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Load Deflection Ratios of Various Initial Ni-Ti Wires

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Abstract

Orthodontic wires generate biomechanical forces communicated through brackets for tooth movements. Nickel titanium alloys used as arch wires have mechanical properties that allow them to exert light continuous forces, with greater working range as compared to elgiloy and stainless steel. The ability of Niti to maintain its resiliency against permanent deformation while maintaining a state of activation maybe be attributed to its properties of low stiffness, high springback, shape memory, superelastic properties and load deflection, making them ideal to be used as initial alignment wires. The variation in wire size and alloy type of different NiTi wires influence their load deflection characteristics, thus having an impact on functional effectiveness. Knowing the load-deflection ratio of a given orthodontic wire allows for selection of the ideal wire during treatment, particularly during the initial alignment phase, during which wire deflection and tooth movement occurs. Understanding the force being applied would enhance the treatment and aid in minimizing side effects such as pain and root resorption.

Keywords :NiTi, archwires, load deflection, alignment

INTRODUCTION:

The appropriate application of biomechanical concepts in orthodontic treatment enable accurate and satisfactory end results. Orthodontic wires are required to generate light and continuous biomechanical forces, communicated via brackets, resulting in tooth movement. Factoring which orthodontic wire is appropriate for a situation can depend on several factors such as composition of the metal alloy, thickness, cross sectional shape, size of the bracket, interbracketdistances, friction between the wire and the bracket, and the modulus of elasticity. Ideal arch wires exert forces capable of eliciting adequate biological response in the periodontal ligament for bone remodeling, while causing minimal pain intensity, root resorption, necrosis of the periodontal ligament, and maximal alignment speed[1].

Initial arch wires are the first wires inserted at the beginning of the treatment for initial tooth alignment by correction of crowding and rotations. They are required to have low stiffness, high strength and long working range[2]. This phase of alignment-levelling is characterized by progressive increase of wire diameter, while maintaining the boundaries of physiological constraints of the periodontium and allowing the prediction of expected results. Wires made of Nickel titanium alloys have favorable mechanical properties, making them ideal for use in initial alignment. Of these properties, an important consideration for its use as initial arch wires is their low modulus of elasticity and hence a low deflection load. This provides Niti the ability to provide a low magnitude but constant duration of force, allowing tooth movement by means of more adequate forces makes them popular choices[3]

This review aims to offer an insight into the mechanical characteristics of NiTi, particularly their load deflection ratios and the factors influencing it, and evaluate and compare their behaviors, with a view towards providing a better understanding to clinicians, so the wire with the best indication may be selected thus increasing the efficacy of the treatment.

Initial arch wires

Contemporary orthodontic treatment involves both fixed as well as removable appliances. However, fixed orthodontic treatment has become increasingly dominant in orthodontic practice throughout the world due to the superior quality of results obtained with it[4].

The first arch wires used at the beginning of fixed orthodontic treatment for initial tooth alignment are referred to as initial arch wires. They are used mainly for correcting crowding and rotations. It is important for the clinician to be well versed in the different types available, those which most appropriate for initial aligning stage in terms of being efficient, causing minimal pain and least amount of root resorption.

According to Proffitt, the requirements of ideal arch wires include[5]

1. Flexibility, formability, low friction, the ability to be welded
2. high strength and resistance to permanent deformation, while having good springback and light and continuous force delivery as a result of low stiffness;
3. good range to be able to maximise activations so there is elastic behaviour over weeks to months;
4. ease of engagement within the fixed appliance attachments within a reasonable time scale;

5. Low cost

The performance of the initial arch wires depend highly on physical properties of the material, dimension of the wire and other geometrical factors such as the cross-sectional shape (whether the arch wire is circular, rectangular, or square), length (i.e. inter-bracket span) and diameter; apart from having to fulfill the above criteria. It is a given that for a certain material, as the diameter of a wire decreases, its strength decreases while conversely as diameter increases, its stiffness increases[2].

Evolution of arch wires:

The evolution of materials available to apply force on the teeth has been paving the way for future trends in alignment. The earliest wires were judged on the structural properties of strength and flexibility. As the stiffness of the materials available at the time were virtually the same, importance was given to wire dimension and shape. However, now it is possible to have wires which are the same size and shape, but of variable stiffness because of the mechanical properties of their constituent materials.

Historically, precious metal alloys like gold were used for as initial arch wires but high material costs limited their use and made them eventually obsolete. This was soon replaced by stainless steel, which, in comparision offered good strength, springiness, corrosion resistance and easy availability. Stainless steel offered good flexibility and could be bent to the desired shape without breaking. Increased flexibility was experienced when length of the wire was increased using loops, to be used as initial arch wires. However, these were time consuming and had to be customized for each patient[6]. Another way was by twisting two or more strands of the springy wire of small diameter wire ($\leq$ 0.01 inch) into a multistrand cable, having admirable qualities of strength and spring qualities. How tightly they were woven and characteristics of the individual wire strands influence its flexibility[7].

Over the past few years, there has been a growing trend of newer materials showing a range of properties which manufacturers claim offer benefits in terms of tooth alignment. However clinical trials are warranted to understand whether different types of initial arch wires actually result in important differences, such as faster alignment, reduced pain or reduced side-effects. In-vitro studies have the ability to mimic intraoral environments only upto an extent, and extrapolating these values to apply in clinical situations may be misleading.

Niti and its current status

Nowadays, “light continuous forces” are thought of as physiologically suitable and efficacious, but the term is used somewhat arbitrarily. In fact, no consensus has been reached among the scientific community about what constitutes a “light” force and what does not. Thus, no concrete scientific evidence is available to quantify the optimal force for orthodontic movement, and clinicians must judge for themselves the most suitable force for each particular clinical situation. In this context, nickel titanium archwires have become increasingly popular in recent years because of their ability to release continuous forces of low magnitude, which are considered to improve the efficiency and efficacy of treatment[8].

Nickel–titanium (NiTi) archwires are widely used for initial alignment due to their properties of

shape memory and superelasticity. Both of these effects are related to thermoelastic transformation (austenitic to martensitic phase), which can either be induced by cooling or be produced by stress.

NiTi wires can be classified into two types: superelastic and thermal. Superelastic wires, in the austenitic active alloy state, undergo martensitic transformation by mechanical deformation. Thermal NiTi wires are a martensitic active alloy and exhibit a thermally induced shape memory effect. For thermal wires, transition temperatures from martensite to austenite occur in the region of the ambient oral temperature.

Nickel is an austenitic element; which means that its presence in the structure of an alloy will promote the establishment and stability of the austenite phase at lower temperatures. The presence of the austenite phase will result in a more rigid alloy as the wire will show a maximum of 2% elastic deformation within the strain limit. Whereas the wire in the marten site phase can undergo 8-10% of elastic deformation until it fulfills its limit and reaches permanent plastic deformation. In other words, the austenite phase resembles steel materials but the marten site phase displays more of an elastomeric behavior. Such low differences in the atomic percentage of the elements may not however result in big changes of the mean force of the wires.

Wires deformed in the martensitic phase and heated up to a certain transition temperature range (TTR), are able to recover their original form as they return to the austenitic phase, and therefore are said to possess shape memory. Although the first nickel titanium archwires featured this characteristic, their TTRs did not permit this property to be exploited for orthodontic purposes.3However, thanks to the recent development of temperature-dependent (heat-activated) alloys, this shape memory characteristic can now be used to clinical effect.

NiTiarchwires can easily be transformed between an austenite and a martensite phase either by temperature changes or by stress application. The transition between the two phases is termed martensitic transformation, and it is responsible for the memory effect. This transformation is the result of changes in the crystal lattice of the material.Superelasticity is the transformation from austenitic to martensitic that occurs by stress application within a temperature range and is manifested by a flat or nearly flat plateau in a force-deflection curve. Shape-memory property is the plastic deformation of NiTi wires from the martensite phase to an austenite crystal structure. The shape-memory properties of archwires can be modified by adding a third element to the NiTi alloy, for example, copper. The copper in the NiTi alloys increases the corrosive resistance and controls the hysteresis width. Copper-added NiTi wires (CuNiTi) consist of nickel, titanium, copper and chromium. According to the manufacturer, due to incorporation of copper, those wires have more thermoactive properties than superelasticNiTi wires and allow acquisition of an optimal force system with a more precise control of tooth movement, thus enabling quantification and application of load levels appropriate to orthodontic treatment purposes[9-13].

The NiTi alloys exert nearly the same amount of force independent of the activation of the wire, thus providing a low magnitude and constant duration of force. Studies have shown, however, that the commercially available NiTi alloys behave in a variable manner, which often deviates from superelasicity.The differences lay in the shape of the force-displacement curve and the position of the superelastic plateau[14].

Stainless steel wires have reduced in popularity for initial alignment with the developments in nickel-titanium (NiTi) wire technology but are still used by a small proportion of orthodontists. NiTi alloys can exist in more than one form or crystal structure: the martensitic (M) form and the austenitic (A) form. According to the crystal structure within NiTi alloys, NiTi wires can be classified as follows[10,11,12].

(1) M-NiTi which are in a stabilized martensitic form, with no application of phase transition effects.
(2) A-NiTi which have an active austenitic grain structure and are subject to phase transformation under comparatively low temperature and stress.

M-NiTi wires are commercially available and have several names, for example Nitinol, Titanal and Orthonol. All the M-NiTi wires have good spring-back and enough strength but poor formability whereas A-NiTi wires exhibit a superelastic property. Superelasticity means that wires exert about the same force irrespective of whether they are deflected either a relatively small or large distance, which is a unique and extremely desirable characteristic in relation to minimising root resorption. A-NiTi wires are very soft at room temperature and become elastic at mouth temperature. These properties make them easier to place into fixed appliances initially but difficult to bend or permanently distort. A-NiTi wires are marketed under several trade names, for example Sentinol, Ni-Ti, Cu-NiTi and NiTi-SE.

Load deflection rates and their significance:

By definition, each orthodontic metal alloy has a modulus of elasticity that does not change, even when the wire thickness or cross section is changed. Alloys with a high modulus of elasticity are more rigid, such as stainless steel and Elgiloy, which is a chromium-cobalt-nickel (Cr-Co-Ni) alloy. Those with a low modulus of elasticity are more flexible, such as titanium-molybdenum (TMA) and nickel-titanium (NiTi)[15].

The modulus of elasticity is directly associated to the load required for the deflection of orthodontic wires, which is called the load-deflection ratio. The greater is the modulus of elasticity of a wire, higher is the load-deflection ratio and its rigidity. As the modulus of elasticity of orthodontic alloys cannot be manipulated to provide greater flexibility to the wire-appliance set, first the load-deflection ratio of the material should be known so that, later, the wire with the best indication for each phase of an orthodontic treatment can be selected[16].

Orthodontic wire superelasticity produces a relatively steady force within a given deactivation interval, the phase during which the wire attached to an orthodontic device induces tooth movement.Lack of steady force at deactivation mischaracterizes the superelasticity proposed by the wire manufacturer, which could produce a less predictable or less biological movement during clinical practice[17].

Measuring Load deflection rates and factors affecting it:

The standard method for evaluating orthodontic wires not containing precious metals is the three-point elastic bending test according to ADA specification no. 32[18]. The results of this method for evaluating the practical value of these wires has been under consideration,1 and a five-point elastic bending test was proposed, imitating more of the clinical process. Later, Hurst et al designed special grips to hold the wire in place in the Instron machine. It is not possible to transfer the laboratory results of the above mentioned test or modification of this test to the clinical orthodontic setting. Only patients with extreme irregularities experience deflections greater than 1.0 mm and in routine orthodontic treatment, the deformation of NiTi wires is not sufficient to take advantage of their superelastic behavior. Also, the force levels applied in vivo may not reach the superelastic plateau, and the force would not be independent of deflection.There are testing methods focusing directly on the orthodontic system or others that are pure evaluation of physical and biomechanical properties of the wires[19,20]. The three-point bending method is not directly transferable to the clinical setting and resembles occlusogingival movements. The three-point bending has been employed as a physical property test. It is a method focusing more on the physical and biomechanical properties of the wires, offers reproducibility, and is useful for purely theoretical evaluations. It is a standardized testing method that makes comparison to other studies possible.

The laboratory tests are not capable of revealing the major characteristics of the new available wires. Such tests should be a comparison between laboratory findings and findings obtained from clinical trials.

Settings were described by Gross and later by Segner and Ibe that resemble the orthodontic clinical situation, the three-bracket bending system. The stiffness values of NiTi wires in 3 mm of deflection in the bracket bending test exceed 7.5 to 40 times the stiffness values of the three-point bending test. In a clinical setting, it is almost impossible to make assessments on the strain that is exerted on the archwire. Factors such as friction should also be considered. Friction increases the effective force in the activation mode, and it decreases the force in the deactivation mode. In this way, the force deflection curve may be distorted.The clinical plateau was introduced so that a more clinically relevant measure could be attained that allows a classification of the wires according to their superelastic properties.The clinical plateau of the unloading curve has been introduced, because in orthodontics, the deactivation curve is the main one of interest in relation to moving teeth.

The new definition was based on the superelastic ratio described by Segner and Ibe and further modified by Meling and Odegaard.These parameters were developed so that more objective criteria could be established for the evaluation of the different products[21].

In the studies performed by Wilkinson and Parvizi three-point bending tests were carried out and it was shown that wires will produce a greater force when they are applied in phantom head tests simulating the dental arch compared with testing by a model of wire fixation between two rods. The models designed for administration of the load-deflection tests therefore affect the outcome of experiments[22].

The temperature at which the experiments are conducted is another important factor that affects the mechanical behavior of the wire. The results of the study of Tonner et al, revealed that the degree of force applied during the loading and unloading phases will increase as the temperature rises from 25ºC to 30 ºC. The fall in temperature until nearly 5ºC during the unloading stage, will eliminate the plateau phase of the graph. An automatic heating element could be used, to mimic oral environmental temperatures[23].

The distance between the two fixed points on the wire (interbracket distance) will also affect the superelastic behavior of the wire. Generally, an increase in the interbracket distance will result in a decrease in the load-deflection properties of the wire, elevates its flexibility and enhances realignment of teeth in dental crowdings. The value suggested for this distance varies in different studies and is based on the inter dental spaces of the dental arch[24].

Load deflection of NiTi:

The superelasticity of NiTi is reflected in a load/deflection graph characterized by a flattish slope upon discharge, known as the plateau, which indicates that the force exerted is relatively constant in the range of tooth movement. This feature is linked to reversible transformation from the austenitic to the martensitic phase beyond a certain stress threshold, which is reached during activation and deactivation.[25].

NiTiarchwires have many theoretical advantages over others in the initial alignment of the teeth. However, most of these advantages are based on in vitro testing methods, and in order for this advantage to be validated, these wires should be assessed clinically. The conclusions of some published clinical trials have not agreed with those of laboratory tests and have found no significant differences in alignment efficiency between NiTi wires and multistranded stainless-steel wires.On the other hand, another trial has proved that a greater amount of tooth movement occurs with superelasticNiTi wires, although the accompanying root resorption was greater[26].

SuperelasticNiTiarchwires (Active NiTi) have been widely accepted for initial alignment of malocclusions, mainly because of their unique properties of superelasticity and shape memory. These are particularly useful where large deflections are necessary to align severely malpositionedteeth.SuperelasticNiTi wires show different behavior than do conventional NiTi wires under laboratory test conditions,typically manifested as a flat or nearly flat plateau. It has been speculated that in order to reach the superelastic plateau of the wire, large deflections (50–70° bending angle) would be necessary[27]. Such deflections are rarely encountered clinically. One should not also forget the individual variations in the metabolic response within the periodontal ligament and bone, which might have masked any possible difference.

Comparision of various initial arch wires :

Multistrand Stainless steel Vs NiTi[28,29].

Different comparisions and different outcomes have been reported. Cobb (1998) compared 0.0175 inchmultistrand stainless steel wire (Wildcat) to 0.016 inch Austenitic-NiTi wire (Sentalloy) or the same 0.016 inch Austenitic-NiTi wire with surface ion implantation. He reported that there was no statistically significant difference between the three arch wires in rate of alignment. However the result must be interpreted with caution due to the unit of analysis error involved; he reported no numerical data, and failed to measure root resorption, time to alignment and pain.

West 1995 compared 0.0155 inchmultistrand stainless steel wire (Dentaflex) with 0.014 inch superelasticNiTi wire (NiTi). he superelasticNiTi wire was found to produce a statistically significant improved alignment in comparison to the multistrand steel wire, but there was no difference in the labial segment of the maxilla.

Single strand Vs multistrandNiti[30,31].

Aghili at al reported that with any type of bracket in deflections of 2 and 4mm, MSNT wire exerted the lowest while single-strand NiTi wire exerted the highest force level at maximum deflection and the plateau phase. Force level at maximum deflection and plateau length increased by increasing the amount of primary deflection, but the average plateau force was not affected significantly. The delivered force in all cases was within the range of the biological threshold and biological corridor defined by Proffit and Field.

Multi-strand wires in low friction systems are superior to single-strand superelastic wires in first phases of orthodontic treatment, because regarding the results of the current study and those of Berger et al, MSNT wires, exerted one-third of the force of conventional NiTi wires with the same size; and were able to express their super elasticity at lower deflections.

Superelastic Vs Multistrand[32,33,34] :

Small deflections (0.5mm) of superelastic wires do not create a significant plateau phase. Garrec and Jordan showed that the load deflection graph of superelasticNiTi wires at a small deflection was similar to that of conventional alloys. Therefore, in cases of low dental irregularity malocclusion index, the super elasticity of this wire will not express, and the advantages of NiTi wire will not be benefited from. Bartzella et al was of the opinion that true superelastic wires are applicable where large deflections are required and relatively constant force during major stages of tooth movements is needed. In the clinical application, the unloading forces are of main importance. The smaller plateau slope in the unloading phase is an indication for lower as well as constant forces on the clinical application.

For derotational procedures, wires with a long clinical plateau along with higher application forces are indicated. Andreasen and Morrow revealed similarly, who suggested use of longer nitinol wires to correct rotations without increasing patient's comfort.According to the results of their study, the true superelastic wires are indicated for the leveling and the borderline superelastic wires with long plateau length for derotational procedures. The true superelastic wires should be recommended especially for the treatment of adult patients and stark crowding cases. The borderline superelasticarchwires are considered suitable for mild to moderate crowding cases.

Conventional vs thermal[35]:

Lombardo et al compared traditional and heat-activated archwires of the same diameter showed that the latter exerted a significantly lighter force (∼24%) and generated a significantly longer plateau (∼13%) than the former. On average, a 0.002 inch increase in cross-sectional diameter generated a 50% increase in plateau force (0.012 × 0.014 and 0.014 × 0.016 inch), and a 0.004 inch (0.012 × 0.016) increase in diameter resulted in an increase in plateau force of roughly 150%.

Thermal Vs Superelastic[36] :

Elda Gatto et al investigated superelastic and thermal arch wires of two different sizes (0.014 and 0.016 inches). The archwires were subjected to bending at a constant temperature of 37°C and deflections of 2 and 4 mm.howed that thermal NiTi wires exerted significantly lower working forces than superelastic wires of the same size in all experimental tests ($P < 0.05$). Superelastic wires showed, at a deflection of 2 mm, narrow and steep hysteresis curves in comparison with the corresponding thermal wires, which presented a wide interval between loading and unloading forces. At 4mm deflection, the curves of all the wires showed wider plateau than those at 2mm deflection. This difference for superelastic wires may be explained due the martensite stress induced at higher deformation levels.

CONCLUSION:

The selection of ideal NiTi can be a tedious task due to inaccurate information of expected TTRs, compounded by varying properties between different manufacturers for similar wires. There is a need for further well conducted, adequately powered randomized control trials to determine whether the performance of initial arch wire materials are as demonstrated in the laboratory, which makes a clinically significant difference in the initial aligning stage of treatment.

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