REVIEW ARTICLE

RECENT ADVANCEMENT IN ORTHODONTIC WIRES: A REVIEW

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ABSTRACT
Orthodontic wires are components of fixed appliances used to carry out the necessary tooth movements as part of orthodontic treatment. A variety of materials like metals, alloys, polymers and composites are used to produce orthodontic wires. The high esthetic demand by the patient, materials used by orthodontist have changed rapidly in recent years and will continue to do so in the future. As esthetic composite arch wire are introduced metallic arch wires will likely be replaced for most orthodontic applications in the same way that metals have been replaced by composites in the aerospace industry., This article reviewed in the order of their development with emphasis on specific properties and characteristics such as strength, stiffness, range, formability, and weldability and their properties along with clinical implications.
Keywords: Orthodontic wire, composite wire, aerospace industry

INTRODUCTION

The aim of orthodontic treatment is to move the teeth to a targeted position by the application of forces to them. An ideal force is the one that produces rapid tooth movement without damage to the teeth or periodontal tissues. Different biological and other factors like the type of movement and tooth size are the important factors to be considered during application of the force, but it is difficult to precisely determine the value of the ideal force[1], orthodontic/orthopedic forces usually range from 01.5-5 N[2,3]. Application of lower forces produces the optimal results and application of excessive force exceeding vascular blood pressure reduces cellular activity in periodontal tissues and slows down or stops tooth movement at least for a period of time[4].

Up till the 1930s, gold was the only orthodontic wire available. Austetenitic stainless steel, with its greater strength, higher modulus of elasticity, good

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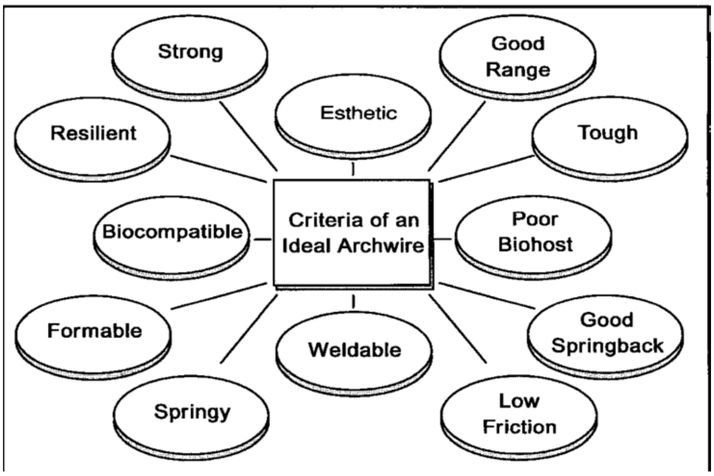
resistance to corrosion, and moderate cost was introduced to the orthodontists in 1929 and within a short span gained popularity over the gold alloy. Since then orthodontics is come a long way. Several alloys like Cobalt – Chromium, Nickel – Titanium, Beta – Titanium, and multistranded stainless steel 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[5].

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, multistranded wires and some recent wires[5].

Criteria of an Ideal Arch wire[6]

1. **Esthetics** : The wire should be least visible in the mouth. This property becomes very important when using ceramic braces. While this is very desirable property but there should be no compromise on mechanical properties.
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. An ideal archwire should poor biohost.
3. **Toug**h : It is the property of being difficult to break, tougher the material, stronger it is. Toughness canbe measured as the total area under the stress – strain graph.
4. **Spring back**: It is the extent to which a wire recovers its shape



after deactivation. 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**: It is basically refers to the resistance of the wire to deformation. Low stiffness provides with the ability to apply lower forces and more constant force over time.
6. **Formability**: This property describes the ease with which a material may be permanently deform. It provides the ease in bending the wires into loops, coils and stops without fracture.
7. **Biocompatibility**: It refers to resistance to corrosion and tissue tolerance to element in wire.
8. **Joinability**: Ability to attach auxiliaries to wires by soldering or welding.
9. **Range**: The distance that the wire bend elastically, before permanent deformation occurs. It 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.

Stainless steel alloy

With the advancement of stainless steel in World War 1 and refinement of drawing process to form wire in the late 1930s, Gold arch wires gradually lost favor to the smaller cross-sectional areas that stainless steel arch wires could provide[7].

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.[8,9]

The austenitic 18-8 stainless steel type is most commonly used. It contains chromium and nickel content of approximately 18% and 8%, respectively. The most important quality of 18-8 stainless steel is its high resistance to corrosion by the formation of a passivated oxide layer, which blocks the further oxygen diffusion to the underlying mass[10]. Carbon content was purposely maintained below 0.02%[11] to reduce the formation of chromium carbides structures that can ultimately faster the corrosion of austenitic steel. Stainless steel wires produce higher forces applied during shorter time periods since they have lower spring back ability

and also store less energy compared to those of beta-titanium or nickel-titanium[12]
Stainless steel wires can be soldered with different biomechanical attachments, using a fastening agent. New welding techniques such as LASER or tungsten inert gas (TIG) are recommended for use in orthodontics without a fastening agent to produce satisfactory results. But, they are too expensive and require the use of sophisticated laboratory equipment[13].

The corrosion resistance of stainless steel is good in general, but releases nickel and chromium in fewer amounts and may induce hypersensitivity reactions[14].

In a study, Kolokitha et al., concluded that orthodontic treatment is not related to an increased likelihood of hypersensitivity reactions to nickel unless there is a history of skin piercing[15].

Stainless steel wires have a lower bracket-wire friction than other types of wires, and this friction can be further reduced by using nanotechnology applications[16].

Australian wires are a kind of stainless steel wires available in different grades with gradually increasing stored energy values (resiliency). These wires contain more amount of carbon content that is up to 10 times higher than that in a standard stainless steel orthodontic wire (up to 0.20%) and this results in increased surface roughness, hardness, porosity, and susceptibility for breakage during clinical bending, particularly for higher grades[17]. So their use is restricted to biomechanical attachments. Recently, super stainless steels have been developed with a lower nickel content, higher corrosion resistance, and improved mechanical properties. These properties have made these wires to be chosen instead of titanium wires since titanium wires are expensive[18].

Cobalt-chromium wires

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 }[19]. High spring tempers (red),
semi spring temper (green), soft or ductile tempers (yellow) are the different types available. They are easy to bend. They can be heat hardened at 482° C for about 7 minutes after manipulation to increase hardness (strength) approximately equal to that of stainless steel. Non-heat treated cobalt-chromium wires have a smaller spring-back than stainless steel wires[20].

These wires have excellent resistance to tarnish and corrosion, are inexpensive and can be soldered (fluoride fluxes are used) and welded. High formability combined with increased elasticity and yield strength following heat treatment by 10% and 20-30%, respectively, have made Blue Elgiloy, a cobaltchromium wire type, popular in clinical practice[21].

NiTi wires

A wrought Ni-Ti alloy known as Nitinol (Nickel-Titanium naval ordinance laboratory) was introduced in 1972[22].

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[23,19,24].

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[25,26].

Beta titanium (TMA)

These wires are also known as titanium-molybdenium alloy (TMA) (ORMCO, Orange, CA, USA) or Titanium- Niobium (ORMCO, Orange, CA, USA), and were introduced in 1979 as an orthodontic wire[27,28].

Modulus of elasticity of these wires is lower than half of stainless steel wires and almost twice that of Nitinol[29,30.]

Advantages of this alloy were several . when compared with nitinol ,TMA was inherently smoother[31], could be welded and had good formability.Moreover when com[ared with stainless steel , TMA produces gentler linaer forces per unit of deactivation and had substantially more range and higher spring back. Indeed, TMA was slmost the perfect wire , since its characteristics were so balanced . Yet TMA , too, had a latent flaw – the *coefficient of friction* were the worst of any orthodontic alloys[32] , and consequently its ability to accommodate the sliding of teeth was limited[33].

Copper NiTi

It was Dr. Rohit Sachdeva who introduced a quartenary alloy of Nickel, Titanium and Copper & Chromium in 1994. This NiTi had both superelastic and shape memory properties. Due to the incorporation of copper these wires have better defined thermal properties than NiTi superelastic wires and showed better control over tooth movement. Wires are available in 3-transition temperatures 27, 35 & 40 degrees[34]. These third generation wires have shape-memory in addition to the low stiffness, high spring back, and super-elasticity of the first and second generation NiTi wires. The temperature range for the transition of martensitic to the austenitic phase forms the basis of the shape memory phenomenon. This was considered too low to be practical for orthodontic treatment earlier. The addition of copper to the alloy increases the transition temperature range approximating the intraoral temperature. This helps the patient to activate and deactivate the arch-wire by rinsing with warm and cold beverages[35].

Super cable arch wires

Super elastic nickel titanium coaxial wire known as ‘supercable’ introduced by Hansen in 1993 united the mechanical advantages of multi stranded cables and the properties of super elastic archwires. These comprises of seven individual strands that are woven together in a long gentle spiral to maximize flexibility and minimize force delivery[36]. Advantages included improved treatment efficiency, simplified mechanotherapy, elimination of archwire bending, flexibility, ease of engagement regardless of crowding, minimal anchor loss, a light continuous force eliminating any adverse response of the supporting periodontium, minimal patient discomfort after initial archwire placement and fewer patient visits due to longer archwire activation periods[34]. But they are not devoid of any disadvantages. The wire ends have a tendency to fray if not cut with sharp instruments. Other disadvantages includes tendency of wires to split and untangle in extraction spaces, inability to create bends, steps, or helices and tendency of wire ends to migrate distally leading to soft tissue irritation as the teeth begins to align[37].

Timolium wires

This is also called Alpha – beta titanium alloy, manufactured by TP Orthodontics[37].These archwires combine the flexibility, continuous force and spring back of Ni-Ti with the high stiffness and bendability of stainless steel wire. Titanium is the major constituent of Timolium with aluminum and vanadium as stabilizing agents. The composition is titanium more than 85%, Aluminum 6.8% and Vanadium 4.2%. Aluminum stabilizes the alpha phase of titanium to room temperature, whereas vanadium stabilizes the beta phase. This alloy contains both stabilizing elements and both alpha and beta phases of titanium alloy and thus display a rare combination of strength and surface smoothness. Surface evaluation by scanning electron microscopy revealed a smooth surface with little surface irregularity for Timolium archwires considerably reducing the friction to a great extent. Though stainless steel with high values for strength,low friction, and smooth surface continues to be most commonly used archwire in orthodontic mechanotherapy, Timolium with its smooth surface, reduced friction, low modulus, and better strength could be also considered as a breakthrough in clinical orthodontic practice[38].

Titanium niobium wires

It was introduced by Dr. Rohit Sachdeva in1995 & is presently manufactured by Ormco.Accordingto manufacturers product information ,Ti-Nb is soft and easy to form and has similar working range of stainless steel. Its stiffness is 20% lower than TMA and 70% lower than stainless steel. Ti-nb wires have a larger plastic range, similar activation and deactivation curves and relatively low spring back. Its bending stiffness is 48% lower than that of stainless steel and a spring back 14% lower than that of stainless steel. Bends can be made easily in this wire and also avoids excessive force levels of a steel wire. The titanium-niobium wires have good weld ability. The stiffness of ti-nb in torsion is only 36% of steel, but the spring back in torsional mode is slightly higher than stainless steel. This property makes the ti-nb wire suitable for even the major third order corrections. The low spring back and high formability of the titanium-niobium arch wire allows creation of finishing bends. Hence, this wire can be used as a finishing archwire[39].

Optiflex archwire

New Orthodontic archwire designed by M.F. Talass[40] in 1992. It combines unique mechanical properties with a highly esthetic appearance.

Structure: Made of clear optical fiber comprises of three layers (Figure):

i. Silicon Dioxide Core: Provides the force for moving teeth

ii. Silicon Resin Cladding: Protects core from moisture and

adds strength and

iii. Nylon Coating: It is stain resistant and prevents damage to the wire and further increases strength.

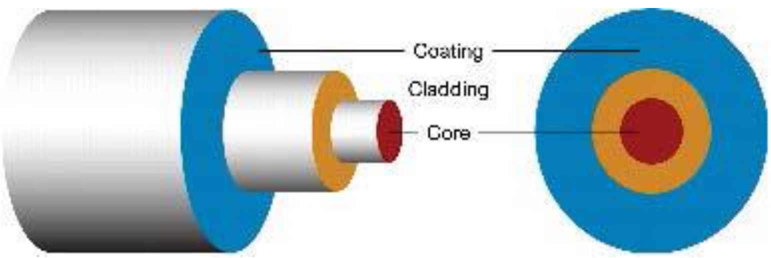


Figure 1: Composition of clear optical fiber: Core – Silicon Dioxide (Silica), Cladding - Silicon Resin (Silane), Coating - Nylon (Nylon 6-6)

Properties:

i. Wide range of action

ii. Ability to apply light continuous forces.

iii. Sharp bends must be avoided since they could fracture the core otherwise optiflex has practically no deformation.

Application: Applications are similar to those of coaxial archwire.

Light continuous force Effective in alignment of High elasticity crowded teeth

Availability: Optiflex (Ormco Corporation) in sizes 0.017” and 0.021”.

Bioforce wires

It was introduced by GAC with the unique property of variable transition temperatures within the same

archwire. They are high aesthetic archwires having a proprietary low-reflectivity rhodium coating giving a white appearance11. These archwires allows graded force delivery by applying low gentle forces to the

anteriors and increasingly stronger forces across the posteriors until plateauing at the molars. The level of

force is thus graded throughout the arch length according to the tooth size. Beginning at around 100g and increasing to 300g, this wire provides the right force to each tooth, reducing the number of wire changes and provides greater patient comfort. They are the first biologically correct arch wires[41].

Combined wires

The anterior portion of combined wire is made of titanal and posterior part is of stainless steel. Titanal is a nickel titanium alloy manufactured by Lancer Pacific. It consists of 3 types. 1. Dual Flex-l, 2. Dual Flex-2, and 3.Dual Flex-3.

The Dual Flex-1: It consists of ananterior section made of 0.016-inch round titanal and a posterior section made of 0.016-inch round steel. At the junction of the two segments, cast ball hooks are present mesial to the cuspids[42].

The Dual Flex-2: It consists of a flexible front segment composed of a 0.016 x 0.022” rectangular titanal and a rigid posterior segment of round 0.018” steel[42].

The Dual Flex-3:This consists of a flexible anterior part of a 0.017 X 0.025-inch titanal rectangular wire and a posterior part of 0.018 square steel wire. The Dual Flex-2 and 3 wires provide anterior anchorage and control molar rotation during the closure of posterior spaces. They also initiate considerable anterior torque[42].

Fiber reinforced composite archwires

Fiber reinforced composite arch wires are fabricated using a procedure called pultrusion. Fiber bundles are pulled through an extruder, in which they are wetted with a monomer resin. Then the monomer is cured with heat and pressure resulting in polymerization. Circular or rectangular wires are formed during curing. This may be shaped into a different morphology by further curing, a process known as beta staging. For this, the monomer should initially only be partially cured. The composite archwires have higher kinetic coefficients of friction than stainless steel but lower coefficients than either Nickel-titanium or Beta-Titanium. At high forces and angulations abrasive wear of the composite surface at the archwire-bracket interface was observed. It can lead to release of glass fibers within the oral cavity, which is unacceptable[43].

Advantages of fiber reinforced composite wires over conventional metal wires are excellent combination of high elastic recovery, high tensile strength, low weight, excellent formability, excellent esthetics because of their translucency, ability to form wires of different stiffness values for the same crosssection which would facilitate the practice of constant cross-section orthodontics. Attachments can be directly bonded to these wires, which eliminate the need for soldering and welding. These wires can also be directly bonded to teeth obviating the need for brackets, in certain situations, e.g. where anchorage from a large number of teeth is required. It is a safer choice for patients with nickel allergy[44,45]. Composite archwires had higher kinetic coefficients of friction than stainless steel but lower than nickel-Titanium or beta titanium. The composite archwire retained sufficient resilience to function during initial stage of orthodontic treatment and also during intermediate stages of orthodontic treatment[43].

Burstone and Kuhlberg introduced a new fiber reinforced composite called "Splint-It" which has S2 glass fibers in a bis GMA matrix. Various configurations such as rope, woven strip and unidirectional strip are available. These materials are only partly polymerized during manufacture, which makes them flexible, adaptable and easily contourable over the teeth. Later they are completely polymerized and can be bonded directly to teeth. It can also be used for various purposes such as post treatment retention, as full arches or sectional arches, and to reinforce anchorage[46].

Teflon coated stainless steel wires

Teflon coating imparts to the wire a hue, which is similar to that of natural teeth. This coating protects the wire from the corrosion process. **Lee white stainless steel** wire has an epoxy coating and is suitable with plastic or ceramic brackets[41].

Marsenol

This is a tooth colored Nickel Titanium wire coated with an elastomeric poly tetra fluroethyl emulsion exhibiting all the same working characteristics of an uncoated super elastic Nickel Titanium wire, manufactured by Glenroe technologies[41].

CONCLUSION

Recent advances in orthodontic wire alloys have resulted in a wide array of wires that exhibit an amazing spectrum of properties. Until the 1930s, the only orthodontic wires available were made of gold. Since then several other materials with desirable properties have been adopted in orthodontics. These include stainless steel, cobalt chromium, nickel-titanium, beta-titanium and composite wires. These wires demonstrate a wide spectrum of mechanical properties and have added to the versatility of orthodontic treatment. Appropriate use of all the available wire types may enhance patient comfort and reduce chair side time as well as the duration of treatment. The individual clinician must always know and understand the needs and options at every stage of therapy. The restricted use of only stainless steel wires to treat an entire case from start to finish, therefore, may be indicated in relatively few cases. It may be beneficial instead to exploit the desirable qualities of a particular wire type that is specifically selected to satisfy demands of presenting clinical situation. This, in turn, would provide most optimal and efficient treatment results.

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