Stiffness in Bending of recently advanced Superelastic Ni-Ti initial Orthodontic Arch Wires

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TITLE: Stiffness in Bending of recently advanced Superelastic Ni-Ti initial Orthodontic Arch Wires.

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ABSTRACT:
AIM & OBJECTIVE: - To evaluate the properties and then compare the data to identify a better efficient material

BACKGROUND:- Archwire are wires that conforms to the dental arch that can be used with dental brackets as a source of force in correcting irregularities in the position of teeth or even used to maintain existing dental positions. Recent advancements must be make it ideal for early to mid-stage treatment with moderate to severe crowding. This wire is best suited for the initial stage because it is easy to engage at lower temperatures. It includes improved surface hardness, reduces sliding friction no separate coation and excellent super-elastic qualities.

REASON:-This study will help to tabulate the comparison of characteristic between various arch wires used in orthodontics, thus providing a clear image whether the new material has added beneficiary values and also to which extent.

KEYWORDS: Arch wires, NiTi, Physical property, elasticity.

INTRODUCTION:

Traditionally, the choice of an orthodontic archwire should be based on estimates of forces produced. Biomechanical considerations require forces that are low in magnitude and continuous in nature, ie, archwire with low stiff- ness. Burstone1 showed that the orthodontist's choice for a wire size is influenced by its stiffness. Stiffness is directly related to elastic modulus and cross-sectional size and shape.2 The past decade has shown that Ni-Ti wires are able to meet the ideal requirements for a fixed archwire appliance and have contributed significantly to the evolution of orthodontic appliance treatment.3–5 With these alloys, the stiffness can be reduced without reducing the cross-section- al dimensions in contrast to a conventional alloy.1
The relationship between the applied force (F) and the deflection under three-point bending conditions is given by: F =48(EI/L3). The forces generated by a deflection in bending are proportional to the deflection, to the modulus of elasticity (E, constant for a conventional alloy), to the moment of inertia of the cross section (I) and inversely proportional (cube power) to the span length between sup- ports (L: interbracket distance). This relationship is useful for comparing the relative values of forces in bending for a few archwires of different alloys and different cross-sectional shapes.6,7 A large majority of orthodontists know this, and when using conventional alloys during ''leveling'' of the teeth (preliminary bracket alignment stage), one must use smaller round cross-section wires (I small) or incorporate complex loop designs (L great) or both to generate small magnitude forces.
However, these requirements suppose that alloys show a linear relationship between stress and strain, which is de- scribed by Hooke's law, where E, the elastic modulus is constant and does not change with stress and strain.7 Shape memory alloys, such as nickel-titanium, are characterized by a reversible phase transformation in solid state, the thermoelastic martensitic transformation, accompanied by a hysteresis. On cooling, the martensitic transformation is governed mainly by the shear of the high–temperature

phase unit cell (austenite). A shape change results from this shear, but a finite number of crystallographic equivalent shears lead to a finite number of equivalent variants of the low-temperature phase (martensite). These variants are gathered into self-accommodating groups for a mutual compensation of the deformation, and the final transformed material exhibits no shape change. The transformation can also be induced by stress. In the case of stress-induced martensitic (SIM) transformation, the property observed is superelasticity. The most favorable variants of martensite, which change in the direction of the external stress, outgrow and are responsible for the large deformation that can be observed. Without the acting stress, the martensite is unstable and specimens recover their original shape after unloading. The reverse transformation causes an unloading plateau. In this case, elasticity has two origins. At small deformations, the alloy shows a linear elasticity (classic Hookean elasticity). At larger deformations, above a given value, the martensitic transformation occurs. The elastic deformation becomes nonlinear.7,8

The aim of this study is to show the evolution of stiffness in bending as a function of cross-sectional dimension. The applied force dependence on cross-sectional size differs from the linear-elastic prediction because of the superelasticity effect.9 A conventional three-point bending test is conducted to determine the nature of forces in a loading and unloading cycle. The level of force and stiffness and their dependence on cross-sectional dimension is discussed.

MATERIALS AND METHODS:

A total of 15 wires of a Ni-Ti orthodontic alloy-conventional NiTi(group A), Thermokimetic plus(group C), black oxide NiTi(group B) were selected for this study. They represented cross-sectional dimensions of 0.14 with round shapes available only as pre- formed arches. Only the straight segments of each pre- formed arch were tested. The choice of only one manufacturer is necessary because the mechanical properties of Ni-Ti are affected by the chemical composition, process fabrication, and heat treatment of the alloy.8,10,11 These parameters are not discussed in this study.

Tests were carried out on five preformed round wires of 0.014 inches (0.406 mm), The cross- sectional dimension of each sample was measured (Table 1).. This value is a geometric quantity that corresponds to the resistance of a particular cross section to bending.

Three-point bending test

To perform bending experiments, a three-point bending test using a free-end beam theory was conducted (Figure 1). All the samples were loaded with the same protocol on a testing machine (GT-Test Gmbh Universal testing ma- chine, model 112) with a span at 14 mm.3,6 The midportion of the wire segment was then deflected at three mm at the rate of two mm/minute under the pressure from a stylus connected to a 20-N load cell. All the measurements were taken in constant-temperature water. Temperature was regulated by a thermostatic water bath and fixed at 37.5C.

Force-deflection diagrams with three cross-sectional dimensions of three groups of wires were determined from the passive position to a total activation of three mm and then during deactivation to zero.

RESULTS:

The mean values for the three different group of wires are about two standard deviations smaller than their commercial size (Table 1). To facilitate wire placement into the brackets, manufacturers have intentionally smaller cross-section wire dimensions than the nominal dimensions. Stiffness in bending is proportional to EI/L, where E represents the alloy contribution and I/L the segment geometry contribution to stiffness.

Region of linear elasticity

At 0.15 mm of deflection, the behavior of elasticity is linear and the level of force or stiffness for each wire is the same at loading and unloading. The slope of the initial and final linear region corresponds obviously to the linear elastic strain. In this small deflection range, Hook's law can be used to describe the stress and strain relation- ship: □ □ E□; where E, the elastic modulus is constant, and does not change with stress or strain. For the same deflection, the level of force or stiffness between the 0.016- and the 0.018-inch wires is increased by 44.5% because the increase of the moment of inertia between 0.016-inch wire and the 0.018-inch wire is over 46%. Between the 0.018 moment of inertia is about 54% between these two sizes.

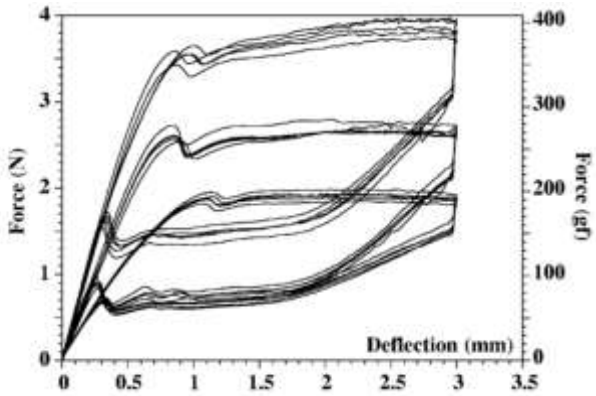
Region of nonlinear elasticity

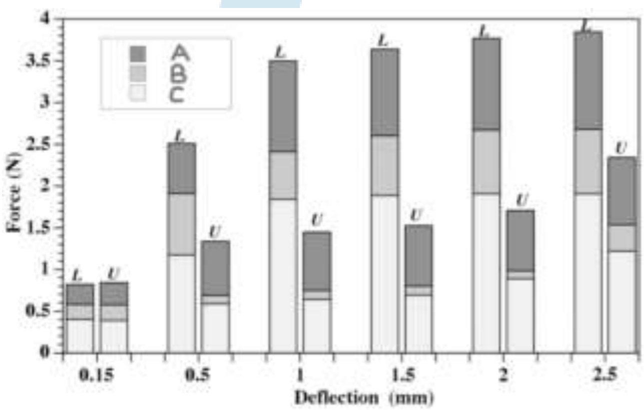
Above a certain force, the elasticity behavior becomes nonlinear. The upper plateau corresponds to the formation of SIM plates preferentially oriented. On unload- ing, the reverse transformation occurs and the force-deflection curve follows the lower plateau region. It corresponds to the reverse transformation, and the martensitic phase is gradually transformed back to the austenitic phase. The difference in the magnitude of the forces on the upper plateau at 1.5 mm between archwire 0.016 /0.018 and 0.018/0.020 is about 40%. This difference is clearly less important in the unloading process where the difference is 15% than upon loading between the 0.016- and 0.018- inches cross section, but more important than for the 0.018 and 0.020 inches cross section about 90%. However, the lower plateau region of the 0.020-inch curve is clearly inferior to the loading plateau of 0.016 inch. Whatever the cross-sectional dimension, the stiffness of the material de- creases when loading and unloading occurs, but the collapse is more important at the unloading process. The mechanical hysteresis, measured as the difference between the forces of the upper and the lower plateaus, increases with the cross-sectional dimension.

Table 1- group A- conventional NiTi, group B- black oxide, Group C- thermo kinetic plus.

TABLE 1. Means, Standard Deviations and Moment of Inertia of Sample Size

Nominal Wire Size Square (inch)	Mean (Standard Deviation) (inch)	Moment of Inertia I (10^{-4} mm^4)	Variation of Moment of Inertia I (%)
A	0.015984 (±0.0001647)	22.64	
B	0.017583 (±0.0003992)	33.15	↓ +46
C	0.019590 (±0.0002202)	51.09	↓ +54





DISCUSSION:

It is of interest to discuss the origin of the nonconventional profile of the loading and unloading curves and thus the origin of reversible deformation of these alloys. Martensitic transformation and deformation have a close relation in various aspects.

At small deformation, the alloy shows a linear elasticity (classic Hookean elasticity) and, similar to conventional alloys, during elastic deformation the atoms move very slightly from their original positions but not to the extent that they take up new positions. When the forces are removed, they return to their original positions. The atomic bonds are just stretched out. The modulus of elasticity is related to the bonding strength between the atoms in a metal or alloy and is constant and independent of wire configuration and nominal wire size.7,13 Therefore EI (stiffness in bending) is invariant at loading and unloading process for each cross-sectional size.16

In our results, the value of EI of the three square-size Ni-Ti wire is largely inferior (between 150 and 315 N mm2).

Then, the experimental values of the moment of inertia (I) are smaller than theoretical values. This can make an important contribution to the force delivery. At large deformation, Ni-Ti alloy wires exhibit super- elastic behavior. This type of behavior is also called pseudoelasticity, because there is a complete return to the origin in a loading-unloading cycle, similar to that in a classical linear or nonlinear elasticity. The path of return generates a hysteresis that depends on the amount of dissipated energy during the mechanical cycling. At the beginning of the strain, the alloy is austenitic and stable. At some critical force (Fc), which depends on temperature, the martensitic transformation occurs. Thus, the mechanical behavior of Ni-Ti wires is largely under the dependence of martensitic transformation. The plateau is caused by the ability of martensite to accommodate the applied deflection, by selecting the most favorably oriented variants along the direction of the strain. Each variant is connected with another variant by a twinning plane (intervariant interface) which moves easily upon loading.14,17

At this temperature and without acting stress, this martensite is unstable, and specimens recover their original shape after unloading. The reverse transformation causes an unloading plateau. The original shape recovers completely by reverse transformation accompanied by the re- verse movement of the interface between austenite and martensite phases. In this case, the elastic deformation is not a stretching out of bonds but results from a phase transformation with new equilibrium positions of atoms. It is a crystallographic structural change. The growth of most favorable martensitic variants accommodates the applied stress. This phenomenon requires lower energy than the pursuit of the Hookean elasticity and prevents the plastic deformation of the austenite in this temperature and stress range.The above equation means that part of the driving force (Erev) is stored in the material through a non-dissipate process during the forward transformation. Then, elastic energy stored in the alloy during the forward martensite transformation and frictional energy, lost because of movement of interfaces, are both con- trolling factors in the profile of curves. The increasing loading plateau and gradient as a function of cross-sectional dimension corresponds to increasing elastic strain energy, ie, the ratio of martensitic transformation and frictional energy transformation is higher. Therefore, the applied stress required to transform austenite to martensite does not stay constant and gradually increases with the volume fraction of transformed martensite.14,15

The unloading process is controlled by the reverse transformation and is dominated by the stored energy. The stored elastic energy (Erev) obviously contributes to the driving force and assists the reverse transformation .17–19 The position of the variants in the deformed state is not stable without stress, and thus, there is this driving force causing them to return to their original positions during unloading.17 Consequently, the unloading plateau (mechanical hysteresis) is reduced compared with the level of the loading plateau.

The main clinical interest of this hysteresis is that the force delivered to the periodontal structures is lower than the force necessary to activate the wire. For the same maximum deformation, the volume of SIM increases with the cross-sectional dimension. Therefore, the area of the mechanical hysteresis increases. The stored elastic energy in- creases with the same proportion and will facilitate the reverse transformation. The stiffness in bending is not constant, and it decreases with deflection. During martensitic transformation (forward and reverse), it is not the relative concentration of the two phases in the alloy that will determine the resultant stiffness of the wire. Rather, it is the process of martensitic transformation, the stiffness of the material collapses and the modulus of elasticity dramatically decreases.2,10 In this case, the term ‘‘pseudomodulus of elasticity’’ is certainly more correct.

CONCLUSION:

It is important that estimations of the forces produced by superelastic Ni-Ti be based on a perfect understanding of the physics and especially the value of the wire stiffness involved. In this manner, this parameter can be controlled with better efficiency.

In our investigation, the influence of recent advancement in initial Ni-Ti archwire was studied. Our results show that the factor of primary importance is the martensitic transformation. The results shows no significant difference in stiffness during load deflection of various initial NiTi arch wires.

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