder to include the crown curvature effect in the tooth as shown in figure 1a & 1b. For maxilla and mandible 28 teeth are modelled excluding third molars along with two bases of maxilla and mandible. The 3D model was exported as a STEP file to the Computer Numerical Controlled (CNC) lathe machine and holes were made with internal threads on the bases to assemble the teeth. The bases were machined as U-shaped similar to the geometry of maxilla and mandible as in figure 1c. Teeth were made as cylindrical shape billets with root-like rods with threads and assembled in the base with holes as shown in figure 1d.

On the tooth labial surface, self-cure acrylic material (DPI-RR Cold Cure, India) was applied as a thin layer on the labial side of the teeth as shown in figure 1e. The SS preadjusted Orthodontic brackets (0.018” x 0.025”, Metro Orthodontics, India) were bonded using a bonding material (Flex Kwik, Pidilite Industries, India) on the resin layer. The SS and NiTi archwires (Rabbit Force, India) were ligated using elastic modules as shown in Figure 1f. The setup was fixed in the lower jaw of the spine tester (370.72; MTS Systems, Eden Prairie, Minn, USA) as shown in figure 2a. This spine tester is computer controlled and records the force-deflection data. An open ended SS rod with a notched end was held in a fixture and attached to the upper arm of the spine tester as shown in figure 2b. This was aligned to apply a deflection of 2 mm between the left central and lateral incisors and the corresponding force was recorded. During the experiment, the force was gradually increased with an interval of 0.5 N to reach 2 mm deflection in the archwires.

Results and Discussion

The loading forces required to deflect an 0.016” archwire upto 2mm between central and lateral incisor in both maxillary and mandible arch were measured. The deflection in this study is kept upto 2mm as it is the commonly used deflection range in minor to moderate malocclusions. More than 2mm deflection is difficult to engage the archwire fully into the bracket slot unless it is heat activated NiTi wire. Also, elastic ligatures are used in our setup as they are commonly used clinically than the SS ligatures.

In the maxillary arch, 10.3 N and 11.4 N forces were noted in NiTi and SS archwires respectively. Similarly, in the mandibular incisor region it was 13.2 N and 15.3 N respectively as presented in Table 1. The forces in the lower anterior were more compared to upper arch. Both SS and NiTi archwire deformed within elastic limits for 2 mm. Similar to our results, an experimental study showed that the 0.016” NiTi archwire produced more than 9.81 N force for the deflection of 2 mm [9]. Our study results are matched with a previous study for a SS archwire which developed similar force [10]. The archwire will be stiffer when the archwire material’s Young’s modulus is higher. The Young’s modulus of SS (2×10^5 N/mm^2) is more than NiTi (83×10^5 N/mm^2). So, the SS archwire generated more force to deflect 2 mm, compared to NiTi archwire which was lesser in both maxillary and mandibular arch.

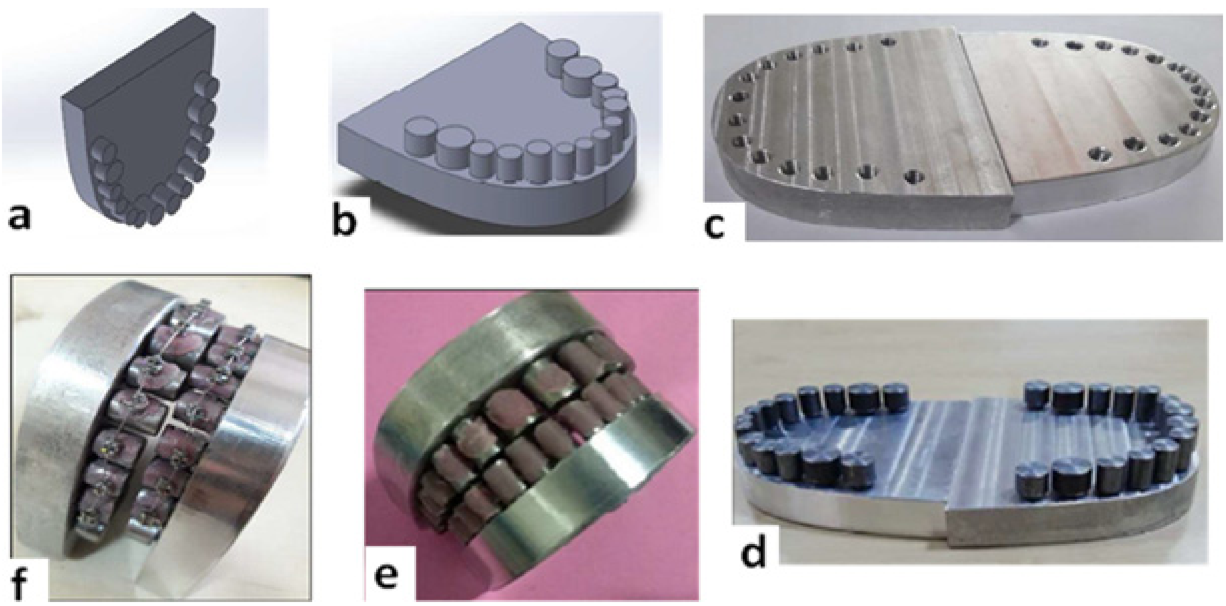

Figure 1: Manufacturing methods of maxillary and mandibular setup a. 3D model of maxilla, b. 3D model of mandible, c. Base plate with internal threaded holes, d. Tooth billets assembled in base plate, e. Acrylic resin layer on labial surface of teeth, f. Assembled setup with brackets, archwire and elastic ligatures

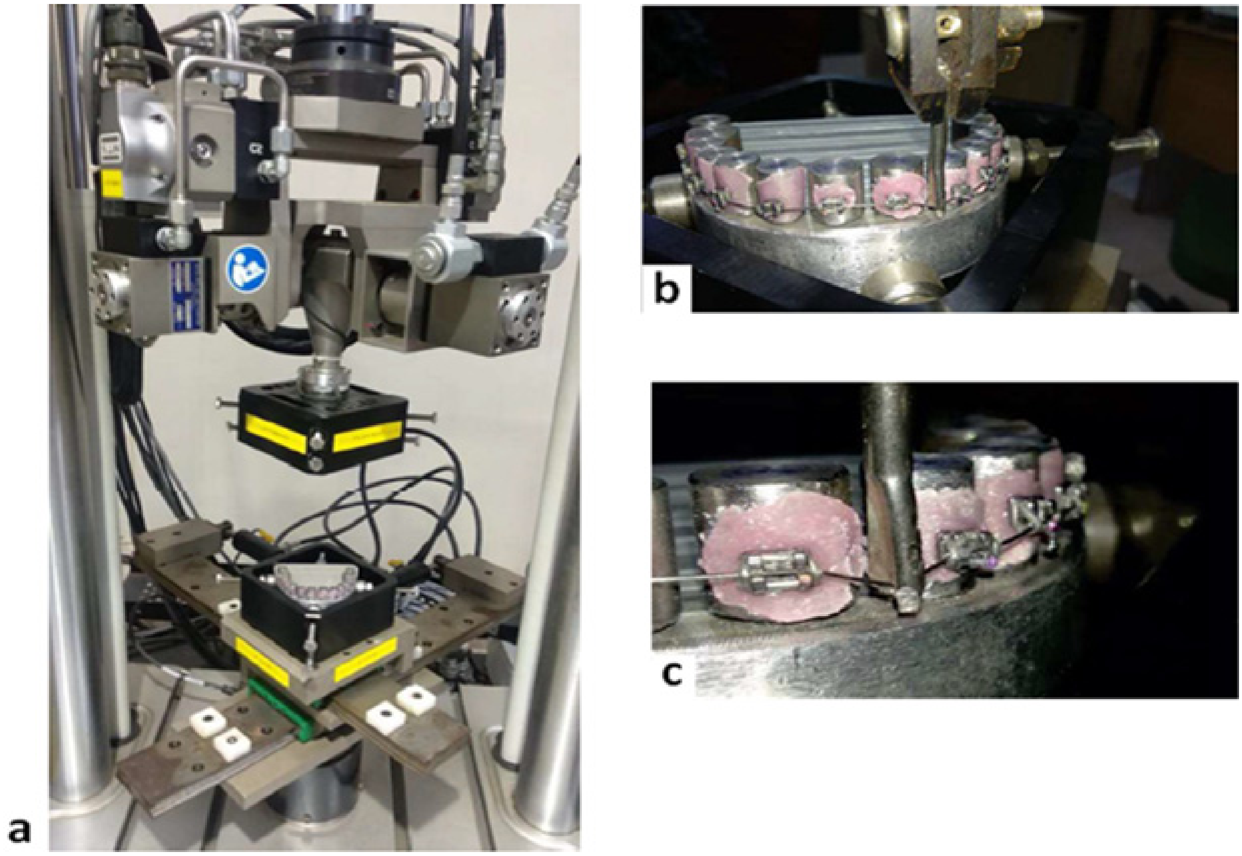

Figure 2: Experimental set-up. a. Spine tester, b. Forked metal rod engaging the archwire between the lower central and lateral incisor and c. Deflected archwire between the incisors

Table 1: Force magnitude to deflect the SS and NiTi archwire for 2 mm simulating the intrusion of tooth in maxilla and mandible

Maxillary				Mandible			
SS		NiTi		SS		NiTi	
Force (N)	Deflection (mm)	Force (N)	Deflection (mm)	Force (N)	Deflection (mm)	Force (N)	Deflection (mm)
1	0.08	1	0.17	1	0.02	1	0.04
2	0.21	2	0.39	2	0.09	2	0.12
3	0.43	3	0.65	3	0.16	3	0.31
4	0.57	4	0.78	4	0.28	4	0.48
5	0.79	5	0.97	5	0.49	5	0.71
6	0.88	6	1.05	6	0.58	6	0.84
7	0.98	7	1.23	7	0.72	7	0.98
8	1.21	8	1.36	8	0.86	8	1.11
9	1.43	9	1.58	9	0.99	9	1.28
10	1.67	10	1.89	10	1.08	10	1.42
11	1.88	10.3	2.00	11	1.22	11	1.54
11.4	2.00	-	-	12	1.44	12	1.76
-	-	-	-	13	1.58	13	1.87
-	-	-	-	14	1.66	13.2	2.00
-	-	-	-	15	1.97	-	-
-	-	-	-	15.3	2.00	-	-

For 1mm deflection in the maxillary anteriors, 5.0 N and 7.0 N forces were noted in NiTi and SS archwires respectively, and in the mandible it was 7.0 N and 9.0 N respectively. In both archwires, as the deflection increased, the loading forces also increased but always more in the mandibular arch. Our results showed deflection from nil to 2mm which displays to the clinicians the amount of ideal deflection required to generate the intrusion forces in the anterior region. The amount of deflection can be maintained during each orthodontic visit to generate similar forces rather than deflecting more which will generate higher damaging forces on the teeth.

The forces were more in mandible compared to maxilla as the inter-bracket distance is lesser in mandible, so that the distance between the supporting points were closer as in a clinical scenario in our simulated three-point bend test. But, the inter-bracket distance in the maxilla was higher and so the distance between supporting points which has more deflection with less force. Similarly, another experimental study showed that higher the inter-bracket distance, lesser the force levels [11]. In our study, the loading forces were measured with an ideal inter-bracket distance with brackets in position along the archform with a full archwire. Such a highly simulated experimental setup was not reported before in the literature.

The limitation of this study is that we did not measure the unloading forces because the whole deflection was within the elastic limit of the archwires evaluated. Further studies are required with more deflection and with variety of archwire materials which will simulate as in the treatment of severe malocclusions. Our results visualise to the clinicians the amount of loading forces generated in a clinically commonly used archwire size of different materials to plan their force applications as per the deflection during intrusion of anterior teeth.

Conclusion

Our study with maxilla and mandible in curved archform with complete archwire engaged showed that the SS archwire produced more force compared to NiTi archwire for 2 mm deflection simulating the tooth intrusion. The forces generated in the mandible arch were more force compared to the maxillary arch. Both SS and NiTi archwire only deformed elastically upto 2 mm. Thus, clinicians can plan the deflection of archwires within the force limits for intrusion of anterior teeth.

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