EVOLUTION IN NICKEL TITANIUM WIRES: A REVIEW

[1] Oshin Sethi, [2] Jaspinder Kaur Manchanda
[1]Senior lecturer, Department of Orthodontics & Dentofacial Orthopaedics, SKSS Dental College & Hospital, Ludhiana.
[2] PG student (3rd Year), Department of Peridontics, BJS Dental College, Ludhiana

Corresponding Author:

Dr. Oshin Sethi
Senior lecturer, Department of Orthodontics & Dentofacial Orthopaedics, SKSS Dental College & Hospital, Ludhiana.
Email id:oshinsethi1993@gmail.com Ph No: 9872661007

Abstract
Results of Orthodontic treatment depend not only on skills of clinician, appropriate diagnosis and treatment planning, but also on material of components used for fixed mechanotherapy. Components of fixed appliance include wires, brackets, Nickel Titanium (NiTi) springs, elastic module, ligature wire etc. A variety of materials with variable physical properties, esthetics and frictional properties are used for manufacturing of orthodontic wires. Therefore an Orthodontist must know the properties and behaviour of different wires for their appropriate clinical use to achieve satisfactory results during orthodontic therapy. This article reviews the NiTi wire and latest trends of these wires.
Keywords: NiTi wire, shape memory, superelasticity, springback.

Introduction
The development of the various orthodontic treatment modalities available today would not have been possible without the introduction of metal and alloy in the form of wires in different dimensions, shapes and configurations.
WIRE is a slender rod, strand or thread of ductile metal, usually formed by drawing through dies or holes.[1]
Orthodontic wires generate biomechanical forces, communicate through brackets for tooth movement and are central to the practice of the profession. Optimum orthodontic tooth movement is produced by light continuous force throughout and over large distances. The challenge in designing and using an orthodontic appliance is to produce a force system with these characteristics, creating forces that are neither too great, nor too variable over time. It is particularly important that the light, continuous forces do not decrease rapidly, decaying away, either because the material itself loses its' elasticity, or, because a small amount of tooth movement causes a larger change in the amount of force delivered.
Initially, in the late 18th and early 19th century, the gold arch wires were the only metal used in orthodontics. Later, newer, better and more economic materials are introduced such as stainless steel wires, in mid 19th century which gradually replaced the gold wires and dominated for almost two decades. After that Nitinol wire was invented in the late 19th century and gained popularity due to its unique features like shape memory, super elasticity, etc.

Nickel Titanium wires
Evolution of NiTi alloys
The nickel-titanium alloy was invented at the Naval Ordnance Laboratory in the 1960s and subsequent application to orthodontics became possible during the early 1970s. Actually, the first NiTi orthodontic wire (Nitinol) was named after the laboratory where the wider metallurgical applications of alloys took place (Nickel Titanium Naval Ordnance Laboratory)[2]
By 1970 Andreason brought this intermetallic composition of 50% nickel and 50% titanium to orthodon¬tics through the University of Iowa[2-4.] The Unitek Cor¬poration licensed the patent and offered a stabilized martensitic alloy that did not exhibit any shape-memory effect (SME) under the name, Nitinol. This product had the lowest modulus for any cross section and the most extensive deactivation (range) capability. Now, light forces could be offered over a protracted range as any of four combinations of passive or active be-havior and of martensitic or austenitic phase were possible. In some cases the thermoelastic or the pseudoelastic effects (or both) are also exploited,the latter of which is also termed superelastic, in part because the material has so much springback after displaying what appears to be pure plasticity.
By 1986, two "superelastic" alloys were offered — a Japanese NiTiand a Chinese NiTi. These are active austenitic alloys that form stress-induced martensite. The first generation of NiTi wires expressed the "shape memory" characteristic, which refers to the ability of the wire to return to a previously manufactured shape when heated through a transition temperature range (TTR). Andreasen in 1985 showed that when a Nitinol wire is deflected over a long distance it eventually springs back to nearly its original position while exerting light, continuous forces.[5,6]
This property of the Nitinol is called as the "superelastic" property. However, in the following years the term "superelasticity" took a different definition based on the structural changes also known as phase transformation that take place during the temperature changes or the loading process of the wire. Superelasticity[7] is now termed as a phenomenon where the wire exhibits a low continuous force with a plateau during loading or unloading. This property gives an almost constant force over a wide range and provides clinical advantages over non-superelastic nickel-titanium wires. During the mid-1980s, two new superelastic nickel titanium archwire alloy types were manufactured and became commercially available: the Chinese NiTi and the Japanese NiTi [8.] The Chinese NiTi (marked as Ni-Ti by Ormco)[9], was introduced in 1985 by Burstone and colleagues, and exhibited 4.4 times the springback of the stainless steel wire and 1.6 times the springback of the original Nitinol .

Some unique properties of NiTi wires
1. Transition temperature range,
2. Shape memory,
3. Super elasticity,
4. Spring back property.

Transition temperature range (TTR):
Transition temperature range is a specific temperature range when the alloy nickel titanium on cooling undergoes martensitic transformation from the cubic crystallographic lattice.
At lower temperatures, the alloy consisting of 55% Ni and 45% Ti is found to be in martensitic crystallographic lattices consisting of lesser symmetric lattices like monoclinic, orthorhombic, tetragonal crystallographic structures. In the martensitic phase, the alloy cannot be plastically deformed.At higher temperatures, the alloy is found to be in cubic crystallographic lattice consisting of body centered cubic crystallographic structures. It is also known as austenitic phase of the alloy. Plastic deformation can be induced in austenitic phase of the alloy. When the alloy is cooled through the critical transition temperature range (TTR) martensitic transformation from cubic crystallographic lattice occurs. Hence, the plastic deformation induced at a higher temperature is alleviated at a lower temperature.
The same plastic deformation induced at the higher temperature returns back when the alloy is heated through a temperature range known as reverse transformation (transition) temperature range, RTTR. Any plastic deformation below or in the TTR is recoverable when the wire is heated through RTTR. Therefore, clinically, reverse transformation (transition) temperature range is used.
The TTR of Nickel Titanium alloy is between 482 - 510°C when the alloy is cooled from higher temperature which is very high for clinical usage. Substitution of 1.6% cobalt results in formation of TiNi and TiCo which have transition temperature ranges of + 164.6°C (+ 330°F) for TiNi and -237.2°C (-395°F) for TiCo giving a very wide range of transition temperature range.
Andreason G.F. used 0.010" 55 Cobalt substituted annealed Nitinol alloy in which the TTR of the wire was adjusted to the oral temperature. The wire was stretched from 8% to 12% of its original length below the TTR at room temperature. When introduced into the oral cavity, the wire was activated by the reverse transition temperature range, which brought the wire back to its original pre – stretched condition.
The use of Nickel Titanium wire in the preformed ideal arch form and allowing it to correct the malocclusion when activated by Reverse Transition Temperature Range, RTTR, shape memory phenomenon is required.

Shape memory
It is the phenomenon, wherein if a plastic deformation incurred within or below the TTR, it is recoverable within certain strain limits of 8%, which is the outer fibre strain limit of the wire.
Formation of the shape memory wires
For clinical use, the wire has to exhibit a shape at a lower temperature, any plastic deformation induced should be alleviated when the wire is heated through the RTTR. The Nitinol wire should be plastically deformed at a lower temperature and casted. The casted wire should be placed in the oven and heated between 482°C to 510°C. Plastic deformation occurs and the wire is then placed in the refrigerator. On cooling, the wire comes back to the original shape. It is then heated again and plastic deformation is induced after which, the wire is again placed in the oven, followed by freezing. This heating followed by freezing is continued until the wire retains the shape exhibited at higher temperature even at room temperature. Hence, the preformed Nitinol arch will have a second TTR, which is lower and clinically applicable.

The mechanism behind this phenomenon can be explained as follows:
First memory of the wire is due to conversion of thermal energy to mechanical energy with excess energy in the crystallographic network of the alloy.
Second memory of the wire is an exothermic reaction with passive return to pre-determined position of the crystallographic relaxation and therefore, not associated with recovery forces or work. This explains how NiTi wire can formed into a preformed arch wire for use in orthodontics.
When the preformed Nitinol wire is ligated to the brackets, the oral temperature will act as the RTTR to activate the wire and alleviate the plastic deformation induced thereby correcting the tooth position.
Nitinol wire is work hardened during the manufacturing process, which induces a martensitic phase in to the alloy. Hence, superelasticity is not exhibited by the Nitinol wire.

Superelasticity
It is the property of the wire explained as even when the strain is added, the rate of stress increase levels off due to the progressive deformation produced by stress induced martensitic transformation.
Another wire called the Japanese NiTi wire introduced by Fujio Miura is manufactured by a different process and demonstrates superelasticity. This property can be produced by stress and not temperature difference. Therefore, it is called as **stress induced martensitic transformation.**[8]
Another Nickel Titanium alloy introduced by Burstone developed by Dr. Tien Hua Cheng called as Chinese NiTi alloy exhibits its superior springback property when compared to Nitinol due to little work hardening and presence of the parent phase which is austenite yielding better mechanical properties. In addition, Chinese NiTi wire has a much lower TTR.

Spring back property
Ability of the wire to return to the original shape without permanent deformation is known as spring back property of the wire. It is related to the ratio of yield strength to modulus of elasticity of the material. Higher springback values provide the ability to apply large activation with a resultant increase in working time of the appliance. This in turn implies that fewer arch wire changes or adjustment will be required. It defines the ability of the wire to return to its original shape when the load is relieved before permanent deformation.

Classification of the NiTi Orthodontic archwire alloys
The mechanical properties of the different types of NiTi alloys that are currently available allow an initial classification to the following categories:
- Super elastic,
- Non - superelastic, and
- True shape memory.

However, this classification introduces confusion with respect to the meaning of the terms and as a result, an alternative, structured-based classification was proposed by Kusy as cited by Brantley (Brantley, 2001).

Martensitic-stabilized: the processing of this type of wires creates a stable martensitic structure and thus no shape memory or super elasticity is expressed. Typical representative of this category is the non-superelastic Nitinol wire.

Martensitic Đactive: this type of NiTi wires employs the thermo-elastic effect to achieve shape memory. The temperature raise within the oral environment leads to the transformation of the martensitic back to the austenitic structure and as result the deformed arch wire returns to the starting shape. This category includes the superelastic, shape-memory wires, such as NeoSentalloy and Copper NiTi.
Austenitic Đactive: these alloys experience a pseudoelasticbe-haviour, where the martensitic structure transformation of these alloys is stress-induced resulting from the activation of the wire. Superelastic wires that do not possess thermoplastic shape memory at the oral environment temperature, such as Nitinol SE, belong to this category.

Advances in NiTi wire alloy
Copper Nickel Titanium alloys
In 1994, Ormco Corporation introduced a new orthodontic wire, copper NiTi. It is a quarternary (Nickel, Titanium, Copper and Chromium) alloy with distinct advantages over formerly available Nickel and Titanium alloys.
Thermo mechanical characteristics of the nickel titanium alloys have enabled to develop this new quaternary alloy based on Ni, Ti, Cu, and Cr. This alloy has the advantage of generating more constant forces than any other superelastic nickel titanium alloy. It is more resistant to deformation as a result of thermo – mechanical insults in the mouth. Also, it demonstrates a smaller mechanical hysteresis, that is, it does not lose its recovery load as do other nickel titanium alloys. Orthodontic archwires fabricated from this alloy have been developed for specific clinical situations and are classified as follows:

- Type I :Af 15°C
- Type II :Af 27°C
- Type III :Af 35°C
- Type IV:Af 40°C

These four alloys form the basis for "variable transformation temperature orthodontics" developed by Dr. Rohit C. L. Sachdeva, Texas. Shape memory behavior is reported by the manufacturer to occur for each variant at temperatures exceeding the specified temperature. These variants would be useful for different types of orthodontic patients. For example, the 27°C variant would be useful in mouth breathers, the 35°C variant is activated at normal body temperature, and the 40°C variant would provide activation only after consuming hot food and beverages.[10]

Supercable arch wire
Hanson in 1993, introduced superelastic NiTi coaxial wire which combine mechanical advantage of multistranded cables and properties of superelastic wires. These wires consist of seven individual strands, woven together in a long, gentle spiral wire. This wire provides better treatment efficiency as it is flexible, eliminate need of archwire bending and can be easily ligated regardless of crowding. These wires generate light, continuous force, so there is no adverse effect on periodontal tissues and patient discomfort is also minimum. Uses of these wires reduce number of visits due to longer arch wire activation.[11]

Turbo wire
These are nine strand rectangular braided NiTi wires having low stiffness and high flexibility. These wires are used for torque control and full bracket engagement. These are also efficient for finishing, retaining torque and allow use of vertical elastics.[12]

Retranol wire
It is 'The Bite Opener' reverse curve arch wire manufactured by work hardening of NiTi. Working range of this wire is greater than that of stainless steel wire and also has ideal dimensional stability, so prevent dumping of anterior teeth during retraction phase. It opens the bite in less than half time as compared to stainless steel wire. This wire remains active throughout the treatment and needs fewer archwire changes and adjustments during treatment. These wires are available in round and rectangular dimension for both maxillary and mandibular arch.[13]

CV NiTi wire
These wires provide predictable force level like copper NiTi wire. These wires eliminate the problems related to copper NiTi wires such as copper allergy, colour change of wire and chemical taste. In these wires, transition temperature range has been changed and set to a specific temperature through pressure variation and heat treatment. These wires are of three types.
• Type 1: Maximum force activation (270C)
This wire works immediately after placement in the mouth. So the wire is first cooled down for bending and engagement. It is best suitable and effective for impacted canine alignment.
• Type 2: Moderate force activation (350C)
This wire gets activated with warm liquids. It is perfect for leveling, aligning and also popular for settling phase.
• Type 3: Minimum force activation (400C)
This wire generates light force, used as initial arch wire and eliminates patient discomfort.[14]

Bactericide orthodontic arch wire: NiTi with silver nanoparticles
These wires are fabricated by electrodeposition of silver nanoparticles, without effecting mechanical properties of wire. This electrodeposition of silver nanoparticles controls the plaque accumulation. It was observed that there is reduction of bacteria due to these silver nanoparticles. As oral hygiene in orthodontic patients get compromised due to brackets. So there are chances of enamel decay, gingivitis and periodontal diseases. To all these problems, these wires give a good solution.[15]

Marsenol
It was manufactured by Glenroe technologies. It is E.T.E (Elastomeric poly tetra flor ethylene emulsion) coated tooth colored nickel titanium wire. Marsenol shows similar working characteristics to an uncoated super elastic nickel titanium wire.[16]

Lee white wire
Lee white wires manufactured by LEE pharmaceuticals are resistant stainless steel or Nickel titanium archwires with a tooth colored epoxy coating. The epoxy coating is opaque, does not show any discoloration and does not chip, peel, scratch or discolor. 16
Orthodontic wires with diamond-like carbon (DLC) Coating
DLC coatings have become popular in biomedical applications. The most noted property of DLC coatings is hardness. DLC coating done by Plasma based ion implantation and deposition (PBIID) gives hardness values of 6-20 GPa. The surfaces of stainless-steel and nickel-titanium orthodontic wires are coated by a DLC layer by PBIID method. The DLC coating decreases the frictional force

and increases the hardness value. DLC coated wires that have lower modulus of elasticity might show higher flexibility.[17-19]

Conclusion

The use of NiTi wires have revolutionized the field of orthodontics as these wires deliver light continuous force over a wide range of displacement as compared to other wires. For desired results, variants of NiTi wires are introduced which provide better physical properties and required behaviour of wire in clinical situation. As number of adult patients seeking orthodontic treatment is increasing, so esthetic variants of NiTi wires are useful for such patients who are conscious for esthetic appearance of fixed appliance.

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