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Ideal Properties of Orthodontic Wires and Their Clinical Implications -A Review

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I. Introduction

Material sciences have made a rapid progress in the recent years. Up till the 1930s, gold was the only orthodontic wire available. Austetenitic stainless steel, with its greater strength, higher modulus of elasticity, good resistance to corrosion, and moderate cost was introduced to the orthodontists in 1929 and within a short span gained popularity over the gold alloy. Since then orthodontics is come a long way. Several alloys like Cobalt – Chromium, Nickel –Titanium, Beta – Titanium, and multistranded stainless steel wires with desirable properties have been adopted in orthodontics. In this vast ocean of different orthodontic alloys available, it becomes very difficult for an orthodontist to select a proper wire with the required properties.

For the correct use of orthodontic appliance one must have a thorough knowledge of the materials from which these appliances are made. The mechanical and physical properties of these materials change greatly under varying conditions of manipulation. Therefore the clinician must be thoroughly conversant with the various mechanical properties of the wires and their clinical applications.

The objective of the article is to review the related literature available in order to describe the mechanical properties and their clinical applications of Stainless steel, Cobalt-Chromium, Nickel-Titanium, Beta-Titanium and multistranded wires.

II. Mechanical Properties

The mechanical properties of orthodontic wires are determined by a, bending test, because this mode of deformation is considered more representatives of clinical conditions. The cantilever bending test in the original form of American National Standard Institute for orthodontic wires not containing precious metals was strongly criticized. A revised specification which is approved contains a three point bending test that better stimulates clinical inter-bracket distances. All bending tests involve the measurement of angular or linear deflection of an arch wire segment resulting from a bending moment or an applied force. The bending moment and the deflection are represented on the vertical and horizontal axis, respectively, of a graphic plot.

There are several basic properties of orthodontic wires that are determined from the bending test plots[1]:

- The force delivery is the slope of the initial straight line and is the amount of force required for unit activation. This property is termed the stiffness of the wire.
- The yield strength is the property at which small amount of permanent deformation is seen.
- The property elastic range or working range of the wire is the maximum amount of elastic activation before the onset of permanent deformation.
- Wire stiffness or elastic force delivery in turn depends on the composition and structure of the wire alloy, and the wire segment geometry, that is, the cross section, shape and the size of the wire.
- The resistance of a cross section shape to elastic bending is given by the moment of inertia (I).
- The stiffness of an arch wire is inversely proportional to the segment length so that if the length is doubled the wire flexibility will be doubled for the same applied force.
- The modulus of resilience is the total biomechanical energy per unit volume available for tooth movement when the wire is loaded to the maximum elastic stress.
- Springback or the working range is related to the ratio of yield strength (YS) to the modulus of elasticity (E) of the material. Higher springback values provide the ability to apply large activations with a resultant increase in working time of the appliance.

III. Ideal Characteristics Of The Archwires

1. **Esthetics**: No wire today meets this criterion. When coated the wire gets affected by the forces of mastication and enzymatic activity of oral cavity, transparent wires have such poor mechanical properties, that they function as a placebo. Although esthetics is important to the orthodontists but function is of paramount importance.

2. **Biohostability:** It is the ease with which the material will culture bacteria, spores or viruses. Therefore wire should be poor bio-host, i.e. neither actively nurtures nor passively acts as a substrate for growth of micro-organism, which will smell foul, cause colour change or compromise in mechanical properties.

3. **Tough:** It is the property of being difficult to break, tougher the material, stronger it is.

4. **Spring back:** Good spring back values provide with greater range of activation, increased working time of the appliance and a fewer changes and adjustments are required in the archwire.

5. **Stiffness:** Low stiffness provides with the ability to apply lower forces and more constant force over time.

6. **Formability & Resilience:** It provides the ease in bending the wires into loops, coils and stops without fracture.

7. **Biocompatiblity & Environmental stability:** There should be resistance to corrosion for maintenance of desired properties. There should be increased tissue tolerance

8. **Joinability:** Ability to attach auxiliaries to wires by soldering or welding.

9. **Range**: Should be good depending on demand of treatment because it will indicate how far a tooth should be moved with single adjustment.

10. **Friction:** It refers to the friction at the bracket- wire interface. Excess friction will lead to loss of anchorage.

IV. Mechanical Properties And Their Clinical Implications

Stainless Steel Wires:

Stainless steel is the most popular wire alloy used in orthodontics because of an outstanding combination of mechanical properties, corrosion resistance, and cost. The wires used in orthodontics are generally American Iron and Steel Institute {AISI} types 302 and 304 austenitic stainless steels.These alloys are known as “18-8” Stainless steels, so designated because of the percentages of chromium and nickel in the alloy.[4,6,7]

The chromium in the stainless steel forms a thin, adherent passivating oxide layer that provides corrosion resistance by blocking the diffusion of oxygen to the underlying bulk of the alloy. The chromium, carbon, and nickel atoms are incorporated into the solid solution formed by the iron atoms. The nickel atoms are not strongly bonded to form some intermetallic compound, so nickel alloy releases from the alloy surface, which may interfere with the biocompatibility of the alloy.

Research has shown that the modulus of elasticity for stainless steel orthodontic wires ranges from about 160 to 180 GPa. This value depends on the manufacturer and temper, and is indicative of difference in alloy compositions, wire drawing procedures and heat treatment conditions.[10,11,15]

The yield strength of the wire ranges from about 1100 to 15000 MPa. The yield strength can be increased to about 1700 MPa after heat treatment. The yield strength to modulus of elasticity ratio indicates a lower spring back of stainless steel as compared to the newer titanium based alloys. This suggests that stainless steel produces higher forces that dissipate over shorter periods therefore requires frequent activations.[12]

Heat treatment of the wire causes decrease in residual stress and increase in resilience. Heat treatment of stainless steel wires at above 650 ^{0} C must be avoided because rapid recrystalization of the wrought structure takes place, with deleterious effects on the wire properties. Heating stainless steel to a temperature between 400 to 900 ^{0} C causes reaction of the Chromium and carbon to form chromium carbide precipitate at the grain boundaries. Loss of chromium from the iron solid solution matrix results in depletion of chromium content which in turn causes the stainless steel alloy to become susceptible to inter-granular Corrosion.[6,7,10]

Joinability with stainless steel is possible. They can be fused together by soldering and welding. Friction experienced with the stainless steel wires is comparatively low.

V. Cobalt Chromium

The alloy was originally developed by the Elgin watch company of America as a material for the main spring of watches, and was advertised as “The heart that never breaks”. These wires are very similar to stainless steel wires in appearance, mechanical properties, and joining characteristics, but have a much different composition and considerably greater heat response. They are also known as Elgiloy which was developed during 1950’s by the Elgiloy Corporation. The Elgioly wires are available in four tempers depending on there resilience and are colour coded by the manufacturer; Soft { blue}, Ductile { yellow }, Semi-resilient { green } , Resilient { red }.[12]

All the four alloy tempers have the same composition, but difference in the mechanical properties is due to the variation in the wire processing. The soft temper wires {Elgiloy Blue} are popular for use in orthodontics because the wires can easily be manipulated into desired shapes, then heat treated to provide substantially increased values of yield strength. The other tempers are less popular than the soft tempe because wires made from them have low formability and are somewhat higher in cost than stainless steel.

The advantage of thse wires over stainless steel wires includes the greater resistance to fatigue and distortion. In most respect the mechanical properties are similarto that of stainless steel so the stainless steel wires can be used instead of cobalt chromium wires.

They have a high modulus of elasticity suggesting that they deliver twice the force of Beta Titanium and four times the force of Nickel Titanium archwires. The elastic modulus of Elgioly blue ranges from about 160-190 GPa when under tension, while after heat treatment it increases to range from about 180-210 GPa.Similarly the yield strength ranges from 830-1,000 MPa under tension, and 1.100-1,400 MPa after heat treatment.

A common misconception is that Elgioly blue has less elastic force delivery as compared to stainless steel because of the “Feel “of the former. But in reality the values are similar.

Another clinical use of Elgioly blue is fabrication of fixed lingual quad-helix appliance, which produces slow maxillary expansion in the treatment of maxillary constriction.

VI. Nickel-Titanium Wires

Nickel-Titanium alloy marketed as Ninitol by the Unitek Corporation is useful in clinical orthodontics because of its exceptional springiness. The generic name Ninitol which is applicable to this group of nickel titanium alloy originates from Ni-nickel, Ti-titanium, NOL-Naval Ordnance Laboratory. The pioneer for the development of these wires for orthodontics was Andreasen. Two new super-elastic nickel titanium wires were also introduced namely; Chinese NiTi and Japanese NiTi.[4,5,8]

Shape memory is one of the remarkable properties of the NiTi alloys. Shape memory refers to the ability of the material to remember its original shape after being plastically deformed. There are two major NiTi phases in the nickel-titanium wires. The austenitic phase has the ordered body centered cubic structure that occurs at high temperatures and low stresses. The martensitic phase has a distorted monoclinic, triclinic or hexagonal structure that forms at low temperatures and high stresses. The shape memory characteristics of the nickel titanium alloys are associated with a reversible transformation between the austenitic and martensitic phases. The martensitic phase forms from the austenitic phase over a certain transformation temperature range or when the stress is increased above some appropriate levels. The difference in the temperature ranges for the forward transformation from the martensitic phase to the austenitic phase, and for the reverse transformation, is termed Hysteresis. In order for a nickel titanium archwire to possess shape memory, the transformation of the phases must be completed at the temperature of the oral environment.[10,12,14]

Nickel-titanium archwires with Ion-implanted surfaces have been introduced to reduce the archwire-bracket friction. As provided for orthodontic use, Ninitol is exceptionally springy and quite strong but have poor formability. The advantages of these wires can be enumerated as fewer archwires are required to achieve the desired changes, less chair side time, and less patient discomfort. Their poor formability makes them best suited for the pre-adjusted appliance. Placing bends in the wire adversely affects the spring back property of the wire.

Clinical disadvantage of these alloys are that permanent bends cannot readily be placed in the wires and that the wires cannot be soldered.[15,16]

VII. Beta-Titanium Wires

A beta-titanium orthodontic alloy, also called as TMA, which represents” Titanium-molybdenum alloy” is marketed by the Ormco Corporation. The wire has a potential for delivering lower biomechanical forces compared to stainless steel and cobalt-chromium-nickel alloy.[3,4,5]

Beta titanium alloy wires have excellent formability due to there body centered cubic structure. The TMA alloy has the elastic force delivery ranging from about 62-69 GPa, which is less than that of stainless steel wires. Another clinical advantage of the alloy is that it possesses true weldablity. Welded joints that are fabricated from stainless steel and cobalt-chromium-nickel alloys must be built up with the use of solders to maintain adequate strength. The excellent corrosion resistance of the wire is due to the presence of a thin, adherent, passivating surface layer of Titanium oxide. Another important feature of the beta-titanium wires is there absence of nickel that is present in the other major alloy type.[16]

Following are some properties which should be considered by the orthodontists before the clinical use of the wires; Heat treatment by the clinician is not recommended. Solution heat treatment between 700-730 degree C, followed by water quenching, and then aging at 480 degree C results in the precipitation of alpha titanium phase. The beta titanium wires are generally the most expensive of the orthodontic wire alloys, but there advantages like excellent formability, intermediate force delivery, and weldeblity when fabrication of more complex appliances makes them to be used widely in orthodontics. It has been shown that TMA wires have high surface roughness. This surface roughness contributes to the high values of arch wire-bracket sliding friction, along with localized sites of cold welding or adherence of the wire to the bracket slots. However recently developed N+ Ion-implanted TMA wires that have substantially reduced arch wire-bracket friction are available from Ormco or Sybron. [8,10,15]

VIII. Optiflex Arch Wires

They are composed of a Silicon dioxide core which provides the force or resilience to the wire. The silicon resin forms the middle layer which adds strength to the wire and also protects the core from moisture. The outer nylon layer makes the wire taint resistant and also prevents it from damage. These wires provide light continuous forces and are used during the initial aligning phase of orthodontic treatment. To prevent permanent deformations, sharp bends should be avoided during ligation to brackets. They are available in round as well as rectangular cross sections.[10]

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