Comparison of Superelasticity of Nickel Titanium Orthodontic Arch wires using Mechanical Tensile Testing and Correlating with Electrical Resistivity

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ABSTRACT

Background: 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 spring back, super elasticity and wide range of action is one of the natural choices 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 evaluation of the properties of these wires is essential.

Materials and Methods: This study is focussed on evaluating the super elastic property of eight groups of austenite active nickel titanium wires. Eight groups of archwires bought from eight different manufacturers were studied. These wires were tested through mechanical tensile testing and electrical resistivity methods.

Results: Unloading curves were carefully assessed for superelastic behaviour on deactivation. Rankings of the wires tested were based primarily upon the unloading curve's slope

Conclusion: Ortho organisers wires ranked first and superior, followed by American Orthodontics and Ormco A wires. Morelli and GAClowland NiTi wires were ranked last. It can be concluded that the performance of these wires based on rankings should be further evaluated by clinical studies.

Key Words: NiTi arch wires, Electrical resistivity, Superelasticity, Springback.

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Introduction

Arch wires were designed to move teeth with light continuous forces. Such forces may reduce the potential for patient discomfort, tissue hyalinization, undermining resorption. 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 spring back and wide force delivery range even in larger cross sections, which is particularly essential for the initial phase of treatment when considerable deflections are required to engage the wire into the brackets[1]. The low deactivation force exerted by Nickel Titanium wires elicit a physiological bone response minimizing undermining resorption. 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[2]. 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.[3]

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

Fig. 1: Wire

behavioural properties through various methodologies like Mechanical testing, X- ray Diffractometry, Differential Scanning Calorimetry, Scanning Electron Microscopy, Electrical Resistivity and Conductivity and Optical Studies[4]. Being the material under study is a metallic alloy in wire form, study of electrical resistivity was found suitable.

Evans[5](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.

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 resistivity tests are also conducted on these wires and the results are correlated with each other.

Aims & Objectives

1. Comparison of superelastic mechanical behaviour 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.

Materials & Methods

Eight groups of archwires bought from eight different manufacturers were studied (Fig.1). Five samples were used from each group for tensile testing and five 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.

Brackets used were of Composite type (Morelli Co., Brazil), and Modules used were Ortho Organizers company.

Table 1: Wires used in the Study		
Group	**Name of the Wire**	**Manufacturer**
1	NitaniumArchwires	Ortho Organizers Inc, 1619, S Rancho, Santa Fe Road, San Marcos, California, USA 92069.
2	NiTiSuperelastic wires	Morelli Orthodontia Alemeda, Jundial 230/250 Sorocaba, Brazil.
3	Tru Arch Align SE 200	Ormco A Sybron dental Specialities, 1332, South Lone Hill Avenue, Glendora, California, USA 91740
4	Nickel Titanium memory wire Force 1	American Orthodontics, 1714, Cambridge Avenue, Sheboygan, USA 53081
5	Nitinol SE	3M Unitek Orthodontic Products, 2724, South Peck Road, Monrovia, California USA 91016
6	Titanol	Lancer Orthodontics, 253, Pawnee Street, San Marcos, California USA 92069
7	Nickel Titanium Super Elastic Wire	American Braces Components and Devices, BPO Trac Marketing, Chennai
8	Lowland NiTi	GAC International, 355 Knickbocker Avenue, Bohemia, New York, USA

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 (Fig.2).

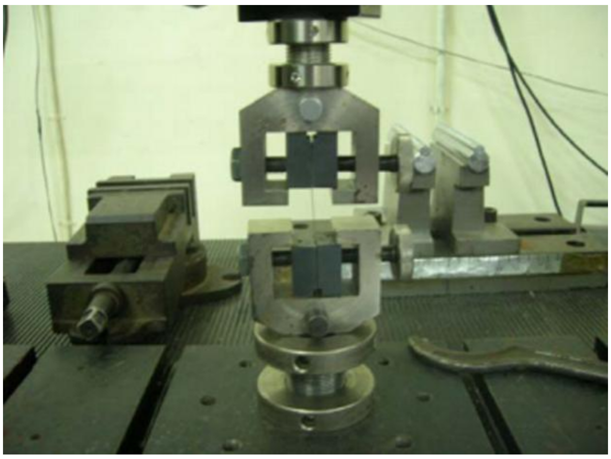


Fig. 2: Testing

Different wire segments cut from the straight sections of the archwires were used for the tensile tests. All testing was done at room temperature approximately 22 degree Celsius as Burstone et al[2] 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/strainplot was calculated.[4] 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 behaviour.

Fig. 3: Circuit

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 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 with 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 in the form of potential divider network produces an output of 20 mV for 50°C.

Signal Amplifying and Conditioning Circuit to amplify 20 mV from transducer to 5V, a two stage instrumental amplifier is designed with an overall gain of 250. Amplification is done in two stages, with a first stage amplification of 10 times and second stage of 25 times.

Filters and Oscillator Circuits filter noises at different levels of harmonic and provide a 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 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 (Fig.3). 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.[6]

The design of the loading device was depicted from the one described by Santoro et al[11] 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. 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 (1mmstep) and maximum loading (6mm step) (Fig 4)

From each group of archwires, five 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.

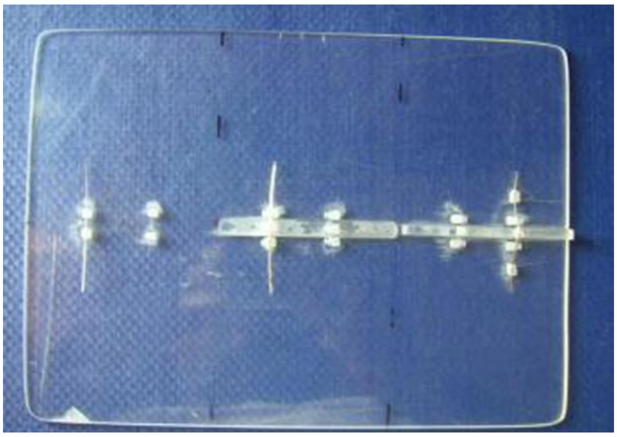


Fig. 4: Bracket Assembly

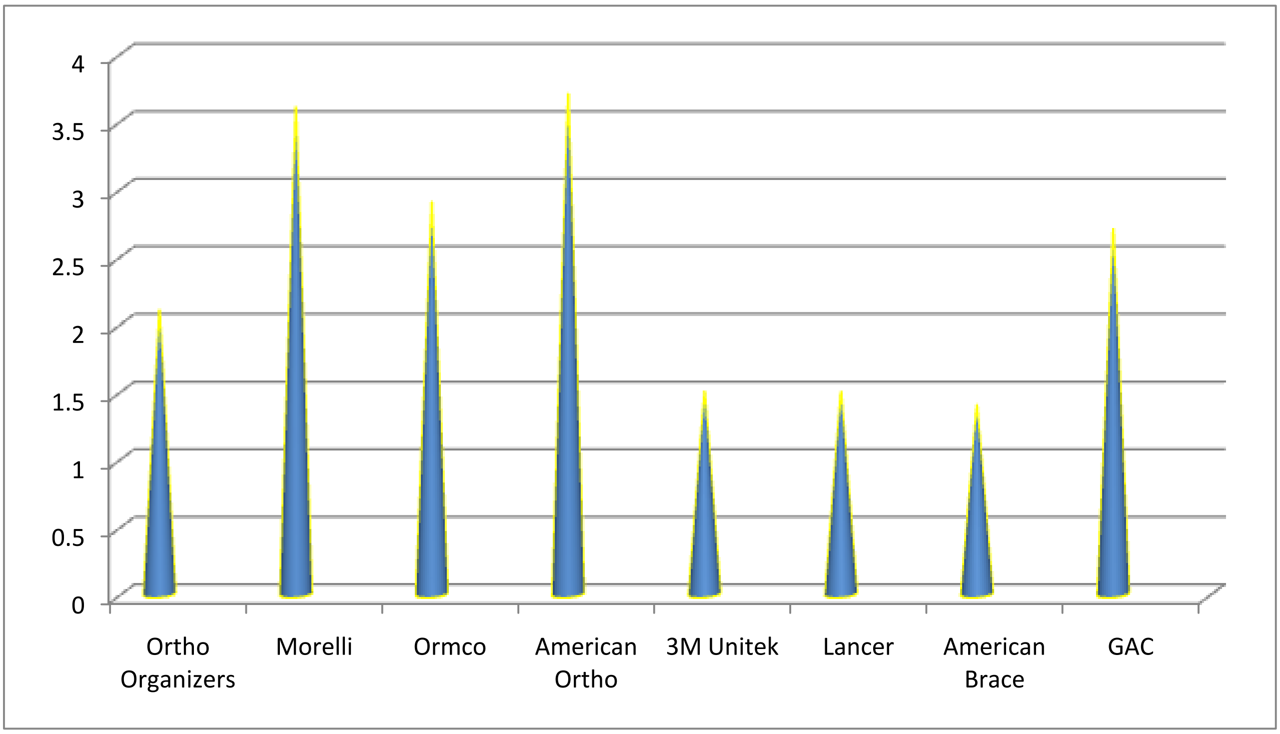
Results

Representative stress-strain curves for the wires tested are shown in Table 2. Unloading curves were carefully assessed for superelastic behaviour 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

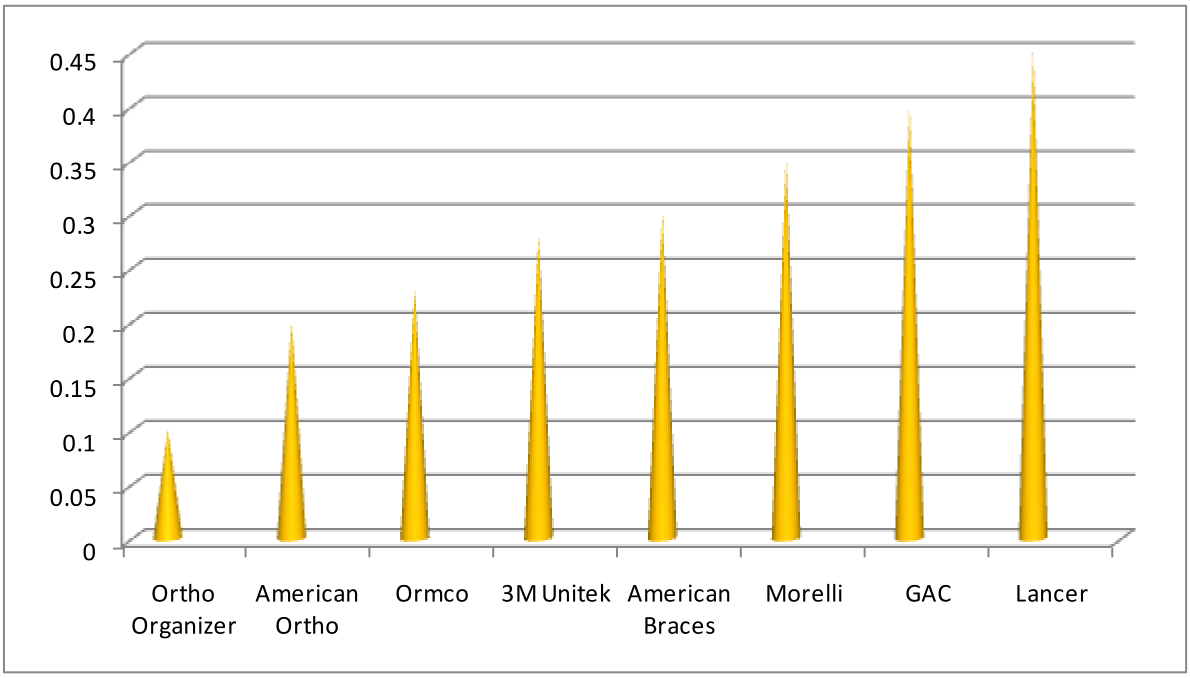
Table 2: Resistance values of samples with maximum strain

Nickel Titanium Wires	Maximum Strain in milli Ohms		P Value
	Mean	SD	
Ortho Organizers	269.5[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**
3M Unitek	271.28[cd]	1.01	
Lancer Orthodontics	277.23[e]	1.25	
American Brace	272.82[d]	0.82	
GAC	264.60[b]	1.42	

Note: 1) ** Represents significance at 1% level
2) Different alphabets between brands denote significant at 5% levels.

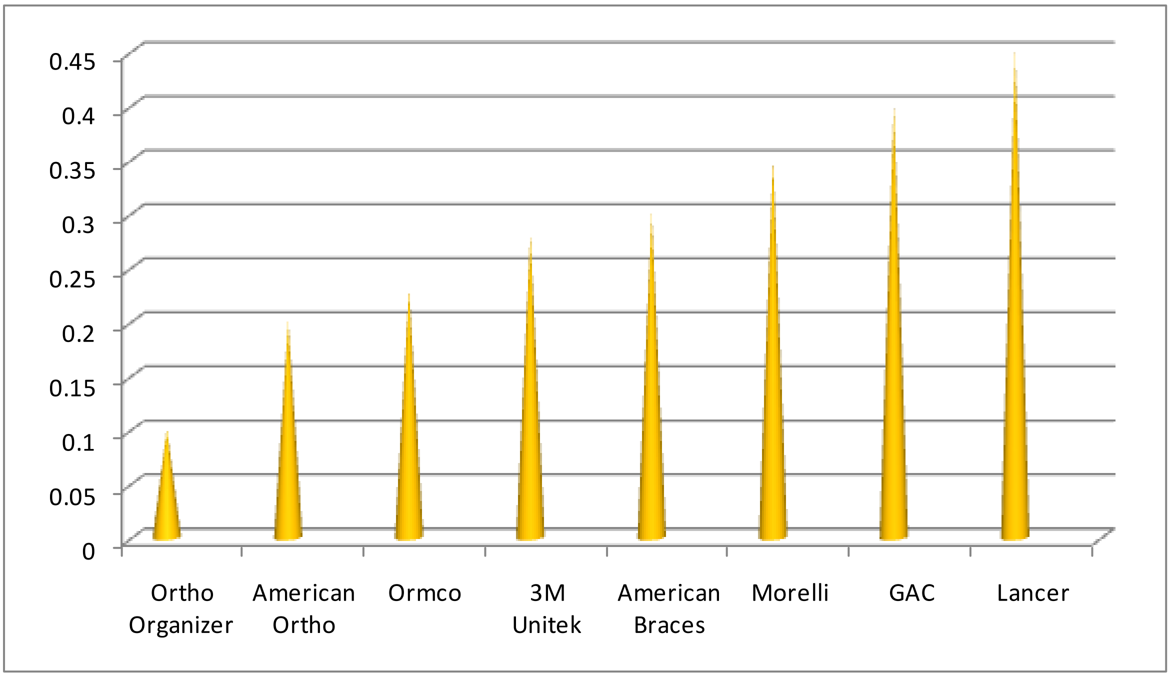


Graph 1: Mean Initial stiffness of Nickel titanium wires

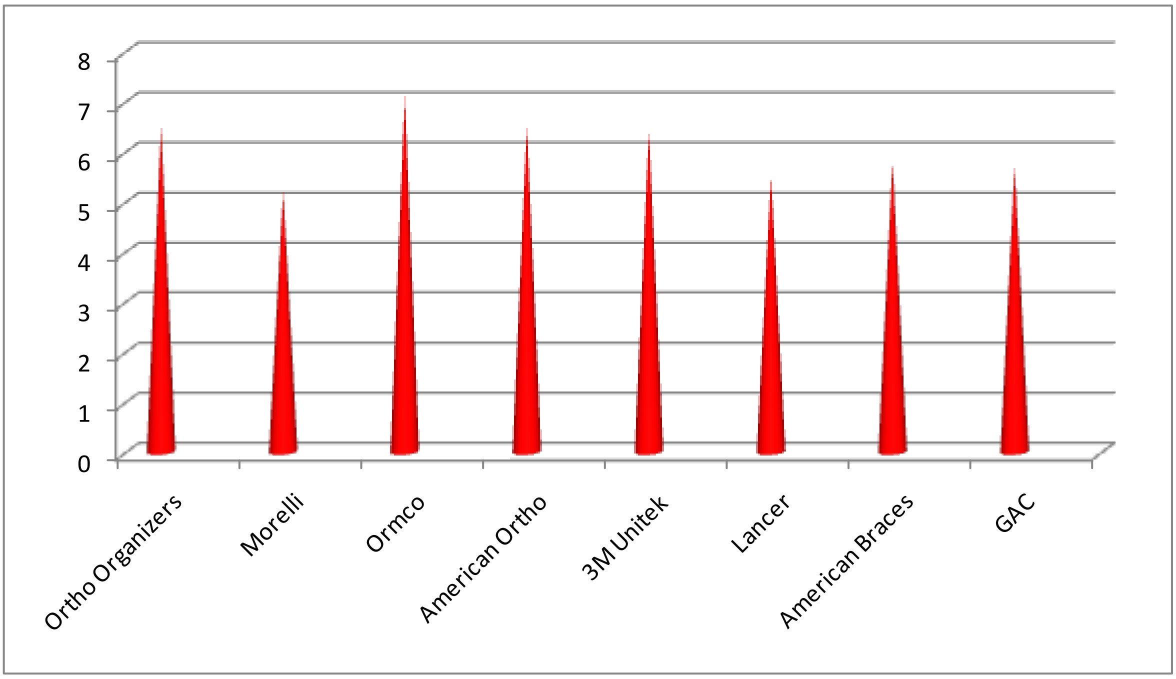


Graph 2: Stress at 10 % strain for Nickel Titanium wires

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 wires by the length of horizontal segment of unloading curve. Morelli wires exerted higher forces during deactivation but somewhat continuous and GAC



Graph 3: Representing ranks in ascending order during mechanical tensile testing



Graph 4: Representing ranks during electrical resistivity

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 Graph No.3. Difference between means for the initial slope and stress at 10% strain werefound to be statistically significant with P value less than 0.001.

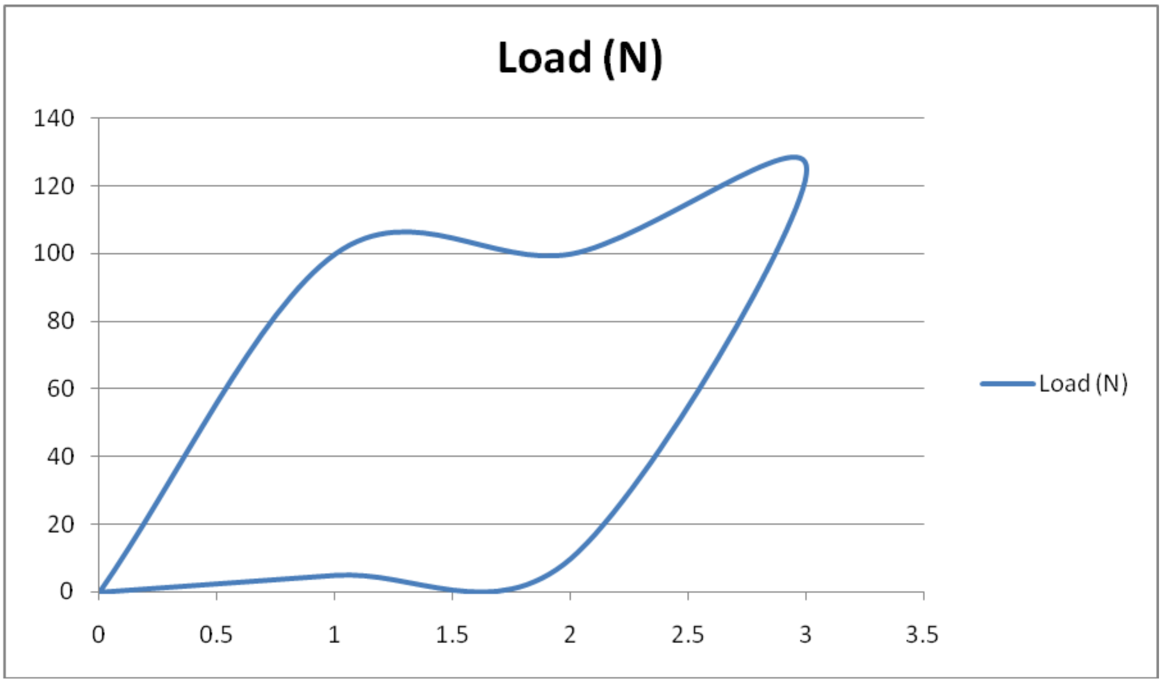
ANOVA followed by Scheffe's test for initial slope shows a significance level of 0.05.The critical differences between subsets were 0.5 units. ANOVA and Scheffe's test for Stress at 10% strain shows the critical differences between two subsets were at 50 MPa level.

Interpretations of these results show that the initial stiffness was maximum for American Orthodontics Wires and minimum for American Braces wires. Stresses at 10% strain were Maximum for 3M Unitek wires and minimum for American Orthodontics wires. The mean initial stiffness and standard deviation of unstrained and minimally strained NiTiwires for the electrical resistivity tests are shown in Graph 1. Table 3 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

Table 3: Change in Resistance

Nickel Titanium Wires	Change in Resistance in milli Ohms		P Value
	Mean	SD	
Ortho Organizers	6.52[bc]	0.56	
Morelli	5.22[a]	0.99	
Ormco A	7.12[c]	0.21	
American Orthodontics	6.60[bc]	0.61	<0.001**
3M Unitek	6.23[bc]	0.53	
Lancer Orthodontics	5.50[ab]	0.75	
American Brace	5.89[ab]	0.31	
GAC	5.78[ab]	0.50	

Note: 1) ** Represents significance at 1% level
2) Different alphabets between brands denote significant at 5% levels.



X= Extension in mm

Y= Load in Newtons

Graph 5: Representative graph for Group 1 wires.

between each group showed significant difference in resistance values. Graph 2 shows the mean and standard deviation for the difference in resistance between unstrained samples and maximally strained samples were tabulated in Table 4. Interpretations 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. (Graph 3) 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 (Graph 4).

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.[7]

In order for the clinician to choose more appropriate arch wire during treatment, an understanding of the optimal characteristics is necessary. Several characteristics of orthodontic wires are considered desirable for optimum performance during treatment. These include large spring back, low stiffness, high formability, high stored energy, biocompatibility and environmental stability, low surface friction, and the capability to be welded or soldered to auxiliaries.[8]

Higher springback values provide the ability to apply large activations with a resultant increase in working time of the appliance.[9] This in turn, implies fewer archwire changes. Springback is also a measure of how far a wire can be deflected without causing permanent deformation.[10] Burstone C.J.[2] 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 overtime as the appliance experiences deactivation.[11]

According to Santoro[12], the physical behaviour of Nickel Titanium alloy can be explained from a metallurgical analysis. 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 an austenite active or martensite active alloy[13].

Superelasticity a phenomenal behaviour 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 behaviour necessary for the release of light continuous forces.[14]

Thurow(1982) stated that a standard specification test data are mostly irrelevant to orthodontics in spite of their scientific basis. . Since E and YS are basic material properties such variation indicates deficiencies in the bending mechanics analysis (Evans)[15].

Thayer and Bagby[13](1995) compared the superelastic mechanical behaviour 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.[16]

In our 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.[17] Three readings were taken for the slope and average is derived. Stress at10% 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(Asgharnia and Brantley 1986)[14].

Kauffmann et al[18](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[19] (2001)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.[19]

This study of electrical resistivity of austenite active nickel titanium differs from the study made by Staggers et al[20] (1993) in keeping the temperature constant and studying the resistivity change due to stress induced martensitic transformation. 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.

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 martensitic 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 martensitic transformation and for ranking.

Thayer and Bagby[13] (1995) after studying x-ray diffraction pattern of nickel titanium wires concluded that the superplastic mechanical behaviour 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 behaviour.

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 choices for the clinicians to achieve this goal. In recent periods, various wire manufacturers have come with a variety of wires exhibiting different properties. 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 therankings 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 GAClowland NiTi wires were ranked last.

In electrical resistivity tests Ormo A wires were found superior closely followed by America n

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 behaviour. Researchers believe that various factors like residual stress, heat treatment, and alloy composition determine the expression of superelastic behaviour 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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