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Load Deflection Rate And Properties Of Three Different Brands Of Single Strand Superelastic CuNiTi - A Material Study

Research Article

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Abstract

Introduction: Niti alloys are superelastic alloys whose mechanical properties allow them to exert light continuous forces enabling them to have a greater working range. Orthodontic forces are transmitted through wires which, when engaged tightly in brackets, try to attain its original shape owing to its resiliency and springback properties.
Aim: This study aims to assess the load deflection rates of three different types of superelastic CuNiTi with thermal reactive properties.
Materials and methodology: Three samples, thirty each, of Damon CuNiTi, Captain Ortho CuNiTi, and Galaxy Orthodontics CuNiTi orthodontic archwires were taken. All the samples were 0.016 inch indiameter. The load deflection rates were tested by the Universal Testing Machine (Instron). A three-point bending test was used with a single pointer placed in between the wire between two flat planks. The laboratory conditions were standardized. Force was exerted at a rate of 1mm/minute upto a total deflection of 5mm. The force levels delivered during the intervals was measured and they were plotted as loading and unloading curves in the load-deflection diagram.
Results: In Galaxy Orthodontics, the force levels delivered from intervals (0-1mm, 1-2mm, 2-3mm, 3-4mm, 4-5mm) were 2.76N, 0.13N, 0.73N, 0.09N and 1.15N during the loading period. For the unloading period, the force levels delivered from intervals (5-4mm, 4-3mm, 3-2mm, 2-1mm, 1-0mm) were 0.58N, 0.46N, 1.34N, 1.00N and 0.34N respectively.In Captain Ortho, the force levels delivered from intervals (0-1mm, 1-2mm, 2-3mm, 3-4mm, 4-5mm) were 1.07N, 2.18N, 1.00N, 0.26N and 0.15N during the loading period. For the unloading period, the force levels delivered from intervals (5-4mm, 4-3mm, 3-2mm, 2-1mm, 1-0mm) were 0.89N, 0.96N, 0.28N, 0.84N and 0.62N respectively.In Ormco Damon Wires, the force levels delivered from intervals (0-1mm, 1-2mm, 2-3mm, 3-4mm, 4-5mm) were 0.32N, 0.78N, 0.39N, 0.52N and 0.19N during the loading period. For the unloading period, the force levels delivered from intervals (5-4mm, 4-3mm, 3-2mm, 2-1mm, 1-0mm) were 0.33N, 1.86N, 1.39N, 0.49N and 0.16N respectively.
Conclusion: Ormco Damon archwires have better and constant force delivery rates and may be suitable for cases with severe crowding and adult dentitions. Galaxy Orthodontics and Captain Ortho have variable force levels and show especially high force delivery during initial delivery. Hence, they are suitable for mild and moderate crowding.

Keywords: NiTi; Load Deflection Rates; Superelasticity.
Abbreviations: NiTi- Nickel Titanium; CuNiTi- Copper added Nickel-Titanium.

Introduction

The amount of displacement that a material undergoes when subjected to a load within its bearing strength is called deflection. For calculating the deflection rate of a material, it is necessary to understand the properties that define its specific characteristics. Calculating the deflection distance gives us an idea about the load-delivering and load-bearing capacity of the wire [1, 2].

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In orthodontics, force applied must be light and continuous for it to be considered as physiologically appropriate and biologically acceptable for optimal tooth movement. The use of NiTi archwires became prevalent because of their ability to exert light continuous force and consequently improve the efficacy of treatment, particularly in the initial phases of treatment [3]. Crystal lattice transformations of the material and transformation from austenite to martensite forms are main reasons for the super-elasticity of NiTi alloys. NiTi alloys should deliver a constantlevel of force without relying on the wire activation, providing a force which is both lowin magnitude and continuous in nature [4, 5].

Commercially available NiTi alloys however have a tendency to behave variably and this factor can be expressed by examining the flattish plateaus in the respective load-deflection curves of the individual wires [6].

Copper, an additional element added in NiTi alloys, adds a new dimension to this super-elasticity by bringing in corrosion resistance and thermal modifiability. Copper NiTi is a quaternary alloy that provides the unique benefit of a low hysteresis and allows the clinician to engage the wire more easily, increasing efficiency and comfort [7, 8]. In this study, we attempt to assess the load-deflection rates and superelasticity of three different brands of Copper NiTi wires along with their clinical reliability and efficiency. These three brands are the most commonly used samples in our Department and hence we wanted to assess the reliability of the force levels delivered by them.

Materials and Methodology

Our study was a material study conducted using three different samples of wires. It was conducted in the Department of Orthodontics, Saveetha Dental College, Chennai. Three samples, thirty each of Ormco Damon CuNiTi, Captain Ortho CuNiTi wire and Galaxy Orthodontics CuNiTi were taken. The sample collection took a period of 1 month and they were purchased from the respective brand manufacturers. The wire samples were then tested at CIPET, Guindy for a period of 2 weeks and the results were obtained. All the samples were 0.016 in diameter, and for testing purposes,the straight sections of the wire posterior to the standardized preformed intercanine-width were cut and tested.

The load-deflection properties of the three types of wires were assessed by analyzing the hysteresis curve between the loading and unloading curves. The flat slope at the unloading curve, the plateau is taken as the reference, and its length was taken to denote the extent of the range of displacement [9].

The Instron universal testing machine was used to conduct the three-point bending test (Fig 1). It was carried out at Central Institute of Plastics Engineering and Technology (CIPET), Guindy under the supervision of a senior staff guided to carry out the procedure. The required sections of the wire were cut and placed horizontally across a metal slab. It was not supported with loads on both ends to prevent distortion of the wire during force application (Fig 2). At the middle of the wire, the sharp end of the metal pole was used to apply pressure vertically at the rate of 1mm/minute until a deflection of 5mm for each individual wire (Fig 3). The diameter of the metal pole was 5mm and all efforts were made to ensure that the same region of the pole was in contact with the wire during the entire duration of the procedure (Fig 4). After the wire was deflected for a length of 5mm, it was gradually unloaded as well at the same time frame fixed (Fig 5).

The length of the plateau was used to indicate extension of the displacement range in which the force may be considered approximately constant [9]. The average force was given by the arithmetic average of the values of force pertaining to this phase identified on the curve. The effective slope is a measure of the degree of plateau flatness; therefore, the closer the slope was to zero, the more constant was the force. A load/deflection curve was obtained for each of the three samples tested(Graphs 1,2 and 3). A sole operator subjectively identified and isolated the discharge plateau. This was identifiable clearly on each graph. The same operator calculated the values yielded by the three samples for each of the parameters considered (average plateau force, plateau length, and plateau slope) and for each type of wire tested.

Results

The results of the loading and unloading force levels were tabulated individually. The graphs indicating the load-deflection diagram were plotted from the values indicating the loading and unloading curves respectively. The force was exerted at a rate of 1mm/minute uptil a deflection of 5mm. Force levels assessed were determined between two intervals (eg: from 1mm-2mm, 2mm-3mm etc.) rather than the cumulative force achieved. This load exerted on the wire was continued upto 5mm.

Table 1 gives the values for Galaxy Orthodontics wire sample. For an extension of 1mm, the force levels delivered was 2.76N. For the next interval (1-2mm), the force levels delivered was 0.13N. The force levels delivered for the next intervals (2-3mm, 3-4mm, 4-5mm) were 0.73N, 0.09N and 1.15N respectively (loading

Figure 1. Instron Universal Testing Machine.

Figure 2. Wire placed horizontally between the slabs.

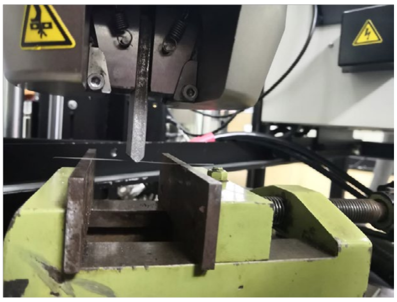


Figure 3. Vertical load being given.

Figure 4. Full deflection of 5mm given.

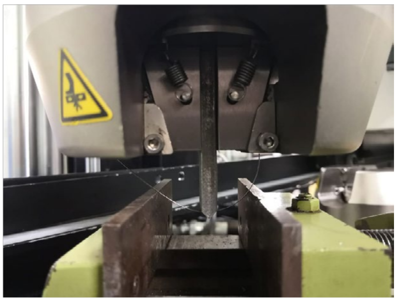
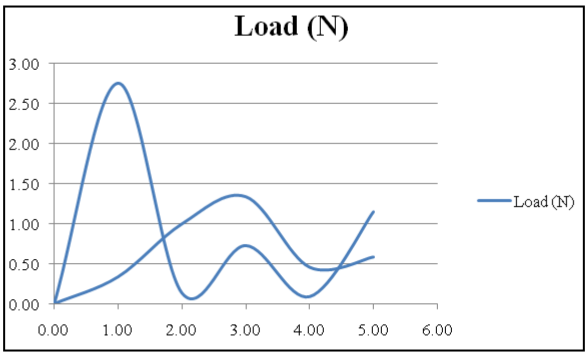
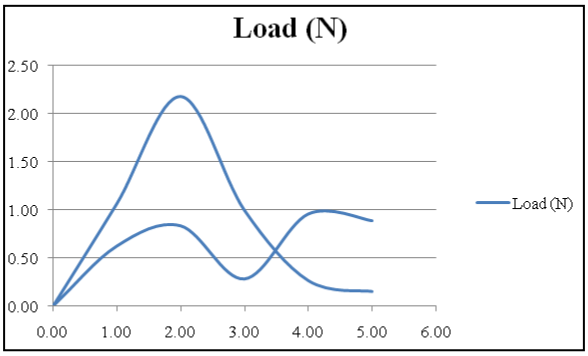


Figure 5. Gradual unloading of vertical load.

Graph 1. Loading and unloading curve for Galaxy Orthodontics.



Graph 2. Loading and unloading curve for Captain Orthodontics.



Graph 3. Loading and unloading curve for Damon Arch wires.

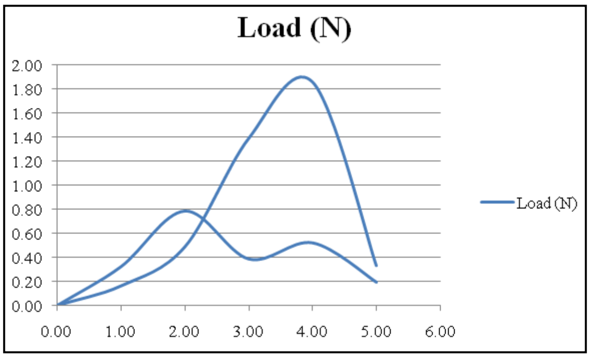


Table 1. Flexure and Load from 1-5 minutes and vice versa (Galaxy Wires).

Time (sec)	Extension (mm)	Load (N)
0.20	0.00	0.00
60.10	1.00	2.76
120.00	2.00	0.13
179.90	3.00	0.73
240.00	4.00	0.09
300.00	5.00	1.15
312.30	5.00	0.58
372.10	4.00	0.46
432.10	3.00	1.34
492.10	2.00	1.00
552.10	1.00	0.34
627.50	0.00	0.00

Table 2. Flexure and Load from 1-5 minutes and vice versa (Captain Ortho).

Time (sec)	Extension (mm)	Load (N)
0.00	0.00	0.00
60.20	1.00	1.07
120.20	2.00	2.18
180.30	3.00	1.00
240.30	4.00	0.26
300.20	5.00	0.15
312.30	5.00	0.89
372.10	4.00	0.96
432.00	3.00	0.28
492.10	2.00	0.84
552.10	1.00	0.62
612.10	0.00	0.00

Table 3. Flexure and Load from 1-5 minutes and vice versa (Damon Wires).

Time (sec)	Extension (mm)	Load (N)
0.00	0.00	0.00
60.10	1.00	0.32
120.10	2.00	0.78
180.10	3.00	0.39
240.20	4.00	0.52
300.10	5.00	0.19
312.50	5.00	0.33
372.10	4.00	1.86
432.10	3.00	1.39
492.20	2.00	0.49
552.40	1.00	0.16
612.00	0.00	0.00

curve). The unloading curve was interpreted similarly. The force levels delivered from intervals (5-4mm, 4-3mm, 3-2mm, 2-1mm, 1-0mm) were 0.58N, 0.46N, 1.34N, 1.00N and 0.34N respectively.

Table 2 gives the values for Captain Ortho wire sample. For the loading curve, the force levels delivered from intervals (0-1mm, 1-2mm, 2-3mm, 3-4mm, 4-5mm) were 1.07N, 2.18N, 1.00N, 0.26N and 0.15N respectively. For the unloading curve, the force levels delivered from intervals (5-4mm, 4-3mm, 3-2mm, 2-1mm, 1-0mm) were 0.89N, 0.96N, 0.28N, 0.84N and 0.62N respectively.

Table 3 gives the values for Ormco Damon wire sample. For the loading curve, the force levels delivered from intervals (0-1mm, 1-2mm, 2-3mm, 3-4mm, 4-5mm) were 0.32N, 0.78N, 0.39N, 0.52N and 0.19N respectively. For the unloading curve, the force levels delivered from intervals (5-4mm, 4-3mm, 3-2mm, 2-1mm, 1-0mm) were 0.33N, 1.86N, 1.39N, 0.49N and 0.16N respectively.

Discussion

The graphs plotted did not display readily identifiable plateau areas. Areas of the graph in which constant forces were seen were scattered. Increase in force levels was seen in initial stages of the discharge period and gradually showed spikes at different application intervals. Slope parameters also showed negative values at certain points indicating different frictional coefficients. The parameters were standardized before force application to account for the microscopic molecular interactions within the wire that could influence values (Graphs 1 and 2).

In Galaxy Orthodontics arch wire, the initial load-deflection was seen to be the greatest of the three wires at range of 1-2mm (Table 1). This indicates that the wire could be at its most efficient range over small deflections and ideal for crowded dentitions where the average anteroposterior discrepancies do not exceed 1-2mm for individual teeth. The plateau of the graph started to recede in discrepancies exceeding 3 mm indicating lack of flexibility and excess force generated by wires if engaged in such severely crowded dentitions (Graph 1). The unloading curve is highly irregular suggesting deficiencies in wire relaxation and this indicates a lack of a definitive fixed force on wire unloading and could lead to a longer waiting period between changing wires with chances of pain and root resorption.

In Captain Orthodontics arch wire, the initial load deflection curve was again good and steep indicating efficient and satisfactory engagement in discrepancies from 1-2mm (Table 2). It involves less force required to involve the teeth and is easier and constant in its force delivery. It also possesses an irregular unloading curve however and this poses questions regarding its force released during unloading (Graph 2). Irregular force release could lead to other undesirable sequelae involving the periodontium and might compromise the long-term stability of the treatment result. The loading and unloading curves start at two different points however, and this could be important to analyse the force dissipated by the wire during its maximum engagement to determine the force decay from loading to unloading.

Damon arch wiresexhibit an optimum loading-unloading curve and are ideally suited for large deflections(anteroposterior discrepancies of 3-4mm). They have a gradual increase in their force levels during initial stages, small discrepancies and exhibit a peak at engagements over 3.5 mm (Table 3). Thus, they exhibit their activity levels over a longer period of time with a more uniform force exerted which is much more consistent and biologically acceptable. This can be helpful in expanding arches and gradually aligning the tooth towards their more favored positions by gradual aligning and presents a more tolerable and acceptable level and range of force exhibited [10, 11]. It also exhibits a gradual unloading curve indicating its efficiency during tooth alignment as force levels exhibited do not rapidly increase or decay and instead follow a more predictable pattern which is much more uniform and consistent to be used (Graph 3).

Assessment of load-deflection ratios and evaluation of the loading-unloading curves is important in determining the efficiency of the wires involved as well as their superelastic properties. It helps in breaking down the comparisons into a true-superelastic and borderline superelastic, which can give a value in reference to the clinical setting [12, 13].

The above attained laboratory results cannot be directly transferred to provide clinical inferences [4-6]. It can help us in understanding the specific characteristics of the wire that we use in initial alignment stages. The force delivered by the wire once the teeth start getting aligned is a direct consequence of the load-deflection rate. A wire having a lower load-deflection rate will deliver more constant forces and subsequently have constant loss of forces as well. This makes the system biologically efficient and periodontally sound. If the wire is able to deliver an adequate amount of force after each mm of movement, then the alignment period is also faster and reactivation intervals/appointments can be kept longer [14, 15].

The three-point bending testing method that we have employed in this study is a test of physical properties of materials [8, 16]. This test is reliable, can be reproduced under standardized conditions and is useful for result evaluations. Moreover, studies in literature use it as a standardized testing procedure and that makes comparison with other studies also possible [17].

Measurements made on labs cannot be readily transferred into a clinical setting. Numerous confounding factors such as friction, saliva, bracket-wire interface can increase or decrease forces during activation and deactivation [18]. Force-deflection diagram obtained with ideal stress-strain curves and adequate plateau width can be useful for deriving observations. They are however impractical when transferred to clinical situations [19]. Hence, in this study we have tried to change the method of measurement of the force-deflection diagram by keeping the wire under load for the entire deflection time period, a scenario which is clinically rare but relevant and then charted the loading and unloading curves.

Wires with stable and larger plateau intervals are termed true superelastic and are useful in most clinical scenarios as they provide relatively constant forces [3, 20]. During the leveling and aligning of treatment, it is preferable to use these types of wires due to the low and stable force delivery levels. These wires are most helpful when large corrections are required and a big deflection of the wire is expected [21, 22].

While evaluating the effectiveness of wires, it is critical to assess the unloading curve in the load-deflection diagram. A smaller length of plateau is a good indicator for lower and constant forces. Larger plateaus are applicable with larger force deliveries as well and are mostly indicated in severe rotation correction [23, 24] In agreement with the above findings are the results of Andreasen and Morrow [25], in which the large Nitinol archwires are appropriate to correct and maintain leveling and rotations without increasing the patient's discomfort.

Conclusion

The interpretation of the results classifies Damon archwires into a true superelastic wire and the other two samples (Galaxy Orthodontics and Captain Ortho) into a borderline superelastic wire.

Damon archwires have a smoother initial loading curve and exert maximum force during the last phase of unloading. Thus, they are ideal for initial leveling and aligning procedures. They are particularly recommended in adult patients and severely crowded dentitions.

Captain Ortho and Galaxy Orthodontics have increased force delivery levels during the initial deflection period (1-3mm) and later shift to a more constant force delivery system. During unloading, their force delivery is variable and shows jiggling tendency. Therefore, they may be more ideally suited for mild to moderate crowded dentitions and in cases which can sustain higher force levels, better for faster derogations.

Availability of data and materials

The wires were gathered from their respective manufacturing companies.
The Instron Machine (Universal Testing Machine) was utilized from CIPET,Guindy for testing purposes and was properly calibrated and evaluated for the sam.

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