Original Article

Load-Deflection Properties of Esthetic Orthodontic Archwires Used in Leveling Stage in Self-Ligating Ceramic Brackets

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Abstract

The purpose of this study was to compare unloading force of glass fiber-reinforced wire (GF), non-coated superelastic NiTi wires (NC), epoxy-coated NiTi wire (EC), and Teflon-coated NiTi wire (TC) in ceramic passive self-ligating bracket. The modified three-point bending test was conducted on an ideal upper arch model with intentionally omitted maxillary right lateral incisor. Ceramic passive self-ligating brackets were bonded, and the model was set in a controlled-temperature water bath at 36 ± 0.5° Celsius. The universal testing machine with 100 newton load cells was used. The arch-shaped preformed GF, NC, EC and TC wire was attached to the model and the indenter was set perpendicular to the middle portion of the space of maxillary right lateral incisor. The crosshead speed was 0.5mm/min and the deflection was settled at 1.5 mm for the GF wire and 3 mm for the NiTi wire. Then, the unloading force was measured at every 0.5 mm until the deflection was 0 mm. The experiment was repeated ten times per group and a new archwire was used on every test. The minimum and maximum unloading force measured from the GF group was 14.54 and 134.36 g, the NC group was 41.60 and 526.49 g, the EC group was 35.54 and 289.12 g and the TC group was 56.57 and 514.58 g. The loading and unloading curve of the GF group showed no hysteresis while the NC, EC, and TC groups presented the comparative style of a force-deflection curve with hysteresis and a steep plateau. The four types of wire listed from the lowest to highest unloading force are GF, EC, TC and NC groups.

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Introduction

Nowadays, a lot of adult patients seek orthodontic treatment for esthetic appearance and restore function of the masticatory system. A concern from these patients is about the distinctiveness of the metal orthodontic appliance. Even though a removable clear plastic aligner was invented and widely renowned as it is almost imperceptible, the cost of treatment was still greater than the conventional fixed orthodontic appliance. To work out both the aesthetic and expense problem, a clear ceramic bracket and a tooth-colored wire is another option which has been developed to satisfy the esthetic need.

The use of light force has always been encouraged throughout orthodontic treatments for frontal bone resorption which should maximize the biologic response of tooth movement, maintain the vitality of the paradental tissue and allow maximum comfort for the patient[1-4]. In the early stage of orthodontic treatment, appropriate archwire for aligning and leveling the teeth should produce light force and has a long range of activation. After the invention of Nickel-Titanium (NiTi) alloy, orthodontic treatments have been simplified by the application of NiTi archwire to straighten the teeth due to its ability to deliver light force with flexibility

In pursuit of esthetic orthodontic wire, the NiTi archwires are coated to appear more appealing. Meanwhile new material has also been used as archwire such as glass fiber. However, the mechanical properties of the material are unclear. As the force level is a crucial factor in determining orthodontic tooth movement, this study aims to compare the force level exerted by the esthetic orthodontic wire with the conventional NiTi wire in the initial stage of orthodontic treatment.

Materials and Methods

A maxillary dental arch model was designed by omitting the right lateral incisor using 3Shape Orthoanalyzer software. The base of the model was set to allow 90° angle of the unsupported wire portion and the indenter. After that, the model was fabricated by Flashforge guider II fused deposition modelling 3D printer with polylactic acid fiber. Passive self-ligating ceramic brackets (Damon clear2, Ormco) were bonded with cyanoacrylate glue by using 0.021x0.028 inch stainless steel wire as the guiding wire to align the position of the bracket slot.

The samples were a 0.018-inch orthodontic archwire divided into four groups according to the types of wire: glass fiber-reinforced composite wire (GF group) (Translucent ideal arch pearl, Dentaurum), Non-coated superelastic NiTi wire (NC group) (Rematitan 'LITE', Dentaurum), epoxy-coated superelastic NiTi wire (EC group) (G4 ultraesthetic, G&H orthodontics) and Teflon-coated superelastic NiTi wire (TC group) (Perfect, Hubit).

A testing chamber was filled with water and attached to the holder at the base of the universal testing machine. The temperature of the water was controlled by a thermostat in the range of 36 ± 0.5 °C according to the ISO 15841:20145 for wire use in orthodontics. The dental model was then fixed to the chamber and the indenter was set to a 90° angle on the middle portion of unsupported wire area between maxillary right central incisor and canine. (Fig. 1)

The indenter was set on the universal testing machine with a 100 N load cell. The crosshead speed was 0.5 mm/min. As glass fiber-reinforced wire was composed of brittle material compared to metal wire, the pilot test was conducted to determine the failure point of GF archwire. The test value was used to set the maximum deflection of GF archwire. The NC, EC and TC group underwent the maximum deflection at 3 mm according to ISO 15841:2014. The unloading force was measured at every 0.5 mm until the deflection became zero. The machine was self-calibrated and allowed to be balanced before commencing each test. A new archwire was applied after each test and ten samples were performed for each group.

The data was recorded on an X-Y recorder. The X–axis represented the deflection of the wire in millimeters and the Y–axis represented the load at the crosshead in gram-force. The raw data from the universal testing machine was exported to Microsoft Excel (Microsoft Corp., Redmond, WA., USA). Then, the data was used to create a load-deflection graph. All Data was analyzed using SPSS 24.0 (SPSS Inc., Chicago, Ill., USA). The means and standard deviations of unloading force of each group was calculated. The Shapiro-Wilk test for normality was performed to ensure normal distribution of the data. One-way analysis of variance and multiple comparison with the Tukey test was performed to identify the differences between mean unloading force of the four types of wire at various levels of deflection. Results were considered statistically significant at $P<0.05$

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Figure 1 *Demonstration of the indenter positioned in the middle of the unsupported wire between maxillary central incisor and canine during the experiment.*

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Results

From the pilot study to determine the maximum load that the GF wire could tolerate before reaching its breaking point, the result showed that the breakage of the GF wire was seen at 1.8 - 2.0 mm of deflection. Therefore, the maximum deflection used in this study for the GF group is limited to only 1.5 mm. To compare the unloading force of all four types of wire, the forces at 0.5-3.0 mm of deflection were measured, except for the GF group that comparison was available at 0.5 - 1.5 mm of deflection.

The minimum and maximum unloading force that was measured at every 0.5 mm deflection point from the GF group was 14.54 ± 6.55 and 134.36 ± 19.10 g, the NC group was 41.60 ± 10.06 and 526.49 ± 13.57 g, EC group was 35.54 ± 2.28 and 289.12 ± 12.01 g and the TC group was 56.57 ± 3.96 and 514.58 ± 21.62 g. All the test groups provided the least unloading force at 0.5 mm and the most force at 3 mm except the GF group that was deflected to only 1.5 mm. (Table 1) At almost all deflections, the NC group gave the highest unloading force that was comparable to the TC group. At 1 and 3 mm the force level of the NC group was not different from the TC group. The GF group expressed the lowest force at 0.5 and 1 mm with statistically different, but at 1.5 mm the unloading force was not significantly different from the EC group. When compared to the other NiTi wires, the EC group displayed the lowest unloading force level with statistical difference. (Fig. 2)

The pattern of force-deflection plot in the GF group, the loading and unloading curve were almost on the same line. On the unloading curve, the force dropped proportional to the release of the deflection, demonstrated by the linear line until 0.5 mm deflection was reached. After that point, the force was almost constant.

The pattern of force-deflection plot in the NC, EC, and TC groups presented the comparative style of force-deflection curve with steeper loading curve compared to GF group, and also presented with hysteresis and unloading plateau. (Fig.3)

Table 1 *Mean and SD of unloading force of 4 types of wire at various levels of deflection*

	0.5mm		1mm		1.5mm		2mm		2.5mm		3mm	
	Force (g)	SD	Force (g)	SD	Force (g)	SD	Force (g)	SD	Force (g)	SD	Force (g)	SD
GF	14.54	6.55	69.64	10.77	134.36	19.10	-	-	-	-	-	-
NC	41.6	10.06	180.33	13.40	250.02	12.48	301.25	13.80	358.1	11.60	526.49	13.57
EC	35.54	2.28	92.49	8.88	123.29	8.037	150.55	10.47	181.97	8.029	289.12	12.01
TC	56.57	3.96	175.82	11.06	217.36	9.77	252.55	11.92	305.32	13.09	514.58	21.62

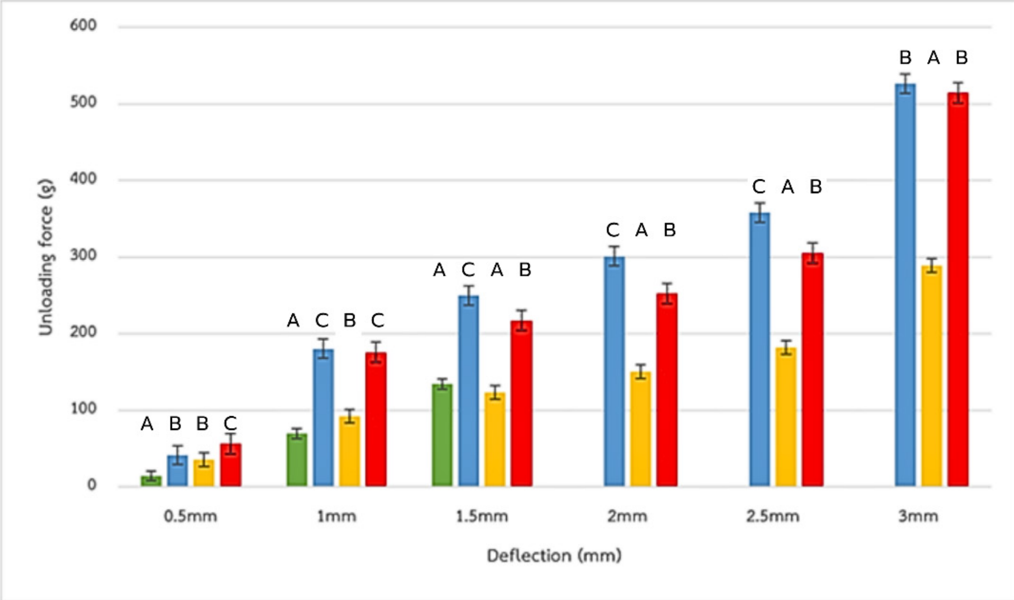

Figure 2 *Mean unloading force of 4 types of wire at various levels of deflection. In each deflection point, the same alphabet means no statistically significant difference (p>0.05). While different alphabets represent statistically significant differences (p<0.05) comparing only in the same deflection point.*

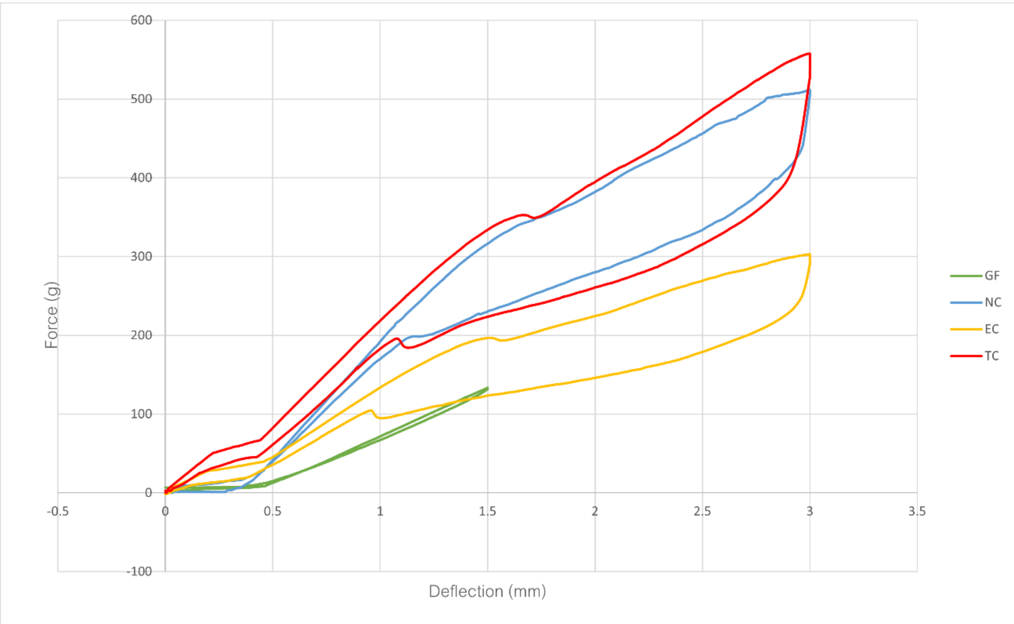

Figure 3 *Force-deflection plot of GF, NC, EC and TC group*

Discussion

To evaluate the mechanical properties of esthetic orthodontic archwire, in this experimental study, non-coated NiTi wire (NC group) and the three types of commercially available esthetic wire: including glass fiber-reinforced composite wire (GF group), epoxy-coated NiTi wire (EC group), and Teflon-coated NiTi wire (TC group) and passive self-ligating polycrystalline ceramic bracket were used. The modified three-point bending test was chosen to simulate the force system in clinical situation of orthodontic appliance and to assess the mechanical properties of

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superelastic wire which allowed reproducibility of the result.[6] Literature showed that the load-deflection performance of orthodontic wires depended on the design of the test model[7], thus the mechanical test was set according to the recommendation of the international standard ISO 15841 that was developed to help comparing the wires used in orthodontics, including preformed orthodontic archwires. The load-deflection diagram from the experiment had two parallel curves: an upper curve depicted the force applied to occupy the archwire into the bracket and a lower curve portrayed the force the teeth was given to bring it into alignment. Only the unloading force was focused for this study since it demonstrated the force that the tooth encountered clinically. One limitation of the method was the cross-head speed. The crosshead speed was recommended at 0.5 - 2.0 mm/min according to the recommendation of the international standard ISO 15841. The crosshead speed could not be addressed as slow as in the real clinical situation. Therefore, 0.5 mm/min speed that was as slow as possible was selected in this study.

The size of the archwire used in this study was 0.018 inch. Because the glass fiber-reinforced composite wire was only commercially available in this diameter, the same size of NiTi wires were selected so that it was logically comparable. Also, the 0.018-inch wire was regularly used later in the leveling and aligning stage before stepping up to the more rigid working wire in the next phase of orthodontic treatment.

The orthodontic wire used in this study were widely grouped into two types of material: glass fiber-reinforced composite and NiTi wire. The mechanical properties, therefore, had dissimilar patterns. The glass fiber-reinforced composite wire possessed a mechanical characteristic that was a linear elastic pattern without prolonged yielding stage, that resulted in a diminished breaking point. The glass fiber-reinforced composite was a brittle material that, even though could tolerate compressive stress well, poorly withstood tensile force. The tensile stress that simultaneously occurred on the opposite surface as the compressive force was applied weakened the material and caused breakage in the wire. Thus, the deflection of this wire was determined by its properties and, in this study, limited the flexure to only 1.5 mm, before the failure of the material according to the pilot experiment. This pilot result is in the same manner as observed in an experiment conducted by Alobeid in 2017 that the 0.018-inch glass fiber-reinforced composite wire of the same brand cracked below 2 mm of deflection.[8]

The glass fiber-reinforced composite wire delivered force with linear pattern and the unloading force was significantly lower compared to all the tested NiTi wires except to the EC group at 1.5 mm deflection. The indistinguishable difference between the loading and unloading force of glass fiber-reinforced wire demonstrated the property within its elastic range. The pattern of force showed the mechanical properties of the plastic material as stated before, linear within elastic limit and a lower yield point. Unlike the NiTi wires, both coated and uncoated, which demonstrated various degrees of the superelastic properties.

Among the three types of NiTi wire: non-coated NiTi wire, epoxy-coated NiTi wire, and Teflon-coated NiTi wire, all of them produced significantly different force at the same point of archwire deflection. The epoxy-coated wire yielded the least unloading force, followed by the Teflon-coated wire and the non-coated NiTi wire gave the highest force. A previous study[9] measured the diameter of the 0.016 inch coated NiTi wire, and showed that the diameter of Teflon-coated wire (Perfect wire, Hubit) was significantly larger than epoxy-coated wire (Ultraesthetic wire, G&H orthodontics) (0.0164 and 0.0153 inch respectively). The epoxy coating of the Ultraesthetic wire was 0.05 mm in thickness (or 0.00196 inch) according to Alavi and Hosseini.[10] The Teflon coating of the Perfect wire was 0.001 inch which meant that the core of Teflon-coated wire of the Perfect wire was larger than that of the Ultraesthetic wire. Thus, the core diameter of epoxy-coated NiTi wire was the smallest among three types of wire and produced the least force. The Teflon-coated group also offered less

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force than the conventional uncoated NiTi wire, indicating the effect of the smaller diameter of the wire. The other concerning point was that the coating layer was not durable and damage was obviously seen at a contact area with a bracket.[10] The unloading force could have been reduced due to the raise in binding of the lacerated coating. From previous literature[11], the retrieved coated archwire produced a lower unloading force than the unused wire in a conventional bracket with an imprint of the bracket on the delaminated area and an increase in surface roughness was detected through the scanning electron microscope. In the as-received wire, the roughness of the coated area of the Teflon-coated wire was significantly lesser than the epoxy-coated wire.[9] This lesser roughness might be contributed to the less resistance on sliding and more unloading force in the Teflon-coated wire. However, the effect of surface roughness on friction was controversial. A study[12] stated that friction was related to surface roughness of the wire. On the contrary, there were studies that found no interaction between surface roughness and friction.[13,14]

The pattern of load-deflection plot of uncoated, epoxy-coated, and Teflon-coated NiTi wires in self-ligating bracket in this study illustrated the hysteresis with exertion of gradually lesser force on the deactivation curve. The experiment by Tikku[15] that tested superelastic NiTi, coated and non-coated, in a ceramic passive self-ligation bracket also showed the same pattern of load-deflection curve in which the deactivation force was continuously lowered as the deflection was decreasing.

In a clinical situation, the ideal orthodontic wire should have a lower load deflection rate. Since the lower load deflection rate delivered more constant force and maintained the appropriate stress along the PDL. Generally, the orthodontic force during the level and alignment stage according to the literature was 35 - 60 g[16]. From this study, all the wire and bracket combination produced an unloading force that was more than the recommended range for the level and alignment stage except at 0.5 mm that all three types of NiTi wire gave optimal force range and glass fiber-reinforced wire delivered slightly less than optimal range. In esthetic-concerned cases, it can be implied from this experiment that 0.018-inch clear glass fiber-reinforced wire and coated NiTi wire could be used in a self-ligating bracket to correct malposition teeth with no more than 0.5 mm wire deflection. To relieve more severe crowding , a smaller size of esthetic archwire is recommended.

The limitation of this study was that the chosen NiTi wire had an 0.018-inch diameter to make a fair comparison with the only commercially available clear glass fiber-reinforced composite wire size. Since the test is set up according to the recommendation of the international standard ISO 15841 that is developed to help compare properties of wire used in orthodontics, 3mm is adopted as the maximum deflection. The situation may not particularly reflect the clinical situation. Thus, care must be taken to apply the results to clinical use, since at this deflection the force is still too high. Also, in order to simulate an oral condition, a water bath was used to control the temperature of the experiment and to mimic a moist environment. According to research[17] the testing friction of an NiTi wire in a self-ligating ceramic bracket, higher friction was observed in the water sample group than in the artificial saliva and natural human saliva group. To postulate the results for clinical application with better accuracy, further experiments should be conducted with modification of the medium.

Conclusion

From the experiment of the study, it can be concluded that among all four types of wire, at low deflection of 0.5 and 1 mm, glass fiber-reinforced wire (GF) gives the lowest unloading force. While all the NiTi wire at more than 1 mm of deflection, the wires that tend to give the lowest to highest unloading force are listed as epoxy-coated NiTi wire (EC), Teflon-coated NiTi wire (TC), and non-coated NiTi wire (NC).

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