COMPARISON OF SUPERELASTICITY OF DIFFERENT AUSTENITE ACTIVE NICKEL TITANIUM ORTHODONTIC ARCHWIRES USING MECHANICAL TENSILE TESTING AND CORRELATING WITH ELECTRICAL RESISTIVITY OF THE SAME ARCHWIRES

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CERTIFICATE

This is to certify that **Dr. D. NAGARAJAN**, Post Graduate Student (2004 – 2007) in the Department of Orthodontics, Tamilnadu Government Dental College and Hospital, Chennai has done this dissertation titled **"COMPARISON OF SUPERELASTICITY OF DIFFERENT AUSTENITE ACTIVE NICKEL TITANIUM ORTHODONTIC ARCHWIRES USING MECHANICAL TENSILE TESTING AND CORRELATING WITH ELECTRICAL RESISTIVITY OF THE SAME ARCHWIRES"** under our guidance and supervision in partial fulfillment of the regulations laid down by the Tamil Nadu Dr. M.G.R. Medical University, Chennai for M.D.S. Branch – V Orthodontics, Degree Examination.

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INTRODUCTION

Orthodontic wires are those which generate the biomechanical forces and these are communicated through the brackets for tooth movement and are vital to the practice of profession according to -William A. Brantley.

Archwires are the real workhorse for any type of fixed appliances. They can be compared to a software of a computer while the other components of fixed appliances serve as hardware.

Arch wires were designed to move teeth with light continuous forces. Such forces may reduce the potential for patient discomfort, tissue hyalinization, undermining resorbtion.

A number of studies concluded that an optimal orthodontic force intends to induce a maximal cellular response and establish the stability of the tissue. An unfavorable force does not result in a precise biological response and may initiate adverse tissue reactions. Earlier studies have emphasized on the importance of light and continuous orthodontic forces for desired tooth movements.

The concept of Variable Modulus in orthodontics is a new approach whereby the wire size remains relatively constant and the material of wire is selected on the basis of clinical requirements. The variable modulus principle allows for the use of oriented rectangular wires or square wires in light force as well as heavy force application and stabilization. A rectangular wire orients in the bracket and hence offer greater control during the alignment procedures and better control is maintained over the roots.

Recent advances in orthodontic wire alloys have resulted in a varied array of wires that exhibit a wide spectrum of properties. Nickel Titanium wires in orthodontic clinical practice has been greatly favoured by the low modulus of elasticity, high springback and wide force delivery range even in larger cross sections, which is particularly adequate for the initial phase of treatment when considerable deflections are required to engage the wire into the brackets. The low deactivation force exerted by Nickel Titanium wires elicit a physiological bone response minimizing undermining resorbtion.

Nickel Titanium alloy finds its application in orthodontics not only as an initial archwire but also used in space closure, intrusion, molar distalisation and even in Begg mechanotherapy.

In early 1960,- William J. Buehler a metallurgist of U.S. Navy was actively involved in search for a shape memory material for a project, discovered the property of impact resistance and shape memory of nickel titanium alloy accidentally. This alloy showed great promise and was dubbed Nitinol an acronym of Nickel Titanium Naval Ordnance Laboratory.

Around 1970,- George Andreasen, recognized the potential of this alloy and along with Unitek company introduced the first Nitinol to Orthodontists.

Ironically this alloy with composition of Nickel and Titanium in the ratio of 50:50 showed no shape memory effect due to heavy cold working during drawing and martensitic stabilization. But still it was quite springy delivering only one fifth to one sixth the force per unit deactivation thereby exerting light continuous force.

In addition to this martensite stabilized alloy two other generic nitinol type alloys are available today that are active and they undergo some form of shape memory effect and are superelastic. They are austenite active alloy and martensite active alloy.

Superelasticity or Pseudoelasticity and shape memory are the two phenomena which can be seen in any nickel titanium wires

The shape memory and pseudoelastic properties of Nickel Titanium alloys in terms of crystallorgraphic transformations. Few metals and many compounds crystallize into more than one structure. If the change in structure is reversible it is known as Allotropy. Some alloys including Nickel Titanium which crystallize in a hexagonal close packed structure, deformation occurs by multiple twinning, a movement that divides the lattice into two symmetric parts; these parts are no longer in same plane, but rather at a certain angle. When these alloys are subjected to higher temperatures detwinning occurs and the alloy reverts to its original shape or size which is called as shape memory effect. Such phase transformations from within now generally referred to as martensitic changes also occurs in other alloys, plastics, ceramics and even in micro organisms. Since this occurs without diffusion or chemical change, this transition is the result of a specific crystallographic relationship between the parent phase and the new phase, a rearrangement of the atoms in the unit cells that has been named the Bain distortion. Unlike boiling and melting martensitic transformation do not occur at a precise temperature but rather within a range known as Transition Temperature Range.

The behavior of Nickel Titanium alloy is directly related to the function of its phase. The mechanical properties such as yield strength, elastic modulus are greater for austenite phase than martensitic phase.

The electrical Resistivity for the austenitic phase and the martensitic phase are 82micro ohm.cm. and 76micro ohm.cm. respectively. This shows there is a change in resistivity for a change of phase. Hence it can be inferred that when stress is induced in austenite active NiTi at constant temperature well above the Transition Temperature Range, there is stress induced phase transformation from austenite to martensite which can be interpreted by change in resistivity values. Other properties like thermal conductivity, magnetic susceptibility and thermal expansion also varies for these two phases.

Considerable variability exists within the different superelastic wires marketed commercially by different wire manufacturers and selecting the wires with the exact properties for a specific clinical situation needs thorough scrutiny from a clinician point of view for better results. Any material can be assessed for its structural and behavioural properties through various methodologies like Mechanical testing, X- ray Diffractometry, Differential

Scanning Calorimetry, Scanning Electron Microscopy, Electrical Resistivity and Conductivity and Optical Studies. Being the material under study is a metallic alloy in wire form, study of electrical resistivity was found suitable.

The purpose of this study is to compare the degree of superelasticity of austenite active Ni Ti from different manufacturers using mechanical tensile testing, one of the gold standard test for testing any material including orthodontic wires. Electrical resisitivity tests are also conducted on these wires and the results are correlated with each other.

AIMS AND OBJECTIVES

1. Comparison of superelastic mechanical behavior of various austenite active nickel titanium arch wires of same dimension from different manufacturers through tensile testing.

2. Correlating with the stress induced changes in electrical resistivity of the similar archwires at constant temperature.

REVIEW OF LITERATURE

Sandstedt[82] in 1904 was the first to investigate scientifically on the tissue changes brought about by orthodontic force. He placed bands on maxillary canines of a dog. A labial arch wire was placed through horizontal tubes and by tightening the screws each day. First maxillary incisors were moved lingually about 3mm in three weeks time. Later the dog was sacrificed and histological sections of the teeth and supporting structures were made. The histological findings showed bone building in the areas of the labial crest and lingual apical area, bone resorption on the lingual crest and labial apical area.

Schwarz A.M.[77] (1932) stated that the most favorable treatment is that which works with forces not greater than the pressure in the blood capillaries, (25gm/sq.cm), moving a tooth less than 1 mm distance. He was the first to coin the word Optimum force.

Bunch W.B.[17] (1942) studied about tissue changes occurring in dogs following depression of teeth. He applied continuous depressing force by specially made auxiliary springs to maxillary and mandibular incisors. His histological findings showed that periapical vessels were obliterated during continuous intrusive force application.

Storey .E. **Smith R.**[79] (1952) conducted experiments with cuspid retraction springs in which they noted that there appears to be an optimum range of force values which will produce a maximum rate of movement of the cuspid tooth. In 1954, Storey restated the optimal force concept which states that optimum range of force produces maximum amount of tooth movement and below this range there is reduced tooth movement.

In 1957- **Reitan.K**[68] initiated the steps to evaluate the forces in orthodontics. He tried to compare the histologic findings with the variation of degree of tooth movement as related to the amount of force applied. He also studied about the individual variation in tissue reaction for the same amount of forces. While discussing about the type of forces he stressed on applying light forces during the initial stage of tooth movement to prevent hyalinization of periodontal fiber bundles. Regarding the type of force he insisted that in addition to continuous forces, interrupted continuous forces must be included. According to him intermittent forces will create a favorable tissue reaction. He conducted series of experiments and found that functional intermittent forces of around 70 to 100 gms may cause formation of cell free areas, but these are less extensive and of a shorter duration than in a continuous tooth movement. Reitan finally concluded that the force exerted in a tipping movement performed with continuous forces will create compressed cell free areas in the periodontal membrane more frequently than in a bodily movement because of the mechanical principles involved.

In 1960- **Reitan**[69] described tissue behavior during orthodontic tooth movement in a detailed manner. He reinstated that continuous forces are preferable than intermittent. He disclosed his findings as a law that says that the distance through which the tooth moves is dependent on the duration of the force applied and for example a plate that is worn night and day will cause tooth movement than a plate worn only at night. In order to obtain maximal tooth movement within a given period, the force applied must be of a sufficient magnitude and act through a distance that is suitable to the prevailing anatomic and mechanical conditions.

Holly Halderson[32] (1957) took some measures to accurately determine the amount of force applied clinically in orthodontic appliances and auxiliary springs. He devised a electronic strain gauge to record minute amount of forces. It consisted of a transducer for converting force to electrical energy, an amplifier, an ink writing oscillograph for providing a written record. The instrument was sensitive to force variations of 0.10gram. He insisted on routine use of minute forces for orthodontic tooth movement.

In 1958, **William J. Buehler**[16], a metallurgist at the Naval Ordnance Laboratory (NOL) in White Oak, Maryland started his research on iron-aluminium alloy project and later in 1959 decided to concentrate on the equiatomic nickel-titanium composition alloys and relegated the intermetallic compound systems to secondary status. He named his discovery NITINOL (Nickel Titanium Naval Ordnance Laboratory).

In the early 1960s **Buehler**[16] prepared a long, thin, (0.010 inch thick) strip of Nitinol to use in demonstration of the material's unique fatigue resistant properties. He bent the strip into short folds longitudinally, forming a sort of metallic accordion. The strip was then compressed and stretched repeatedly and rapidly at room temperature without breaking. In 1961 a laboratory management meeting was scheduled to review ongoing projects. Unable to attend, Buehler sent the Raymond C. Wiley to the meeting to present Buehler's work. During presentation the strip was passed to one of Technical Director Dr. David Muzzey, who was a pipe smoker and applied heat from his pipe lighter to the compressed strip. To everyone's amazement the Nitinol stretched out longitudinally. The mechanical memory discovery, while not made in Buehler's metallurgical laboratory, was the missing piece of puzzle of the earlier mentioned acoustic damping and other unique changes during temperature variation. This serendipitous discovery became the ultimate payoff for Nitinol.

In 1962, **Dr. Frederick E. Wang**[16] joined Buehler's group at the Naval Ordnance Laboratory as an expertise in crystal physics. The commercial applications of Nitiniol that were to come would not have been possible without Wang's discovery of how the shape memory property of Nitiniol works.

In 1970s. **Dr. George Andreasen**,[2] of the University of Iowa, developed Nitinol for use in orthodontic purpose.

Burstone C.J., Baldwin J.J. and Lawless D.T.[18] (1961) discussed about basic biomechanical principles involved in the production of light continuous forces. From the experimental data they found that Load defelection rates can be lowered by reducing the cross-sectional dimension of a wire. For a unidirectional loading, the optimum shape for a cross section is rectangular with wire depth at a minimum and width at a practical maximum. At low temperature stress-relief increases the proportional limit of a cold worked stainless steel wire and thereby, increases its allowable working load. No spring is completely constant in its action. The most constant forces at optimal force levels, are derived from springs possessing low load-deflection rates and high allowable working loads. Although the mechanical properties of a wire partly determine its action, the primary factor in the delivery of continuous force is the design of the spring.

Sam Weinstein[91] (1967) after reviewing various literatures and by conducting various studies concluded that when a tooth is moved by low magnitude force and the force is then removed, the rate of the initial displacement is significantly less than the reverse rate of return. The amount of tooth movement and the rate of tooth movement associated with low force values are significantly smaller in young that deliver forces of a low order of magnitude.

George F. Andreasen and Brady .R.[2] (1972) suggested a hypothesis for the use of two other types of Nitinol wire. The first is a 55 Nitinol wire with a TTR of 16° to 27° C, and the second is a 55 Nitinol wire with a TTR of 32°C to 42°C. The hypothesis of utilization would be to use each wire as a closing force much the same way as a molar to molar elastic is now used. The stiffness rate of this wire is at much lower rate than even the smallest diameter of twist-o-flex wires. Therefore, it is suggested that it be used only for its closing forces and not for its leveling forces. In this context the closing wire would have to be used as an auxiliary wire rather than the main archwire.

George F. Andreasen[5] (1980) demonstrated the shape memory effect of Nitinol using a 0.019 inch thermal nitinol wire with a transition temperature range between 31°C and 45°C in a clinical trial. The thermal nitinol wire when engaged clinically got activated by the heat in the mouth and brought alignment in 163 days.

Charles J. Burstone.[20] (1981) presented a new approach to force control called the Variable Modulus orthodontics in which the wire size remained relatively constant and the material of the wire is selected on the basis of clinical requirements. When the material instead of the cross section is varied, superior orientation should be achieved with fewer wires during tooth alignment, and bracket wire play becomes independent of the forces needed. Since wire stiffness is determined by wire cross section and material, a simplified numbering system is described which aids clinicians in evaluating any orthodontic wire.

N.E. Waters and W.J.B. Houston[89] (1981) discussed the properties of clinical relevance to the selection of wires for the initial alignment of irregular teeth. They investigated into the load-deflection characteristics of a single span of commonly used orthodontic wires and found remarkably stiff and are not capable of applying light forces. The effects of incorporating loops in the wire in order to modify span were also discussed.

R.P. Kusy [43](1981) compared the theoretical strength, stiffness, and range of nickel titanium and beta titanium arch wires with several stainless steel or cobalt-chrome wires. With the apparent stiffness as the criterion, equivalent force systems are established in the elastic region between the conventional and the new arch wire alloys. In bending, such calculations show that the nickel-titanium alloy makes superior starting wire, 0.016, 0.018 and these wires having stiffness similar to multistranded 0.0175, round 0.012, and 0.014 inch stainless steel wires, respectively, but with about twice the strength and range. By the same method beta titanium alloy makes a particularly good intermediate arch wire. However in torsion not even the largest sizes of nickel-titanium (0.021 by 0.025 inch) or beta titanium of (0.019 by 0.025) wire meet the stiffness requirements of an 0.019 by 0.026 inch stainless steel wire, thereby making the stainless steel wires the finishing wires of choice.

Thurow R.C.[86] (1982) in his book Edgewise Orthodontics discusses about beams their characteristics and loading and also describes about cantilever beams and their applications in orthodontics. Basic properties of wire like the range, stiffness and strength are also described elaborately. Behavioral differences during bending and torsion of wires and significance of differences between bending and torsion are also discussed.

Drake S.R. et al [24] (1982) studied the mechanical properties of three sizes of stainless steel, nickel-titanium, and titanium molybdenum wires in tension, bending and torsion. In tension, the stainless steel wires had the least springback, whereas the titanium molybdenum wires had the most and hence had higher range. In bending and torsion, the stainless steel wires had the least stored energy at a fixed moment, whereas the nickel-titanium the most. Spring rates in bending and torsion, however were highest for stainless steel wires and lowest for the nickel-titanium wires.

Kusy R.P and Greenberg[44] (1982) compared the elastic strength, stiffness, and range of nickel-titanium and beta titanium archwires. Four beta titanium and eight nickel-titanium wires of different sizes were evaluated both in bending and torsion. Results show that the stiffness of the two alloy compositions overlap substantially, except for those wires with the lowest and the highest stiffnesses-that is, the 0.016 and 0.018 inch nickel-titanium and the 0.017 by 0.025 and 0.019 by 0.025 inch beta titanium arch wires, respectively. Both ‘variable cross section’ and ‘variable-modulus’ orthodontics are illustrated within the context of an equivalent wire stiffness chart which includes conventional stainless steel archwires.

Kusy R.P. (1983)[45] explained on the use of nomograms to determine the elastic property ratios of orthodontic wires. Nomograms are fixed charts which display mathematical functions, provided each scale is adjusted in space appropriately. Through these nomograms three distinct situations are addressed: the overall spectrum of elastic property ratios among stainless steel, nickel-titanium, and beta titanium wires; the intra and inter property relationships of these wire compositions and the role which elastic property ratios play in the selection of the right arch wire.

Goldberg.L and Theodore Laptook[28] (1984) treated 25 patients with 0.016 inch maxillary and mandibular nitinol archwires in Stage I, Step I, and the results were compared to those of 22 similar patients treated with 0.016 stainless steel looped archwires in Begg Mechanotherapy. They found that nitinol wires do facilitate and simplify Begg mechanotherapy by unraveling and leveling occurring faster than with stainless steel looped arches, treatment time is diminished. Patient response is good and less discomfort is reported.

Burstone C.J. Bai Qin and John Y.Morton[21] (1985) introduced a new orthodontic alloy called Chinese NiTi wire. This wire was studied by means of bending test to determine wire stiffness, springback and maximum bending moments. It had an unusual deactivation curve and had long range of action. This Chinese NiTi demonstrated phenomenal springback and can be deflected 1.6 times as far as nitinol wire or 4.4 times as far as stainless steel wire without appreciable permanent deformation.

Asgharnia M.K. and William Brantley[7] (1986) evaluated stainless steel, cobalt-chromium-nickel (Elgiloy), nitinol, and beta titanium wires with diameters from 0.010 to 0.040 inch and in rectangular cross sections form 0.017 by 0.025 to 0.019 by 0.025 inch with the American Dental Association Specification No. 32 bending test and the conventional tension test. Results agreed with each other only in the modulus of elasticity for the 0.040 inch diameter stainless steel wires They concluded that improved procedures should be adopted for performing the tension test on the relatively small cross-sectional orthodontic wires.

Miura et al[52] (1986) studied the superelastic property of Japanese NiTi developed by the Furukawa Electric Co. Japan. According to them the wire when subjected to uniaxial tensile testing and three point bending test to determine stiffness, springback, shape memory and superelasticity the alloy delivered a constant force over an extended portion of deactivation range and manifested the property of superelasticity. Heat treatment enabled the load magnitude at which superelasticity is reflected to be influenced and controlled by both temperature and time. They believed that the new alloy could generate physiologic tooth movement because of the relatively constant force delivered for a long period of time during the deactivation of the wire.

Kusy R.P., John Q. Whitley, Michael J. Mayhew[46]**(**1988) using specular reflectance, the surface roughness of six representative orthodontic archwire products were studied.. Among the four alloy groups which are commonly used in orthodontics, stainless steel appears the smoothest, followed by cobalt-chrome, beta titanium, and nickel-titanium. A clearer understanding of the parameters which contribute to sliding mechanics will be possible when these results are combined with future experiments on the coefficient of friction.

Rock and Wilson[72] (1988) measured the forces produced by 10 orthodontic archwires in a simulated clinical situation and also in simple three point loading. The findings indicate that the forces generated by orthodontic mechanisms cannot be calculated by straightforward physical principles.

Mayhew M.J. and Robert P. Kusy[50] (1988) studied the effects of sterilization on the mechanical properties and the surface topography were determined on 0.017 by 0.025 inch Nitinol and Titanal archwires. Three approved heat sterilization methods were used: dry heat, formaldehyde-alcohol vapour, and steam autoclave. Elastic moduli were obtained on 1-inch segments in 3- point bending. Laser scans of flatwise wire surfaces were conducted to detect surface alterations whether they were caused by tarnish, corrosion, or pitting. Tensile properties were determined on 7inch lengths: the 0.1% yield strength, the ultimate tensile strength, and the percent elongation at break. Within the confines of the present sterilization experiments no detrimental changes were observed for either the selected mechanical properties or the surface topography. Nitinol was less compliant but stronger than Titanal. Laser Spectroscopy showed that Titanal possessed atleast 3 times more specular reflectivity than nitinol.

Harris E.F. et al[33] (1988) observed the changes in the mechanical properties of a nickel-titanium orthodontic alloy, nitinol (0.016-inch arch wires), in a simulated oral environment across time, at various levels of acidity, and at different amounts of static deflection. Significant decreases in specific mechanical properties were observed in these incubated wires compared with a group kept dry and unstressed. Ultimate tensile strain, modulus of elasticity, and 0.2% yield strength each decreased. Acidity (pH 3 to 7) and amount of deflection (0 to 4 mm in a 1 0-mm span) did not affect the wire, but there was a significant, monotonic decrease in yield strength with time in the simulated oral environment. By 4 months this measure of susceptibility to permanent deformation increased by 15%. Consequently, long-term use (or reuse) of a nitinol wire may be associated with a modest, but statistically significant, degradation in performance, notably in the limit of the wire's elasticity.

Miura et al[53] (1988) subjected closed and open Japanese nickel titanium alloy coil springs to evaluate the mechanical properties. The closed coil springs were subjected to a tensile test and the open coil springs were subjected to a compression test. At the same time, a test with the commercially-available steel coil springs also was done. Japanese NiTi alloy coil springs exhibited superior springback and super-elastic properties similar to the properties of the Japanese NiTi alloy arch wires. In addition they found that the load value of super-elastic activity can be effectively controlled by changing the diameter of the wire, the size of lumen, the martensite transformation temperature, and the pitch of the open coil spring. The most important characteristic of the Japanese NiTi alloy coil springs was the ability to exert a very long range of constant light, continuous force the coil can be selectively used to obtain optimal tooth movement.

Buckthal and Kusy[15] (1988) studied the effects of disinfectants on the mechanical properties and surface topographies for 0.017 ´ 0.025-inch Nitinol and Titanal wires. Three disinfectants approved by the American Dental Association were tested at maximum antimicrobial concentrations: 2% acidic glutaraldehyde, chlorine dioxide, and iodophor. Bending and tensile tests were evaluated to determine whether the stiffness, strength, or range of the wires changed after disinfectant treatment. Laser spectroscopy was used to detect surface changes from corrosion or tarnish after treatment. No detrimental changes were detected in the mechanical properties or surface topography of either wire product after disinfectant treatment. Nitinol was found to be stronger and stiffer than Titanal. On average, Titanal exhibited five times more specular reflectivity than Nitinol.

Kapila and Sachdeva[38] (1989) reviewed the mechanical properties and clinical applications of stainless steel, cobalt-chromium, nickel-titanium, beta-titanium, and multistranded wires. Mechanical properties of these wires are generally assessed by tensile, bending, and torsional tests. Although wire characteristics determined by these tests do not necessarily reflect the behavior of the wires under clinical conditions, they provide a basis for comparison of these wires. The characteristics desirable in an orthodontic wire are a large springback, low stiffness, good formability, high stored energy, biocompatibility and environmental stability, low surface friction, and the capability to be welded or soldered to auxiliaries. Stainless steel wires have formability, biocompatibility and environmental stability, stiffness, resilience, and low cost. Cobaltchromium (Co-Cr) wires can be manipulated in a softened state and then subjected to heat treatment. Heat treatment of Co-Cr wires results in a wire with properties similar to those of stainless steel. Nitinol wires have a good springback and low stiffness. This alloy, however, has poor formability and joinability. Beta-titanium wires provide a combination of adequate springback, average stiffness, good formability, and can be welded to auxiliaries. Multistranded wires have a high springback and low stiffness when compared with solid stainless steel wires. Optimal use of these orthodontic wires can be made by carefully selecting the appropriate wire type and size to meet the demands of a particular clinical situation.

Hurst C.L., Ram S. Nanda et al[35] (1990) evaluated the shape memory phenomenon of nickel- titanium orthodontic wires. Orthodontic wires (0.018 inch) of seven commercially available nickel-titanium alloys were used in this study. The mean shape recovery for all alloys tested was between 89% and 94%, except for Sentinol Heavy, which showed a shape recovery of only 41.3%. The percent recovery of Ni-Ti, nitinol, Orthonol, Titanal, Sentinol Light, and Sentinol Medium alloys were statistically similar. However, the percent recovery of Sentinol Heavy showed a significant difference when compared with other alloys at $p < 0.0001$.

Khier S.E. and Brantley W.A. and Fournelle R.A.[42](1991) evaluated cantilever bending properties for three superelastic and three nonsuperelastic brands of nickel-titanium orthodontic wires in the as-received condition, and for 0.016-inch diameter wires after heat treatment at 500° and at 600° C, for 10 minutes and for 2 hours. A torque meter apparatus was used for the bending experiments, and the specimen test-span length was 1/4 inch (6 mm). In general, the bending properties were similar for the three brands of superelastic wires and for the three brands of nonsuperelastic wires. For the three brands of superelastic wires, heat treatment at 500° C for 10 minutes had minimal effect on the bending plots, whereas heat treatment at 500° C for 2 hours caused decreases in the average superelastic bending moment during deactivation; heat treatment at 600° C resulted in loss of superelasticity. The bending properties for the three brands of non superelastic wires were only slightly affected by these heat treatments. The differences in the bending properties and heat treatment responses are attributed to the relative proportions of the austenitic and martensitic forms of nickel-titanium alloy (NiTi) in the microstructures of the wire alloys.

Prososki R.R., Bagby M.D. and Erickson L.C.[66] (1991) measured surface roughness and static frictional force resistance of nine nickel-titanium alloy arch wires, one beta-titanium alloy wire, one stainless steel alloy wire, and one cobalt-chromium alloy wire for comparison. Arithmetic average roughness in micrometers was measured with a profilometer. Frictional force resistance was quantified by pushing wire segments through the stainless steel self-ligating brackets of a four-tooth clinical model. The cobalt-chromium alloy and the nickel-titanium alloy wires, with the exception of Sentalloy and Orthonol, exhibited the lowest frictional resistance. The stainless steel alloy and the beta-titanium alloy wires showed the highest frictional resistance. The stainless steel alloy wire was the smoothest wire tested, whereas NiTi, Marsenol, and Orthonol were the roughest. No significant correlation was found between arithmetic average roughness and frictional force values.

Kapila et al[39] (1991) investigated the effects of clinical recycling on the load-deflection characteristics and the surface topography of nickel-titanium alloy wires. Thirty wires each of Nitinol and NiTi were subjected to a three-point bending test in an as-received condition and after clinical exposure of one cycle and two cycles. Ten wires made up the sample at each of these time points. One cycle was defined as 8 weeks, plus or minus 1 week, of clinical use. Wires undergoing two recycles were cold sterilized after their first clinical exposure. Recycling produced significant changes in both the loading and unloading characteristics of NiTi wires, but only with the loading forces associated with nitinol wires. Representative scanning electron micrographs demonstrated increased pitting of both nitinol and NiTi wires. Several areas were also observed to be smoothened on nitinol wires and scored on NiTi wires.

Chen R. et al[22] (1992) studied Chinese Ni Ti with six other nickel titanium alloy wires. Bending and torsional tests were conducted and temperatures of phase transformation compared. The Chinese NiTi wire was found to have low stiffness, high springback and constant bending and torsional moments on unloading in a very large deformation region.

Kapila S., Haugen J.W. and Watanabe L.G.[40](1992) observed the load deflection characteristics of nickel-titanium alloy wires after clinical recycling and dry heat sterilization. Two types of nickel-titanium wires, namely Nitinol and NiTi were subjected to a three-point bending test in an as-received condition after one cycle. Clinical recycling appears to reduce the "pseudoplasticity" and "pseudoelasticity" of NiTi wires and increases the stiffness of both NiTi and Nitinol wires.

Sangkyu Han, Donald C. Quick.[73](1993) undertaken a study to determine whether the mechanical properties of nickel titanium springs are affected by prolonged exposure to a static, simulated oral environment. Stainless steel springs and polyurethane elastic chains were also studied for comparison. Nickel-titanium springs suffered no degradation of their spring properties in the simulated oral environment. In contrast, stainless steel springs became slightly more compliant to stretching, and polyurethane elastics lost a large portion of their force-generating capacity. These findings confirm and extend earlier reports which indicate that nickel-titanium is a preferred material for many orthodontic applications.

Thayer, Bagby, Moore, and DeAngelis[83] (1995) compared the super elastic mechanical behavior of nitinol wires to stress-induced phase changes. Superelastic mechanical behavior of nitinol alloy orthodontic wires is thought to be the result of a stress induced crystallographic transformation from austenite to martensite. Eight nitinol arch wires having rectangular cross-sections were strained from 0% to 10% in tension with a mechanical testing machine. Load/extension plots were subjectively ranked for SE behavior. X-ray diffraction patterns were collected with and without 6% strain. Without strain, nitinol wires were found to be predominantly austenite with some wires containing a small amount of martensite. When strained 6%, superelastic wires demonstrated a phase transformation from austenite to martensite. XRD patterns were ranked for percent transformation and 110-peak width. Product rankings of the degree of superelasticity were positively correlated with the rank of martensitic transformation ($p < 0.05$). Superelasticity ranks were negatively correlated with XRD peak width ranks ($p < 0.01$). Increased peak width indicates greater cold work. A range of superelastic mechanical behavior and martensitic transformation is exhibited by wires currently on the market. They concluded that cold work and heat treatments are important variables to be controlled during the manufacture of nitinol products.

Bishara S.E. et al[11](1995) compared the thermodynamic properties of three nickel titanium orthodontic wires.The purpose of this study was to determine the transition temperature ranges (TTR) of three commercially available thermodynamic archwires and to determine the rate of recovery of the wires when bent to a uniform shape.

The results indicate that the TTRs for the three commercially available thermodynamic wires are of similar magnitudes (B =6.7° C, 6.2° C and 6.7° C). The greatest differences were in the standard deviations (1.3° C, 2.2° C and 3.7° C) which may be a function of manufacturing during alloying of the wire and/or its heat treatment.

Coluzzi B. et al[23](1996) made a resistometric investigation of premartensitic and martensite phase transitions in NiTi orthodontic wires which has been carried as a function of temperature between -20 and +60°C, during cooling and heating. Transformaton features of two types of commercial wires were examined in either their undeformed state or under application of constant bending strain. For the undeformed case the transformation behaviour was also characterized by differential scanning calorimentry (DSC). Above room temperature electrical resisitivity data taken under bending did not give clear indications of stress- induced martensite for material of type 2, which however displayed superelastic behavior. This lack of clarity arises from complex alterations taking place in the structure (lamellar) and proportions of the different phases (Austenite, Martensite, Rhombohedral) present under inhomogeneous bending strains when the temperature is changed. To fully clarify this point stress-strain tensile experiments were carried out. Preliminary results were presented.

Oltjen. J.M, Manville, G. Duncanson Jr.,and Joydeep Ghosh,[61](1997) investigated the stiffness characteristics of several solid and multistrand nickel-titanium and stainless steel orthodontic wires at selected clinically relevant deflections. Twenty specimens of 24 different wires were tested in both three-point and three-bracket bending modes. The results of this investigation show that wire stiffness can be altered not only by changing the size, but also by varying the number of strands and the alloy composition. An equally important finding was the dependence of stiffness on deflection for most of the wires measured.

Kusy.R.P.[47] (1997) reviewed the orthodontic archwires in the order of their development with emphasis on specific properties and characteristics, such as strength, stiffness, range, formability, and weldability. He also insisted that archwires should be selected within the context of their intended use during treatment. A glossary of terms was also provided.

Nikolai R. J.[60] (1997) reviewed the history and current status of wires used in clinical orthodontic treatment, with particular emphasis on archwires and their thermo-mechanical behaviors. He also made an abbreviated attempt to envision where archwire research and development are directed in the near future. His overview on arch wire history and structural evaluation interests both researchers and practititioners.

Torstein R. Meling, M.Philos; Jan Ødegaard, Odont[85] (1998) studied the effect of temperature changes on the torsional stiffness of nickel titanium alloys. Eight rectangular superelastic wires were activated to 20 degrees, in longitudinal torsion at body temperature and subjected to cold (10°C) or hot (80°C) water with the strain held constant. The torsional stiffness of some wires was strongly affected. The effect of hot water disappeared quickly, but the wires remained at a level of reduced torsional stiffness (up to 85% less than baseline) after short applications of cold water. The most thermodynamic archwires showed incremental reductions in torsional stiffness when cold water was repeatedly applied. Furthermore, the torsional stiffness remained low (up to 50% less than baseline) and showed no tendency to increase even after 2 hours of post-exposure restitution. It is conceivable that some wires may provide inadequate forces for tooth movement after ingestion of cold liquids.

Evans T.J.W, Malcolm L. Jones and Robert G.Newcombe[25] (1998) evaluated three commonly used orthodontic tooth aligning arch wires: 016 × 022 inch active martensitic medium force nickel titanium, 016 × 022 inch graded force active martensitic nickel titanium, and 0.0155 inch multistrand stainless steel. They concluded that heat activated nickel titanium arch wires failed to demonstrate a better performance than the cheaper multistrand stainless steel wires in this randomized clinical trial.

Ravindra Nanda, Marzban and Kuhlberg[67] (1998) introduced a multifunctional wire made of nickel titanium called The Connecticut Intrusion Arch. They claimed that the wire gave high performance in incisor intrusion and other functions by inducing minor modifications. They also claimed that the wire remained active at a constant force level for a long period of time, allowing long intervals between appointments and virtually eliminating the need for adjustments.

Santoro.M. And Daniel Beshers (2000) studied the influence of mechanical stress on the transitional temperature range of orthodontic nickel titanium wires. Three brands (Sentalloy, GAC, Copper Ni Ti of Ormco, Nitinol Heat Activated of 3M Unitek) of heat activated NiTi wires were used and subjected to temperature cycles between 4°C and 60°C. Electrical resistivity was used to study the phase transformations. The wires were loaded in a loading device simulating clinical situations of minimum and severe dental crowding. They concluded that Copper Ni Ti and Nitinol heat activated are the alloys most likely to express superelastic properties when subjected to significant stress and liable to oral temperature variation, since their wide stress related TTRs correspond to the potential oral temperature range.

Santoro .M and O.F. Nicolay and T.J. Cangialosi[74] (2001) reviewed systematically about orthodontic nickel titanium alloys and their applications in orthodontics. They discussed about mechanical properties, composition of nickel titanium alloys and about thermoelasticity and shape memory effect. Changes in Transformation Temperature Ranges due to stress induced martensiste formation were also discussed elaborately. Role of Resistivity in identifying the phase changes in a given nickel titanium alloy is also briefed. They concluded that two fundamental properties should be taken into account to make a selection of NiTi wire. They are the stress related TTR and low deactivation force released to the dentoalveolar structures.

The same authors also reviewed mechanical characteristics of the alloys such as the magnitude of the forces delivered and correlation with the temperature transitional range and torsional behavior. They also compared the NiTi with multistranded stainless steel in their performance in the second part of the literature.

Gurgel J.A. et al[31] (2001) evaluated torsional moments on activation and deactivation in nine commercial, rectangular nickel titanium wires of

0.017 by 0.025 inches.. They found that the torsional moments varied among superelastic nickel titanium wires even with the wires with the same transition temperature range. Some superelastic wires had torsional moments that were comparable with conventional nickel titanium wires.

Wilkinson P.D et al[92] (2002) found that previous mechanical testing of orthodontic wires has, in many cases, failed to simulate some key features of the clinical environment. So they investigated the load-deflection characteristics of 7 different 0.016-in initial alignment archwires (Twistflex, NiTi, and 5 brands of heat-activated superelastic nickel-titanium [HASN]) with modified bending tests simulating a number of conditions encountered clinically. Twistflex and the 5 HASN wires produced a range of broadly comparable results, and NiTi gave the highest unloading values.

Pascal Garrec and Laurence Jordan[64] (2004) studied 15 nickel titanium archwires with three different cross-sectional dimensions by three-point bending test to determine the nature of forces in a loading and unloading cycle. The evolution of stiffness in bending as a function of wire size was discussed. The applied forces or stiffness dependence on cross-sectional size differs from the linear-elastic prediction because of the superelasticity property. During martensitic transformation, the rigidity (elastic modulus) of the alloy is not constant. These results and their understanding show the need of a different approach of biomechanical considerations, ie, a large-size square wire does not produce necessarily high forces.

Pascal Garrec Bruno Tavernier and Laurence Jordan[64] (2005) compared bending in 10 archwires made from NiTi orthodontic alloy of two cross-sectional dimensions. The results were based on micro structural and mechanical investigations. With conventional alloys, the flexural rigidity was constant for each wire and increased largely with the cross sectional dimension for the same strain. With NiTi alloys, the flexural rigidity is not constant and the influence of size was not as important as it should be. This result can be explained by the non-constant elastic modulus during the martensite transformation process

MATERIALS AND METHODS

Eight groups of archwires bought from eight different manufacturers were studied. Five samples were used from each group for tensile testing and nine samples were used for electrical resistivity tests. All the samples used for the study are of same dimension 0.017X0.025 inch and of rectangular cross section as per manufacturers' specification. The trade name of the different groups of wires and their manufacturers are listed in table-1.

ARMAMENTARIUM

1. Universal Testing Machine (Lloyd)
2. Electrical Circuit integrated with Computer.
3. Custom made wire loading device.
4. Digital Vernier Caliper.
5. Thermometer.

TENSILE TESTING

Principle

Tensile properties indicate how the material will react to forces being applied in tension. A tensile test is a fundamental mechanical test where a carefully prepared specimen is loaded in a very controlled manner while increasing the applied load and the elongation of the specimen over some distance.

Tensile tests are used to determine the modulus of elasticity, elastic limit, elongation, proportional limit, tensile strength, yield point, yield strength and other tensile properties.

Apparatus

Two types of sophisticated mechanical testing machines are used in the dental materials research laboratory. These machines are classified as screw-driven or servo hydraulic depending upon the method employed to move the cross head and load to the specimen. A Universal Testing Machine of Lloyd Instruments Ltd. UK Model No LR.100 K with Dapmet and Control was used for this study.

A load cell senses the amount of force, and the raw data (the testing machine output) are typically plotted as load on the vertical axis and time or distance of crosshead movement on horizontal axis. In order to plot stress strain diagrams, the values of load and change in specimen length must be converted to stress and strain respectively. With the newer computer controlled machines, the original specimen cross sectional area and length can be programmed, so that a direct plot of stress and strain is obtained. In this study a Lloyd Universal Testing Machine of servo hydraulic type was used.

Procedure

Different wire segments cut from the straight sections of the arch wires were used for the tensile tests. All testing was done at room temperature approximately 22 degree Celsius as -Burstone et al found little difference between austenitic NiTi mechanical properties at 22 degree Celsius and 37 degree Celsius.

Tensile tests were performed using Lloyd universal testing machine. Grips were set 30 mm apart, wires inserted and tested with a crosshead speed of 1mm per minute. After 3 mm of extension, 10% strain, the direction of cross head movement was reversed. The test was performed on five specimens of each group.

The stress at 10% was calculated. The initial slope of the stress/strain plot was calculated. This initial slope is not being presented as modulus of elasticity. Rather it is a subjective estimate of the initial stiffness(in tension) of the various wire products tested. The load is measured in Newtons which is later converted to Mega Pascals by dividing the Newton value by area of cross-section of the specimen, the strain is measured in millimeters.

Data for stress at 10% strain and the initial slope were statistically analysed with an analysis of Variance (ANOVA) and Scheffe tests with $P<0.05$. Stress/Strain plots of each product were ranked for superelastic behavior. This subjective ranking now based on both the length and low slope value of the unloading “nearly horizontal” segment of the load/deflection plot.

The lower(flatter) the slope of this segment of the plot the greater the degree of superelasticity. Similarly the longer this segment, the greater the degree of superelasticity. Wires without a horizontal unloading segment of their plot, but with a somewhat horizontal loading segment, were ranked as having a small degree of superelasticity.

TEST FOR ELECTRICAL RESISTIVITY:

Principle

One of the most important properties of metals is the electrical conductivity. The reciprocal of conductivity known as the Resistivity. The Resistivity for a given material is a constant value at a particular temperature and unstrained state and is represented by the symbol ρ, Roe. Resistivity is derived by dividing the product of resistance and area of cross section, by the length of the material.

$$\text{Roe}, \rho = R.a/L$$

where , ρ is Resistivity and R is the Resistance and a, area of cross section and L, length of the material. The unit for Resistivity is ohm.inch or µohm.cm.

APPARATUS

An electrical circuit is assembled with the following components. A transformer, a rectifier, a regulator, a filter, a microcontroller and an oscillator are all connected in a series in a circuit board and the circuit is integrated with a computer through the serial port.

For explanatory reasons, the circuit can be sub-divided into

1. Power circuit
2. Power regulating circuit.
3. Signal conditioning circuit.
4. Thermistor circuit.

5. Signal amplifying and conditioning circuit.

6. Filters and Oscillator circuit.

7. Microcontroller circuit

8. Computer

Power Circuit

An alternating current, AC source of 230 Volts is the main power supply to the circuit. This AC source is stepped down by a step down transformer to almost 6 to 9V. A rectifier converts the stepped down AC supply to a Direct Current, DC supply.

Power Regulating Circuit

The stepped down DC input of 9V enters the regulator which is a zener diode where it is regulated to 5V and has a cut off above 5V. Thus a regulated power supply is maintained throughout the experiment.

Thermistor Circuit

Thermistor in the form of potential divider network produces an output of 20 mV for 50°C. In general to obtain clear and constant output with respect to the input change we must have lower power consumables. If we draw a lower current sensitivity of the thermistor will provide better performance. Due to the above reasons the thermistor circuit is constructed to produce low millivolts which can be amplified to higher voltages.

Signal Amplifying and Conditioning Circuit

In order to amplify 20 mV from transducer to 5V, a two stage instrumental amplifier is designed with an overall gain of 250. Amplification of 250 times using single amplifier seldom gives good results. Due to this amplification done in two stages with a first stage amplification of 10 times and second stage of 25 times.

Filters and Oscillator Circuit

These circuits filter noises at different levels of harmonic and provides clear and noise free output with a constant frequency of approximately 100Hz which can be arrested using low pass filter. Hence noise free, ripple free constant output is received if the input is constant.

Microcontroller Circuit

This contains the microprocessor which interprets and processes signals from the circuit and translates to the computer system in a digital format through the serial port. The power supply to this microcontroller circuit is through another step down transformer and a rectifier.

Computer

From the microcontroller the signal is processed and sent through the serial port in a digital format to the computer. In computer a software program in ‘C’ language interprets this signal and compensates for the amplifications and displays the exact required and recordable data.

CUSTOM MADE LOADING DEVICE

The design of the loading device was depicted from the one described by Santoro et al in their literature. The loading device was built of plexiglass to take advantage of electrical insulation properties of the material. A rectangular platform supported a step (tooth) of rectangular section. The height and width of the tooth were obtained after analyzing casts of 30 clinical cases of lower anterior minimum crowding (upto 3mm of space deficiency) and severe dental crowding (upto 10mm of space deficiency) as measured with a caliper between the distal surfaces of the lower incisors. For the 15 casts affected by minimum crowding the average labiolingual distance between vestibular surfaces of the two most displaced lower incisors was 1mm; 1 of the 2 central teeth was, therefore, 1mm high. The 15 severely crowded cases showed an average labiolingual distance of 6mm; this measure was selected as the width of the central teeth. Two columns of brackets (made of composite plastic) to avoid interference with the electrical measurements were glued to the base of loading device close to the central tooth. Another column of brackets were glued on the surface of the central tooth. The type of loading generated will be referred to as minimum (1mm step) and maximum loading (6mm step).

PROCEDURE

Different wire segments cut from the straight sections of preformed archwires of uniform length were used for the electrical test. From each group of archwires, nine samples were taken for the resistivity test. Three segments of wires were mounted on the plastic brackets and ligated with elastomeric modules. The range of loading was minimum with 1mm step, maximum with 6mm step and without any load. Detachable terminals are connected to both the marked ends of the wire segment and the resistivity values are calculated for each segment of the loaded and unloaded specimens. The results are tabulated in a tabular column.

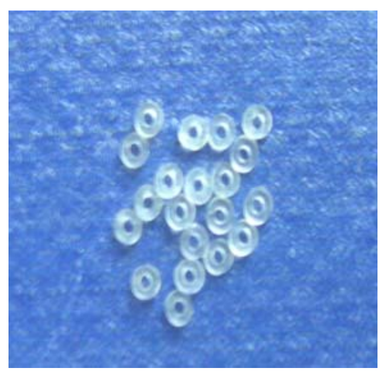
Table – 1

NICKEL TITANIUM ORTHODONTIC ARCHWIRES

Group No.	Name of the Wire	Manufacturer
1	Nitanium archwires	Ortho Organisers. Inc. 1619, S.Rancho, Santafe Rd, San Marcos, C.A 92069, U.S.A.
2	NiTi Superelastico wires	Morelli Orthodontia Alameda, Jundial 230/250 Sorocaba, Brazil
3	Tru-Arch Align SE 200	Ormco A Sybron Dental Specialities 1332, South Lone Hill Avenue, Glendora, CA 91740, U.S.A
4	Nickel Titanium memory wire Force -1	American Orthodontics 1714, Cambridge Avenue, Sheboygan, U.S.A 53081
5	Nitinol SE	Unitek 3M Orthodontic Products, 2724, South Peck Road, Monravia, CA 91016 U.S.A
6	Titanal	Lancer Orthodontics 253, Pawnee Streeet, San Marcos, California U.S.A 92069.
7	Nickel Titanium Superelastic wire	American Braces Components and Devices, BPO-TRAC Marketing, Chennai.
8	Lowland NiTi	GAC International, 355, Knickerbocker Avenue, Bohemia, NewYork, U.S.A.

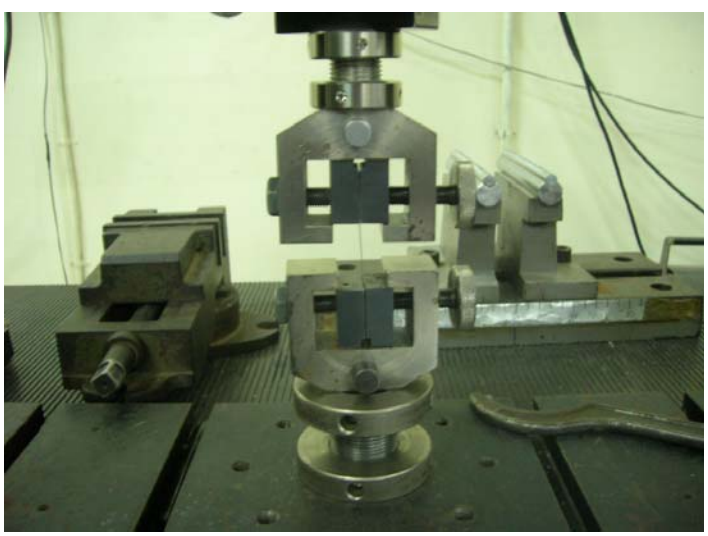
NICKEL TITANIUM WIRES

COMPOSITE BRACKETS



ELASTOMERIC MODULES

UNIVRRSAL TESTING MACHINE (Llloyd Instruments , UK)



TENSILE TESTING

THERMOMETER

DIGITAL VERNIER CALIPER

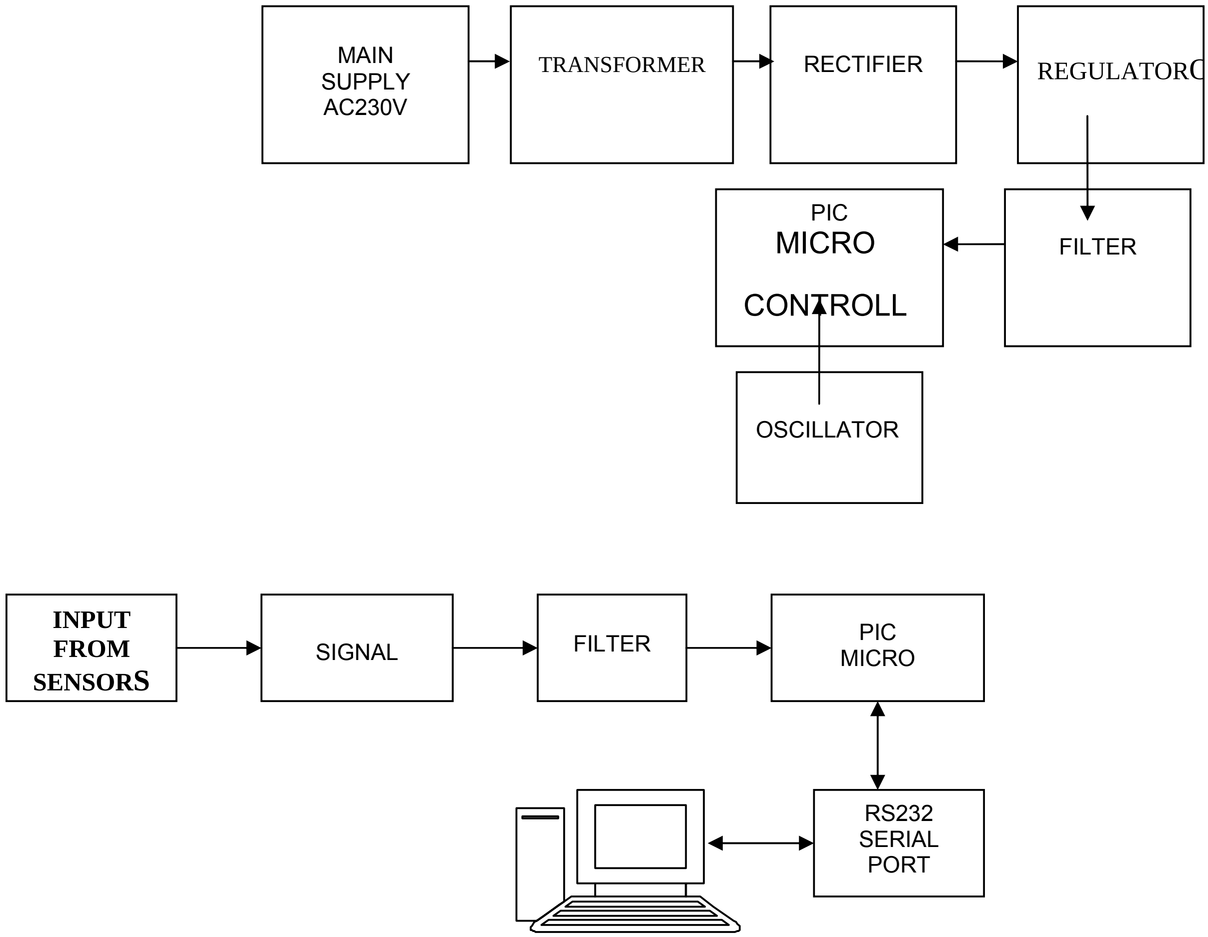
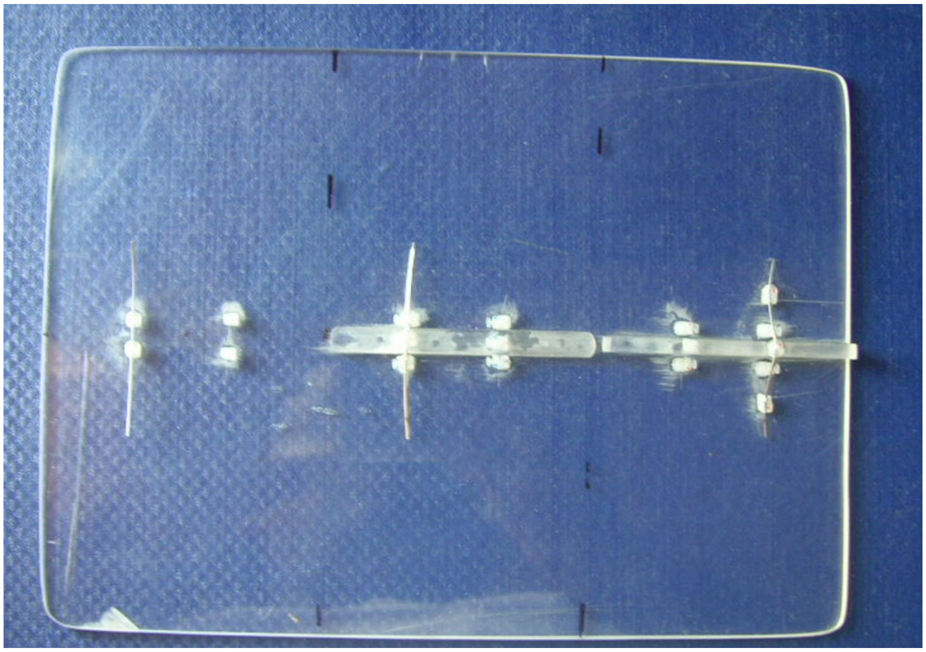


FIG. 9 CIRCUIT DIAGRAMS

ELECTRICAL RESISTIVITY CIRCUIT DEVICE



WIRE STRAINING DEVICE

WIRE STRAINING DEVICE (LATERAL VIEW)

RESULTS

Representative stress-strain curves for the wires tested are shown in figures 1 to 8. Unloading curves were carefully assessed for superelastic behavior on deactivation. Rankings of the wires tested were based primarily upon the unloading curve's slope which is indicative of the magnitude of the deactivation force and secondarily upon the length of the horizontal segment which is indicative of continuous forces during deactivation.

Among the wires tested Ortho Organisers wires had the lowest slope value and longest horizontal segment of unloading curve making it superior than other wires tested. American Orthodontics and Ormco A wires followed the Ortho Organisers wires exerting light forces during deactivation but with shorter horizontal segments indicative of less continuous forces. Unitek 3M wires followed by American Braces wires exerted somewhat higher forces than the prior ranked wires. American Braces wires excelled Unitek 3M wiresby the length of horizontal segment of unloading curve.

Morelli wires exerted higher forces during deactivation but somewhat continuous and GAC Lowland NiTi followed Morelli wires in its ranking. Among the wires tested Lancer's Titanal wires exerted highest magnitude of force but continuous with reasonable horizontal segment and ranks last among all the wires tested. Unitek 3M wires had the shortest horizontal segment showing less continuous deactivation force.

The rankings in ascending order are illustrated in the diagram No.3

Table 2 and table 3 shows the mean and standard deviation of the initial slopes and stresses at 10% strain for the different wires tested. Difference between means for the initial slope and stress at 10% strain were found to be statistically significant with P value less than 0.001. ANOVA followed by Scheffe's test for initial slope shows a significance level of 0.05. The critical difference between subsets were 0.5 units. ANOVA and Scheffe's test for Stress at 10% strain shows the critical difference between two subsets were at 50 MPa level. Interpretation of these results show that the initial stiffness were maximum for American Orthodontics Wires and minimum for American Braces wires. Stress at 10% strain were maximum for 3M Unitek wires and minimum for American Orthodontics wires.

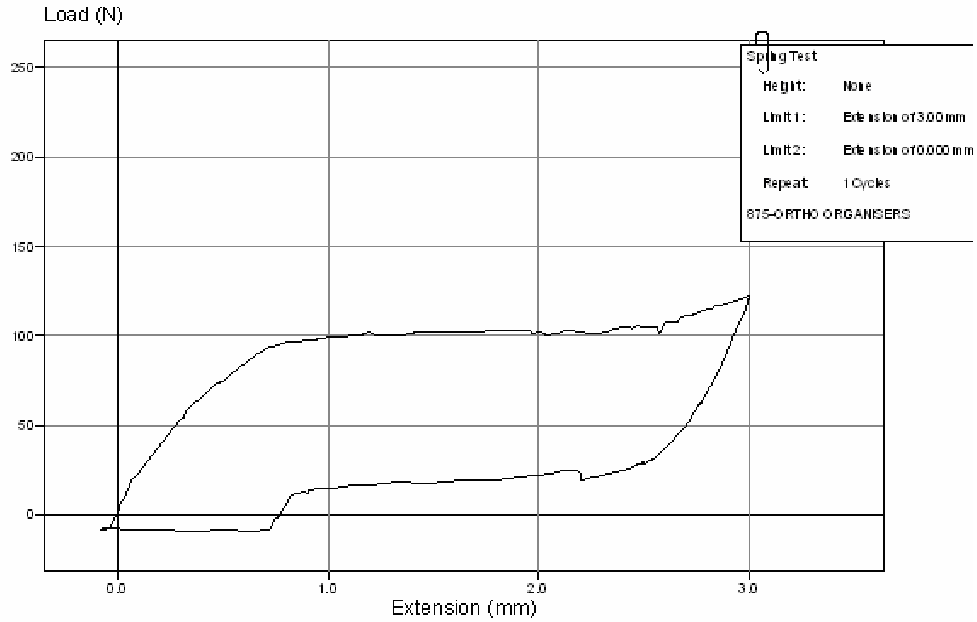
Table 4 and table 5 shows the data, mean and standard deviation of unstrained and minimally strained wires for the electrical resistivity tests. And table 6 shows mean and standard deviation following maximum strain. All the values of electrical resistivity tests were analysed and found statistically significant with P value less than 0.001. ANOVA followed by Scheffe's were conducted on all the data recorded.

Different samples of same length and dimension within same group and between each group showed significant difference in resistance values. The mean and standard deviation for the difference in resistance between unstrained samples and maximally strained samples were tabulated in table 7.

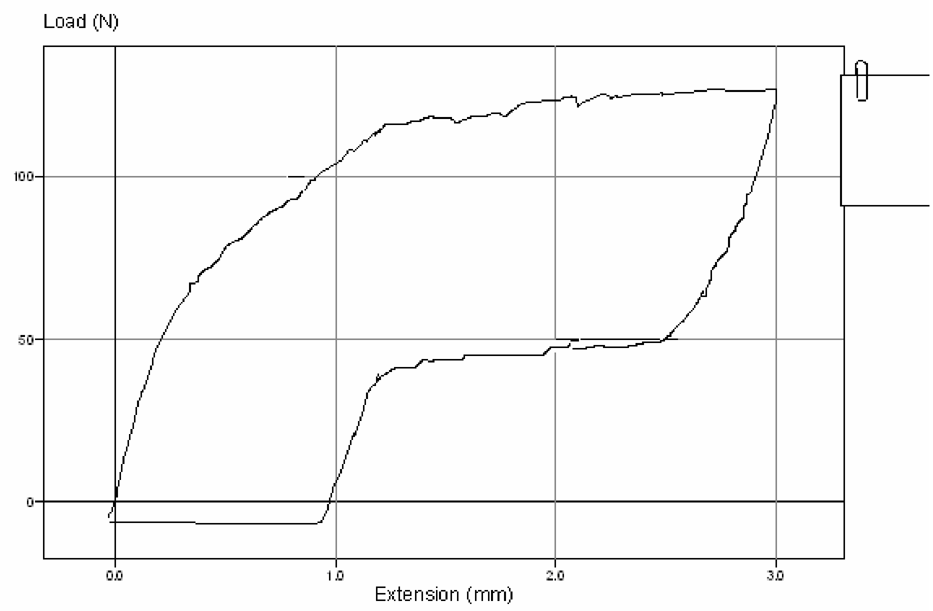
Interpretation of results were based upon change in resistance values. Wires with greater change in resistance were ranked higher. Ormco A wires remained superior followed by American Orthodontics and Ortho Organisers wires. Unitek 3M, American Braces and GAC Lowland NiTi wires did not show much difference between each other and Lancer followed by Morelli remained last in the ranking .

The Bar diagram No.4 shows the change in the resistance of the wires tested.

Graph No.1 and 2

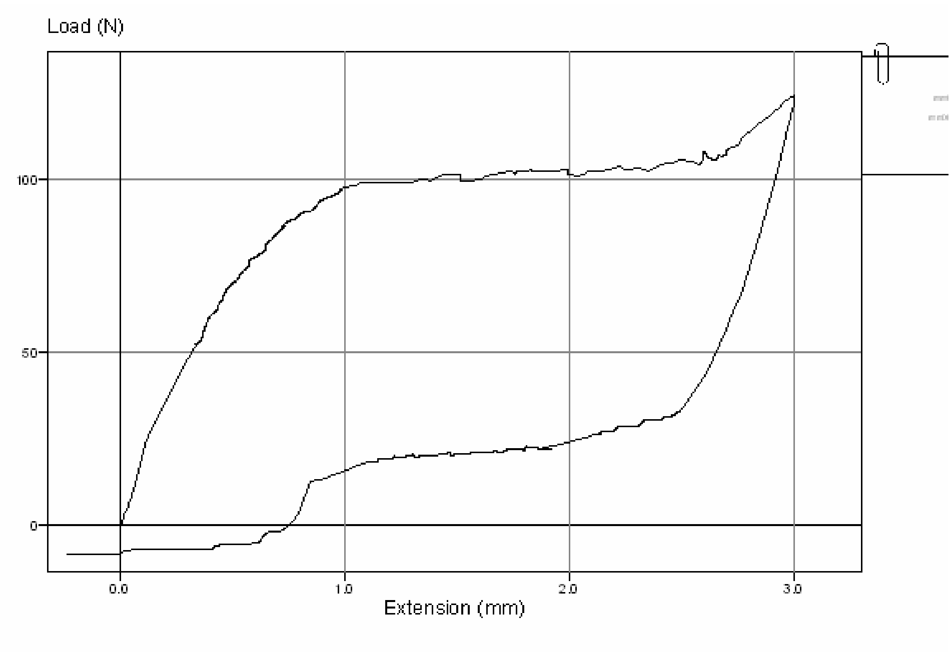


Representative Graph for Group 1 Wires (Ortho Organisors)

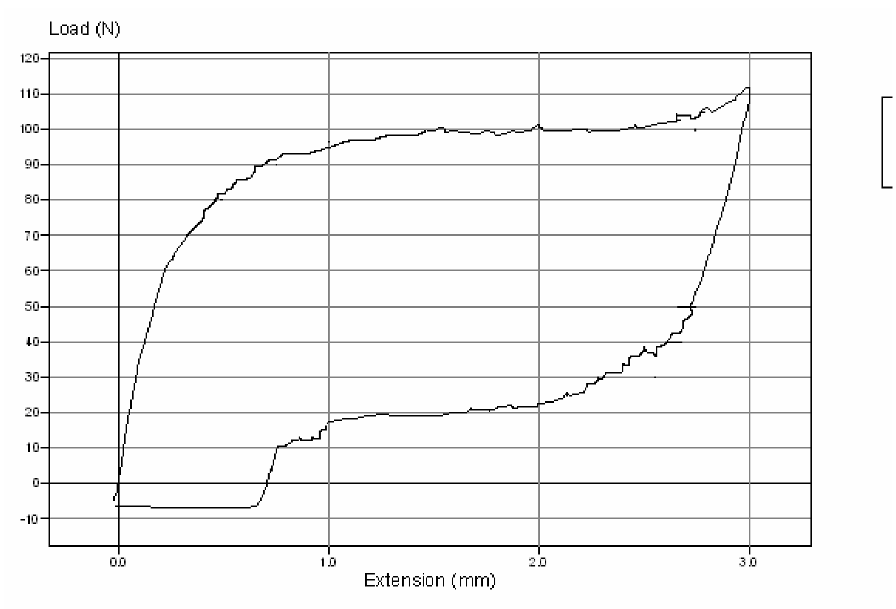


Representative Graph for Group 2 Wires (Morelli)

GRAPH NO. 3 AND 4

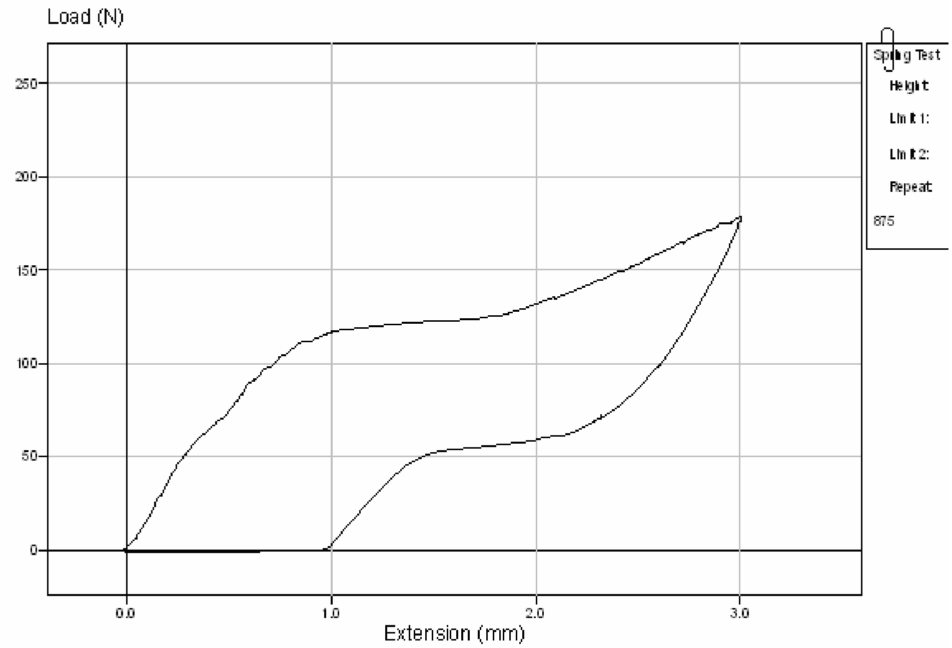


Representative Graph for Group 3 Wires (Ormco A)

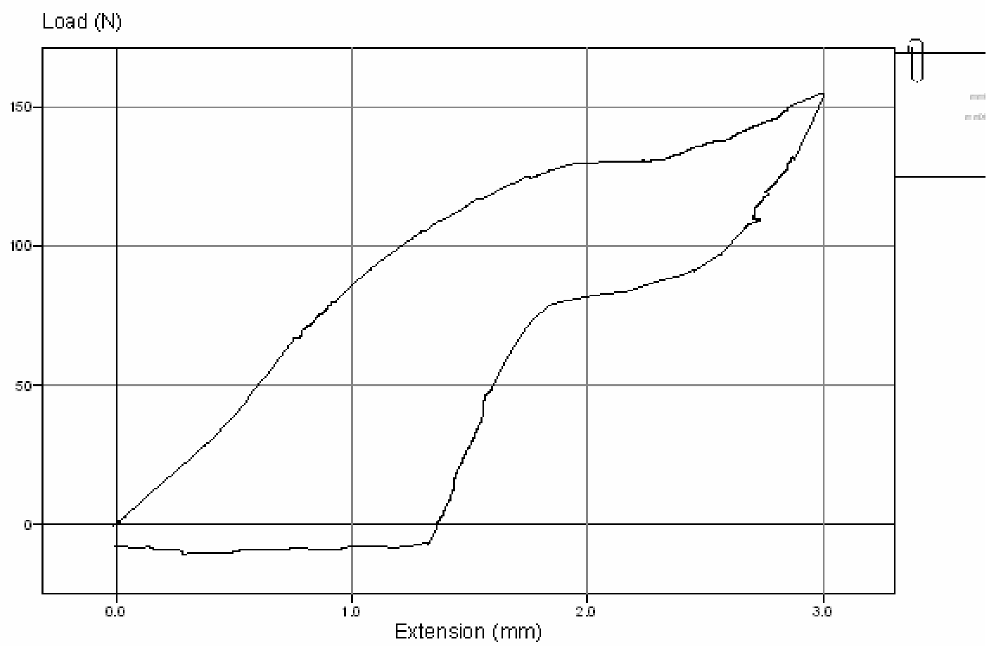


Representative Graph for Group 4 Wires (American Orthodontics)

GRAPH NO. 5 AND 6

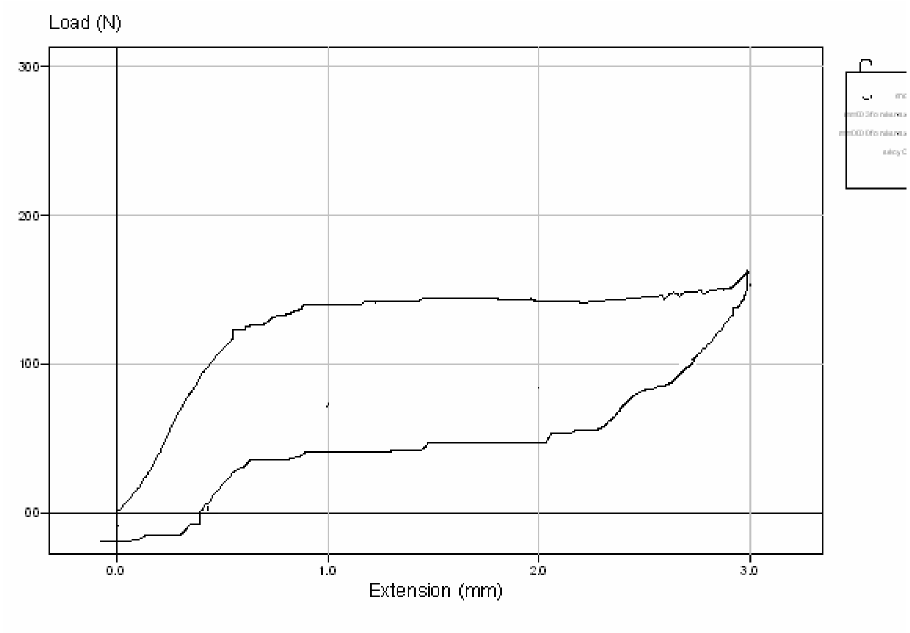


Representative Graph for Group 5 Wires (Unitek 3 M)

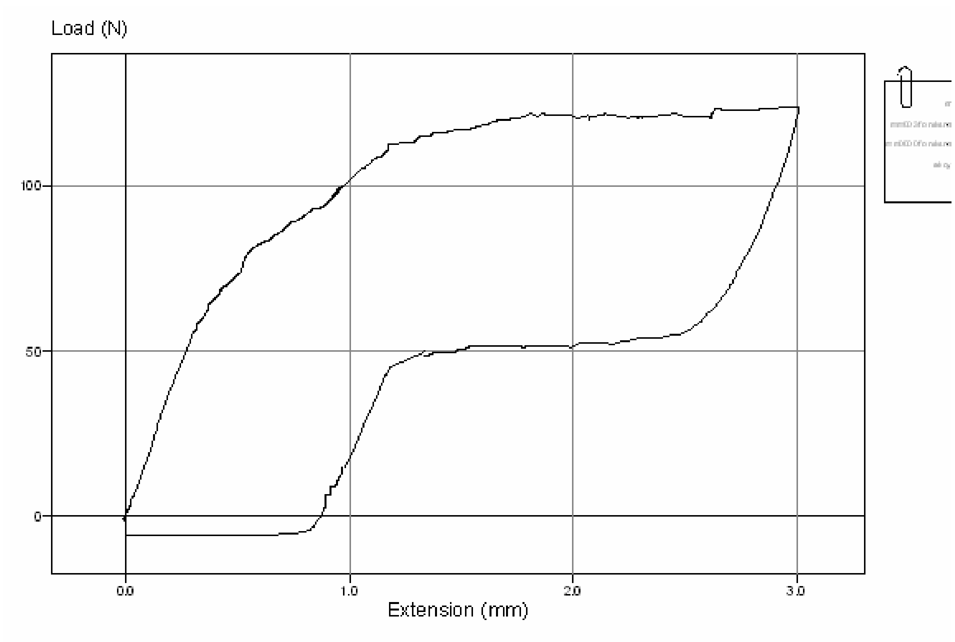


Representative Graph for Group 6 Wires (Lancer)

GRAPH NO.7 AND 8



Representative Graph for Group 7 Wires (American Braces)



Representative Graph for Group 8 Wires (GAC Lowland NiTi)

Table - 2

Initial Stiffness of Nickel Titanium Wires

Nickel Titanium Wires	Initial Slope		P Value
	Mean	SD	
Ortho Organisers	2.08[ab]	1.05	
Morelli	3.52[c]	0.72	
Ormco A	2.85b[c]	0.72	
American Orthodontics	3.63[c]	1.66	< 0.001 **
Unitek 3M	1.53[a]	0.19	
Lancer	1.54[a]	0.84	
American Braces	1.41[a]	0.19	
GAC Lowland NiTi	2.79[bc]	0.43	

Note 1) ** denotes significant at 1% level
2) Different alphabet between brands denotes significant at 5% level.

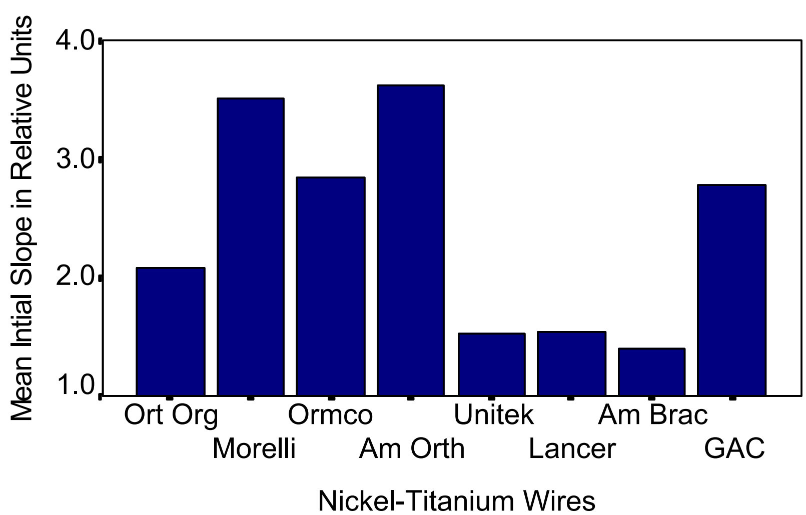


Diagram 1 - Mean initial stiffness of nickel titanium wires

Table - 3

Stress at 10% Strain

Nickel Titanium Wires	Stress at 10% Strain in MPa		P Value
	Mean	**SD**	
Ortho Organisers	444.84[ab]	33.12	
Morelli	485.23[b]	11.94	
Ormco A	577.77[c]	8.28	
American Orthodontics	394.07[a]	28.52	< 0.001 **
Unitek 3M	661.72[d]	4.10	
Lancer	605.92[cd]	53.84	
American Braces	586.66[c]	21.21	
GAC Lowland NiTi	480.00[b]	10.01	

Note 1) ** denotes significant at 1% level
2) Different alphabet between brands denotes significant at 5% level.

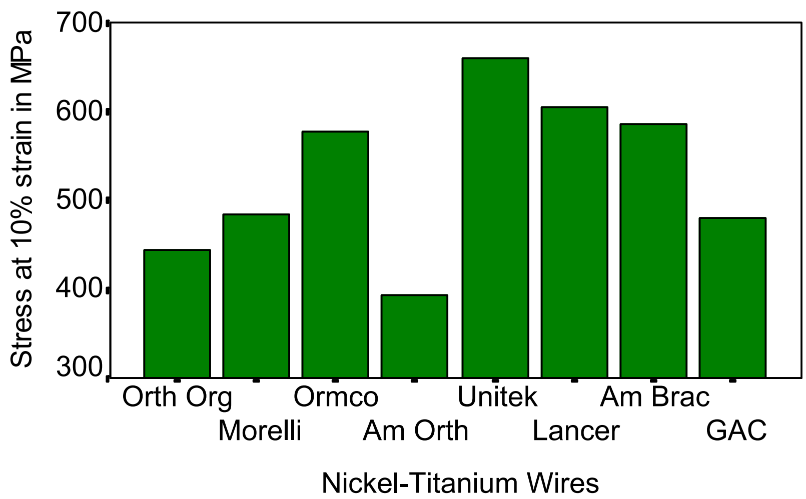


Diagram 2 Stress at 10% strain for nickel-titanium wires

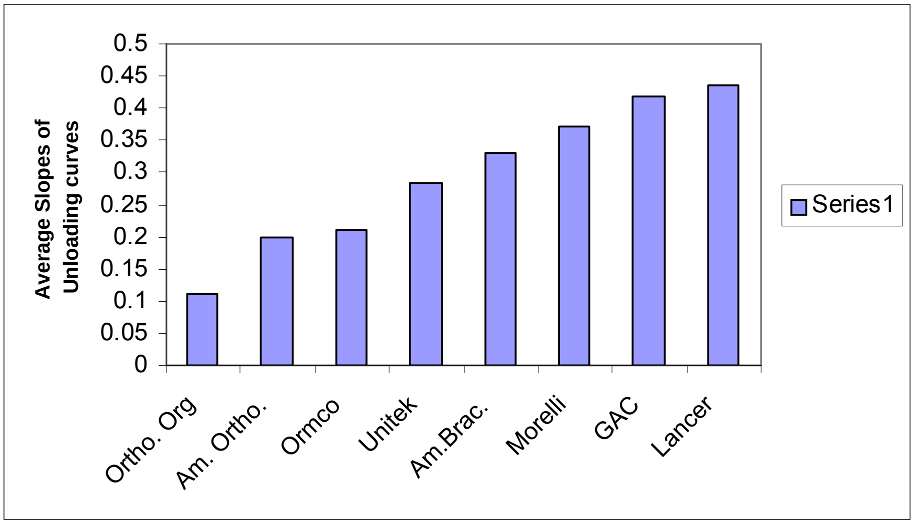


Diagram 3 Representing ranks in ascending order during mechanical tensile testing

Table - 4

Resistance Values of Samples without Strain

Nickel Titanium Wires	Resistance Without strain in milliohms		P Value
	Mean	SD	
Ortho Organisers	275.85[c]	1.01	
Morelli	269.00[b]	1.85	
Ormco A	260.75[a]	1.03	
American Orthodontics	276.67[cd]	0.54	< 0.001 **
Unitek 3M	277.48[cd]	1.02	
Lancer	282.73[e]	1.21	
American Braces	278.70[d]	0.90	
GAC Lowland NiTi	270.72[b]	1.17	

Note 1) ** denotes significant at 1% level

2) Different alphabet between brands denotes significant at 5% level.

Table - 5

Resistance Values of Samples with Minimum Strain

Nickel Titanium Wires	Minimum Strain in milliohms		P Value
	Mean	SD	
Ortho Organisers	272.73[c]	1.63	
Morelli	266.27[b]	1.93	
Ormco A	257.28[a]	0.65	
American Orthodontics	273.28[c]	1.18	< 0.001 **
Unitek 3M	274.48[cd]	0.74	
Lancer	279.52[e]	1.26	
American Braces	276.10[d]	1.20	
GAC Lowland NiTi	268.53[b]	1.46	

Note 1) ** denotes significant at 1% level
2) Different alphabet between brands denotes significant at 5% level.

Table - 6

Resistance Values of Samples with Maximum Strain

Nickel Titanium Wires	Maximum Strain in milliohms		P Value
	Mean	SD	
Ortho Organisers	269.50[c]	1.04	
Morelli	263.95[b]	2.28	
Ormco A	253.80[a]	1.18	
American Orthodontics	270.07[c]	0.73	< 0.001 **
Unitek 3M	271.28[cd]	1.01	
Lancer	277.23[e]	1.25	
American Braces	272.82[d]	0.82	
GAC Lowland NiTi	264.60[b]	1.42	

Note 1) ** denotes significant at 1% level

2) Different alphabet between brands denotes significant at 5% level.

Table - 7

Change in Resistance

Nickel Titanium Wires	Change in Resistance in milliohms		P Value
	Mean	SD	
Ortho Organisers	6.52b[c]	0.56	
Morelli	5.22[a]	0.99	
Ormco A	7.12[c]	0.21	
American Orthodontics	6.60[bc]	0.61	< 0.001 *
Unitek 3M	6.23[bc]	0.53	
Lancer	5.50[ab]	0.75	
American Braces	5.87[ab]	0.31	
GAC Lowland NiTi	5.78[ab]	0.50	

Note 1) ** denotes significant at 1% level
2) Different alphabet between brands denotes significant at 5% level.

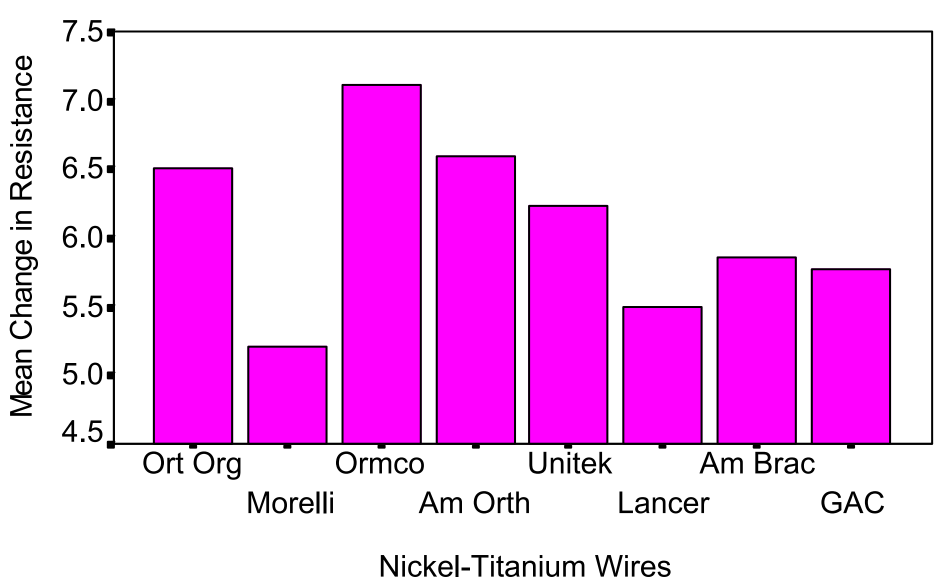


Diagram 4 representing ranks during electrical resistivity testing

DISCUSSION

Fixed appliance therapy is a treatment modality based on the theory that by applying light continuous force to a tooth, it may be moved optimally through the alveolar bone of the jaws without causing permanent damage. However, quantifying this force is difficult because of individual variation in tissue response, root morphology, and the type of tooth movement induced. In order for the clinician to choose more appropriate arch wire during treatment, an understanding of the optimal characteristics is necessary.

The clinician must therefore conversant with the mechanical properties and the relevant clinical applications of these properties for these wires. Several characteristics of orthodontic wires are considered desirable for optimum performance during treatment. These include large springback, low stiffness, high formability, high stored energy, biocompatibility and environmental stability, low surface friction, and the capability to be welded or soldered to auxiliaries.

Springback also referred as maximum flexibility or working range. Higher springback values provide the ability to apply large activations with a resultant increase in working time of the appliance. This in turn, implies fewer archwire changes. Springback is also a measure of how far a wire can be deflected without causing permanent deformation. **Burstone C.J.**[20] considered stiffness is the most important variable in clinical wire selection and is defined as the force magnitude delivered by an appliance and is proportional to the modulus of elasticity. Low stiffness or load deflection rate provide the ability to apply lower forces and a more constant force over time as the appliance experiences deactivation.

Nickel Titanium the space age alloy discovered by **William J.Buehler**[41] and introduced by **George Andreasen**[3] to Orthodontics with outstanding springiness and flexibility with constant delivery of force during deactivation is the automatic choice of the clinicians during initial stages of treatment. These properties permit the orthodontist to apply an almost continuous light force with large activations that results in a reduction of tissue trauma and patient discomfort, thus facilitating enhanced tooth movement. Shape memory and superelasticity are the most desirable properties of any Nickel Titanium orthodontic alloy. According to Fujio Miura[52], the physical behavior of Nickel Titanium alloy can be explained from a metallurgical analysis. The alloy is nearly a equiatomic intermetallic compound that demonstrates variety of properties which is controlled by manufacturing method. At high temperature range, the crystal structure of Ni Ti alloy is in an Austenite phase which is a body centered cubic structure. The Martensite phase which is a close packed hexagonal lattice is at a low temperature range. Depending on the predominance of the phase present in a given nickel titanium alloy it behaves as a austenite active or martensite active alloy. The martensite transformation can be reversed by heating the alloy to return to its austenite phase and it is gradually transformed by reversing back into the energy stable condition by remembering its shape. Superelasticity a phenomenal behavior of the NiTi alloy delivering a constant force during deactivation that can be induced by stress and is called stress induced martensite formation (SIM) indicating a movement similar to the slip deformation occurring in other metals and alloys. In austenite active alloys the formation of stress induced martensite will guarantee the presence of superelastic behavior necessary for the release of light continuous forces.

Thurow[86] (1982) stated that a standard specification test data are mostly irrelevant to orthodontics in spite of their scientific basis. For instance, American Dental Association specification No. 32 (1977) is based upon a cantilever bending test. The method produces calculated values for Modulus of Elasticity,E and flexural Yield Strength, YS that vary significantly with span length **(Asgharnia and Brantley 1986)**[7] . Since E and YS are basic material properties such variation indicates deficiencies in the bending mechanics analysis (Brantley 1976).

Tensile test is a fundamental mechanical test which indicate how the material react to forces being applied in tension. Tensile tests are used to determine the modulus of elasticity, elastic limit, elongation, proportional limit, yield point, yield strength and other tensile properties. **Thayer and Bagby**[83] (1995) compared the superelastic mechanical behavior of nitinol alloy orthodontic wires. Tensile testing was done on all wires and the ranking was done on the basis of slope and horizontal length of the unloading curve which indicates the kind of deactivation force. X-ray diffraction studies were also conducted to correlate the results. Diffraction study was done to examine the degree of conversion of austenite to martensite which is responsible for superelasticity. However some peaks were of not good resolution and interpretation was difficult. Another question concerning the validity of this interpretation is the penetration of roentgen x-rays. Hardly 50μm is sampled leaving the bulk of the material unexamined. Though Differential Scanning Calorimetry is an ideal method to identify the phase transformation it is not a useful method to identify the stress induced phase transformation. Differential Scanning Calorimetry is ideal for identifying the Temperature induced phase transitions above and below the Transitional Temperature Range.

In this study tensile testing was done and stress/ strain curves are obtained. From the graph the loading and unloading curves are carefully examined and the initial slope is determined within the extension of 0.5mm. Three readings were taken for the slope and average is derived. Stress at 10% strain was calculated. Slope of the unloading curve showed the deactivation force exerted by the wire. Lower the level of the slope lighter the force and more the length of the unloading horizontal segment more continuous was the force exerted by the wire.

Coluzzi et al[23] (1996) used a resistometric investigation of premartensitic and martensitic phase transition in NiTi wires as a function of temperature between -20°C and + 60°C. Santoro and Nicolay[76] (2000) proved that austenite and martensite present different amounts of resistance to passage of electric currents, it is possible to infer the phase transformation temperatures through the study of resisitivity.

Electrical Resistivity is the opposition of a body or substance to the flow of electrical current through it, resulting in a change of electrical energy into heat, light, or other forms of energy. The amount of resistance depends on the type of material. Electrical conductivity arises form the motion of conduction electrons through the lattice. Resistance must be caused by the scattering of electron waves by any kind of irregularity in the lattice arrangement. Irregularities in the lattice can arise from anyone of several sources, such as temperature, alloying, deformation, or nuclear irradiation since all will disturb, to some extent, the periodicity of lattice.

The effect of temperature is particularly important and the resistance increases liniearly with temperature alone about 100°K upto the melting point. On melting the resistance increases markedly because of the exceptional disorder of the liquid state. But for some metals like Bismuth, a poor conductor of electricity, the resistance decreases with increase in temperature since a special zone structure which makes it a poor conductor in solid state is destroyed on melting. In most metals the resistance approaches zero at absolute zero, but in some metals like lead, tin, mercury the resistance suddenly drops to zero at some finite critical temperature above the absolute zero. Such metals are called superconductors. Resistivity of certain metals remain constant or show little change until certain temperature and increases steadily thereafter with increase in temperature. An explanation of electrical and magnetic properties of a material requires more detailed consideration of electronic structure.

The electrons with negative charge revolve around regular array of atoms on the metallic lattice and behave as a three dimensional diffraction grating since the atoms are positively charged and interact with moving electrons. For electrical conduction to occur it is necessary that the electrons at top of a energy band should be able to increase the energy when an electric field is applied to a material so that a net flow of electrons in the direction of applied potential which manifests itself as electric current.

This study of electrical resistivity of austenite active nickel titanium differs from the study made by Santoro et al (2000) in keeping the temperature constant and studying the resistivity change due to stress induced martensite transformation. Earlier, pilot study was done by keeping the temperature as constant for a given length and dimension of wire and change in resisitivity was appreciable before and after strain. Care is taken that there is not any influence of temperature in change in resistivity. This is done by using minimal strength of current so that heat produced is negligible and use of highly sensitive thermistors which automatically shut downs the circuit if at all there is any change in the temperature. The resistance is also plotted against time and the values are taken after a minute ensuring that the resistance change is only due to strain induced martensitic change. Since the length of the wire tested was taken as constant for all samples which is 40 mm and the dimension of all the wire samples were of 0.017X0.025 inch as per manufacturer's specification the Resistivity value was directly proportional to the measured Resistance in milliohms. It is related by the formula, $\rho = R.a/L$, where ρ is Resistivity, and a the area of cross section and L, the length of the material. Since area of cross section and the length of the material was a constant value Resistivity is assumed to be equivalent to the resistance multiplied by a constant value.

The Resistance values varied for various samples of the same group of equal dimensions in unstrained state. It may be attributed to the atomic composition and the percentage of austenite and martensite phases present at that particular portion of the segment, area of cross section and some minor variations in length. However change in resistance after inducing strain in the wires were taken into account for the calculation of degree of martensite transformation and for ranking.

Thayer and Bagby[83] (1995) after studying x-ray diffraction pattern of nickel titanium wires concluded that the superelastic mechanical behavior depends more than the phase composition. Heat treatments during manufacture may change defect structure, residual stress and other material characteristics. Since mechanical properties and the electrical properties can be influenced by various factors apart from phase composition correlating the ranking do not give similar results. However these rankings should be effectively compared with the clinical performance of these wires for selecting the best method for evaluating the superelastic behavior.

SUMMARY AND CONCLUSION

Application of light and continuous forces for optimum physiological response and least damage to the tooth supporting structures should be the primary aim of the orthodontist. Nickel titanium alloys with the properties of excellent springback, superelasticity and wide range of action is one of the natural choice for the clinicians to achieve this goal. In recent periods, various wire manufacturers have come with a variety of wires exhibiting different properties. It is the duty of the clinician to select appropriate wires during various stages of treatment for excellent results. For achieving this an evaluation of the properties of these wires is essential. This study is focussed on evaluating the superelastic property of eight groups of austenite active nickel titanium wires. These wires were tested through mechanical tensile testing and electrical resistivity methods. The following are the rankings based on mechanical tensile testing. Ortho organisers wires ranked first and superior, followed by American Orthodontics and Ormco A wires. Unitek 3M and American braces wires were ranked after American Orthodontics & Ormco A wires as they exerted higher forces on deactivation . Morelli and GAC lowland NiTi wires were ranked last. In electrical resistivity tests Ormo A wires were found superior closely followed by American Orthodontics and Ortho Organisers wires. Unitek 3M, American Braces and GAC Lowland NiTi wires did not show much difference between each other and Lancer followed by Morelli remained last in the ranking.

These rankings were given on the basis of the degree of phase transition from austenite to martensite, a crystallographic transformation contributing to superelastic behavior. Researchers believe that various factors like residual stress, heat treatment, alloy composition determine the expression of superelastic behavior apart from phase transition. It can be concluded that the performance of these wires based on rankings should be evaluated clinically by conducting further studies. In the future more studies should be focussed on the search for an ideal method for accurate evaluation of properties of orthodontic wires.

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