Comparison and ranking of superelasticity of different austenite active nickel-titanium orthodontic archwires using mechanical tensile testing and correlating with its electrical resistivity

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ABSTRACT

Introduction: The application of light and continuous forces for optimum physiological response and the least damage to the tooth supporting structures should be the primary aim of an orthodontist. Nickel-titanium (NiTi) alloys with their desirable properties are one of the natural choices of the clinicians.

Aim: This study was aimed to compare and rank them based on its tensile strength and electrical resistivity.

Materials and Methods: The sample consisted of eight groups of 0.017 inch × 0.025 inch rectangular archwires from eight different manufacturers, and five samples from each group for tensile testing and nine samples for electrical resistivity tests were used. Data for stress at 10% strain and the initial slope were statistically analyzed with an analysis of variance and Scheffe tests with \( P < 0.05 \). The stress/strain plots of each product were ranked for superelastic behavior. The rankings of the wires tested were based primarily on the unloading curve’s slope which is indicative of the magnitude of the deactivation force and secondarily on the length of the horizontal segment which is indicative of continuous forces during deactivation. For calculating the electric resistivity, the change in resistance after inducing strain in the wires was taken into account for the calculation of degree of martensite transformation and for ranking.

Results: In tensile testing Ortho Organizers wires ranked first and GAC Lowland NiTi wires ranked last. For resistivity tests Ormco A wires were found superior and Morelli remained last. Conclusion: these rankings should be correlated clinically and need further studies.

KEY WORDS: Electrical resistivity tests, mechanical tensile testing, nickel-titanium orthodontic wires, ranking

Biomechanical forces which are generated by orthodontic wires are transmitted to the brackets and hence, initiate tooth movement which in turn is vital to the practice of our profession. Attainment of maximal cellular response with minimum damage to the tissues is possible only with optimum orthodontic force. For desired tooth movements, light and continuous orthodontic forces are essential and this is established by many earlier studies. During the initial phase of treatment, a lot of deflections are required to engage the wire into the brackets. Wires with low modulus of elasticity and high spring back wide force delivery range even in larger cross-sections are required during this phase of treatment. Nickel-titanium (NiTi) wires are the ultimate choice of selection to fulfill these criteria. A physiological bone response with minimal undermining resorption is exerted by titanium-based archwires.

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NiTi alloy’s behavior is an exact function of its phase. In austenite phases, the mechanical properties such as yield strength and elastic modulus are larger than martensite phase. Resistivity for the martensite phase and austenite phase is 76 $\mu\Omega\cdot$cm and 82 $\mu\Omega\cdot$cm, respectively. Change in resistivity takes place whenever a stress is induced in austenite active NiTi at constant temperature well above the transition temperature range. This change in resistivity is due to stress-induced phase transformation from austenite to martensite. Properties such as magnetic susceptibility, thermal expansion, and thermal conductivity also vary for these two phases.

Commercially marketed NiTi wires vary in their properties, and hence, selecting a wire with desirable properties and for a specific clinical situation needs thorough scrutiny from the clinician for obtaining better results.

Comparing the degree of superelasticity of austenite-active NiTi from different manufacturers using mechanical tensile testing and correlating with the stress-induced changes in electrical resistivity of the similar archwires at constant temperature is the purpose of this study.

Materials and Methods

Wires of dimension 0.017 inch $\times$ 0.025 inch and of rectangular cross-section were acquired from eight different manufacturers and used for the study [Table 1]. From each group, five samples were used for tensile testing and nine samples were used for electrical resistivity tests. All the wires used for testing were of similar dimension 0.017 inch $\times$ 0.025 inch and of rectangular cross-section. For mechanical tensile testing, universal testing machine (Lloyd) was used. For electrical resistivity tests, a custom-made wire loading device connected to an electrical circuit integrated with computer is used. A digital Vernier calipers and thermometer were also used.

Wire segments of uniform length cut from the straight portions of the archwires were taken for mechanical tensile testing. A room temperature of 22°C was maintained throughout testing.

Ends of segments of wires were inserted into the grips of universal testing machine, which were placed 30 mm apart. A crosshead speed of 1 mm/min was established and 10% of strain was induced after the segments were extended by 3 mm. Unloading was done by reversing the direction of crosshead movement. The stress at 10% tensile extension was calculated. Tests on five specimens from each group were performed. The plotting of values of stress/strain gives the value of the initial slope. This initial slope value is an indicator of initial stiffness (in tension). Stress induced in the wires were measured in Newton and converted to MegaPascal by dividing the Newton value by the area of cross-section of wire samples. Stress-induced strain in length is measured in millimeters. Statistical analysis of the data for stress at 10% strain and initial slope was done with analysis of variance (ANOVA) and Scheffe tests with $P < 0.05$.

Table 1: Nickel titanium orthodontic archwires

| Group number | Name of the wire | Manufacturer |
|-------------|-----------------|--------------|
| 1           | Nitinum archwires | Ortho Organizers. Inc. 1619, S.Rancho, Santafe, Bohemia, New York, USA |
| 2           | NiTi superelastic wires | Morelli Orthodontia, Alameda, Jundial 230/250 Sorocaba, Brazil |
| 3           | Tru-Arch Align SE 200 NiTi memory wire force-1 | Ormco A Sybron Dental Specialities 1332, South Lone Hill Avenue, Glendora, CA 91740, USA |
| 4           | Titanal | American Orthodontics, 1714, Cambridge Avenue, Sheboygan, USA 53081 |
| 5           | Nitinol SE | Unitek 3M Orthodontic Products, 2724, South Peck Road, Monrovia, CA 91016 USA |
| 6           | Titanal | Lancer Orthodontics, 253, Pawnee Street, San Marcos, California USA 92069 |
| 7           | NiTi superelastic wire | American Braces Components and Devices, BPO-TRAC Marketing, Chennai |
| 8           | Lowland NiTi | GAC International, 355, Knickerbocker Avenue, Bohemia, New York, USA |

NiTi: Nickel titanium, SE: Superelastic

Ranking based on superelastic behavior was derived from stress/strain plots of each product. Larger this segment greater the degree of superelasticity, and shorter the slope of the segment lesser the superelasticity. Wires with good horizontal unloading segment of their plot and with somewhat horizontal loading segment were ranked as having a good degree of superelasticity. The basic design of the loading device for testing electrical resistivity was adapted from the Santoro and Beshers where it was built on plexiglass material which is a nonconductor and insulator. Three segments of uniform length of straight sections from each of eight groups were used for electrical resistivity tests. These segments were loaded on the plastic brackets bonded to plexiglass, and the range of loading was done using 1 mm step as minimum and 6 mm step as maximum and without any load (flatter). At the ends of wire segments, detachable terminals were connected through a circuit integrated with a computer. Resistivity values were calculated for each minimally loaded, maximally loaded, and unloaded wire specimen using the formula $\rho = R/aL$, where $\rho$ is resistivity and $R$ is the resistance, $a$ is the area of cross-section, and $L$ is the length of the material. The unit for resistivity is ohm-inch. The results were tabulated and analyzed.

Results

Figures 1-8 show the stress/strain curves of the tested wires unloading curve’s slope which is indicative of the magnitude of the deactivation force and the length of the horizontal segment which is indicative of continuous forces during deactivation considered for ranking. Having the lowest slope value and longest horizontal segment of unloading curve makes Ortho Organizers wires superior than other wires tested.

American Braces wires were better than Unitek 3M wires by the length of horizontal segment if unloading curve
while Unitek 3M excelled American Braces by exerting lesser forces when strained. During deactivation, Morelli wires exerted higher forces but somewhat continuous. GAC Lowland NiTi ranked below Morelli wires. The last ranked wire is Lancer’s Titanal wire which had highest magnitude of force but with reasonable horizontal segment. Unitek 3M wires having the shortest horizontal segment showed less continuous deactivation force.

![Figure 1: Representative graph for Group 1 wires (Ortho Organizers)]()

![Figure 2: Representative graph for Group 2 wires (Morelli)]()

![Figure 3: Representative graph for Group 3 wires (Ormco A)]()

![Figure 4: Representative graph for Group 4 wires (American Orthodontics)]()

![Figure 5: Representative graph for Group 5 wires (Unitek 3M)]()

![Figure 6: Representative graph for Group 6 wires (Lancer)]()
Tables 2 and 3, Figures 9 and 10 show the mean and standard deviation of initial slopes and stresses at 10% strain for the different wires tested. Difference between means for the stress at 10% strain and for the initial slope was found to be statistically significant with $P < 0.001$. ANOVA followed by Scheffe test for initial slope shows a significance level of 0.05. The critical difference between two subsets was 0.5 units. ANOVA and Scheffe test for stress at 10% strain show the critical difference between two subsets where at 50 MPa level. This shows that initial stiffness was minimum for American Braces wires and maximum for American Orthodontics wires. Stress at 10% strain was minimum for American Orthodontics and maximum for Unitek 3M wires. The ranks in ascending order are depicted in Figure 11.

Tables 4 and 5 show the data, mean, and standard deviation of unstrained and minimally strained wires for the electrical resistivity test. Data such as mean and standard deviation following the maximum strain are shown in Table 6. All the values of electrical resistivity were analyzed and found statistically significant with $P < 0.001$. ANOVA followed by Scheffe test was conducted for all the data recorded. The different samples of the same dimensions and length and between the same and different groups showed difference in resistivity.

Table 7 shows the mean and standard deviation for the difference in resistance between unstrained samples and maximally strained samples. The results were interpreted based on change in resistance values. Wires showing greater change were ranked superior.

Ormco A wires were superior followed by American Orthodontics and Ortho Organizers. American Braces, Unitek 3M, and GAC Lowland NiTi wires scored similar while Morelli and Lancer wires were ranked last as depicted in Figure 12.

### Table 2: Initial stiffness of nickel-titanium wires

| NiTi wires          | Initial slope | SD  | $P$   |
|---------------------|---------------|-----|-------|
| Ortho Organizers    | 2.08$^{ab}$   | 1.05| $<0.001^{**}$ |
| Morelli             | 3.52$^c$      | 0.72|       |
| Ormco A             | 2.85$^{a}$    | 0.72|       |
| American Orthodontics| 3.63$^c$    | 1.66|       |
| Unitek 3M           | 1.53$^c$      | 0.19|       |
| Lancer              | 1.54$^a$      | 0.84|       |
| American Braces     | 1.41$^a$      | 0.19|       |
| GAC Lowland NiTi    | 2.79$^{ab}$   | 0.43|       |

**Significant at 1% level. Different alphabet between brands denotes significant at 5% level. NiTi: Nickel-titanium, SD: Standard deviation.
Table 3: Stress at 10% strain

| NITi wires               | Stress at 10% strain in MPa | P          |
|-------------------------|-----------------------------|------------|
| Ortho Organizers        | 444.84<sup>ab</sup>         | 33.12 <0.001** |
| Morelli                 | 485.23<sup>b</sup>          | 11.94      |
| Ormco A                 | 577.77<sup>b</sup>          | 8.28       |
| American Orthodontics   | 394.07<sup>a</sup>          | 28.52      |
| Unitek 3M               | 661.72<sup>c</sup>          | 4.10       |
| Lancer                  | 605.92<sup>c</sup>          | 53.84      |
| American Braces         | 586.66<sup>d</sup>          | 21.21      |
| GAC Lowland NiTi        | 480.00<sup>c</sup>          | 10.01      |

**Significant at 1% level. Different alphabet between brands denotes significant at 5% level. NITi: Nickel‑titanium, SD: Standard deviation

**Discussion

In fixed appliance therapy, quantifying the light continuous force is difficult because of individual variation in tissue response, root morphology, and the type of tooth movement induced. This depends on choosing the appropriate archwire during treatment, with an understanding of its optimal characteristics. The desirable characteristics of orthodontic wires 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. Burstone<sup>2</sup> considered stiffness as the most important variable in clinical wire selection. Low stiffness or
load-deflection rate provides the ability to apply lower forces and constant force overtime as the appliance experiences deactivation. NiTi alloys are used in orthodontics for its outstanding springiness and flexibility with constant delivery of force during deactivation. Regarding its tensile properties, Thayer et al. had compared the superelastic mechanical behavior of NiTi alloy orthodontic wires, but the method used, differential scanning calorimetry, though an ideal method to identify the phase transformation, is not useful for identifying the stress induced phase transformation.

This study was conducted to compare the degree of superelasticity of austenite NiTi from various manufacturers using mechanical tensile testing and also correlating the results with the stress-induced changes in electrical resistivity of the archwires at constant temperature. The sample consisted of eight groups of 0.017 inch × 0.025 inch rectangular archwires from eight different manufacturers and five samples from each group for tensile testing and nine samples for electrical resistivity tests were used.

In this study, the tensile testing was done and stress/strain curves were obtained. The loading and unloading curves were plotted and the initial slope was determined within the extension of 0.5 mm. Three readings were taken for the slope and average was 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. The following were the rankings based on mechanical tensile testing. Ortho Organizers wires ranked first and superior, followed by American Orthodontics and Ormco A wires. Unitek 3M and American Braces wires were ranked after American Orthodontics and Ormco A wires as they exerted higher forces on deactivation. Morelli and GAC Lowland NiTi wires were ranked last.

The study of electrical resistivity of austenite active NiTi differs from the study made by Santoro and Beshers in keeping the temperature constant and studying the resistivity change due to stress-induced martensite transformation. The change in resistance after inducing strain in the wires was taken into account for the calculation of degree of martensite transformation and for ranking. In electrical resistivity tests, Ormco A wires were found superior closely followed by American Orthodontics and Ortho Organizers wires. Unitek 3M, American Braces, and GAC Lowland NiTi wires did not show much difference between each other and Lancer followed by Morelli which remained last in the ranking.

**Conclusion**

Superelastic behavior of a wire is due to crystallographic transformation from austenite to martensite phase. In this study, based on the degree of phase transition, rankings were given. Factors such as residual stress, heat treatment, and alloy composition determine the level of expression of superelastic behavior apart from phase transition. Performance of these wires clinically in relation to ranking should be evaluated by further studies. In future, the focus of research should be on ideal and accurate methods of evaluation of orthodontic wires for their properties before being used clinically.

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**Conflicts of interest**

There are no conflicts of interest.

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