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Research Article

ORTHODONTIC ARCHWIRES: PAST, PRESENT AND FUTURE (REVIEW PART 1)

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A R T I C L E I N F O A B S T R A C T

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Aim- The aim of this review is to discuss about the orthodontic wires from its evolution to future.Also, to discuss in detail about their mechanical, physical properties and clinical applications.
Background- 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. Various laboratory tests are performed to evaluate the properties of the archwires. However, oral conditions may influence their behavior and it is important for the clinician to understand the properties of orthodontic wires as well as their clinical implications to achieve optimal results. This article reviews different materials used for manufacturing orthodontic wires and their properties along with clinical implications.

INTRODUCTION

Orthodontic wires which generate the biomechanical forces communicated through brackets for tooth movement, are central to the practice of profession.In the rational selection of wires for a particular treatment,the orthodontist should consider a variety of factors,including the amount of force delivery that is desired,the elastic range or springback,formability and the need for soldering and welding to assemble the appliance.Currently, orthodontists principally use wires of four major base metal alloy types: stainless steel, cobalt-chromium-nickel, nickel-titanium and β-titanium.With the need to maintain a relatively large inventory, orthodontists must be concerned with the costs of wires, which can vary considerably among wire alloys as well as among companies that distribute these products.

The purpose of this article is to review the available literature pertaining to a wide range of archwires and compile the knowledge to facilitate choice of archwire at a particular stage of orthodontic treatment. Future of orthodontics lies in esthetic treatment which involves the use of esthetic wires. Since there are variety of archwires at the clinician's disposal, this review will be completed in two parts to provide with a complete overview.

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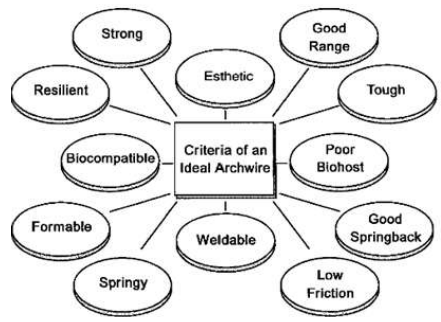
***Criteria of an ideal archwire*[1]**



***Manufacturing of orthodontic wires*[2]**

Metallic orthodontic wires are manufactured by a series of proprietary steps, typically involving more than one company.

Ingot: Initially the wire alloy is cast in the form of an ingot which must be subjected to successive deformation stages until cross section becomes sufficiently small for wire drawing.

Rolling: The first mechanical step is rolling the ingot into a long bar. This is done by series of rollers that gradually reduce the ingot to a relatively small diameter.Considerable work hardening of the alloy occurs during rolling. It may fracture if rolling is continued beyond this point.

To Prevent This:Rolling process is interrupted. Metal is **annealed**by heating to a suitably high temperature.

Drawing:After ingot has been reduced to a fairly small diameter by rolling, it is further reduced to its final size by drawing. Before it is reduced to orthodontic size, a wire is drawn through many series of dies and annealed several times along the way to relieve work hardening.

Rectangular wires

Rectangular cross section wires are fabricated from round wires by a rolling process using TURK'S HEAD apparatus having two pairs of rollers positioned at right angles. Rectangular or square cross section wires – have some degree of rounding at corners. (figure 1)

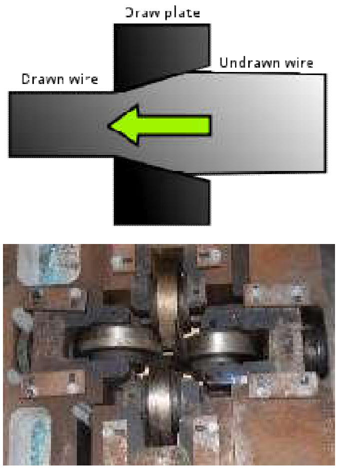


Figure 1 Manufacture of rectangular wires

Evolution of orthodontic archwires

The Early Archwires

(German Silver and Piano Wires)

Before Angle began his search for new materials, orthodontist made attachment from noble metals and their alloys gold (at least 75%, to avoid discoloration), platinium, iridium, and silver alloys were esthetically pleasing and corrosion resistant, but they lacked flexibility and tensile strength. These alloys also were inappropriate for complex machining and joining when used in the traction bars of the time. In 1887, Angle tried replacing noble metals with German silver, a brass. An accomplished metallurgist, Angle knew that he had to preparetheGermansilveraccordingtotheuseforwhich it was intended. 'To obtain the desired properties, Angle acted, as stated in 1888, 'by varying the proportion of Cu, Ni and Zn' around the average composition of the Neusilberbrass (Germansilver,65% Cu,14%Ni,21%Zn), as well as by applying cold working operations at various degree of plastic deformation.[3] As a result, ANGLE made German silver rigid enough for jack and traction screws, elastic enough for expansion arches, or malleable enough for bands.

Gold Wires

They come under precious metal alloys. Until 1930's the only orthodontic wires available were made of Gold and their alloys primarily because nothing else would tolerate intraoral conditions. Gold in its pure state is very soft, malleable and ductile.[1] Modulus of elasticity—96,500 to 1,17,200 MPa which is slightly higher than that for gold casting. It increases approximately 5% after hardening heat treatment.Gold alloys are esthetically pleasing, excellent Corrosion resistance, low proportional limit.NowadaysuseofGoldisgreatlyreduced because it is too soft to use as an ortho appliance high costand becauseofrecentadvancesinwirematerials and mechanical properties of thesame.

1940: With the substantial rise in the cost of gold, Austenitic stainless steel began to displace gold. In early 1940's Begg partnered with Wilcock to make what they envisioned to the ultimate in resilient orthodontic wires – AUSTRALIAN STAINLESS STEELS. By 1960s gold was universally abandoned in favor of stainless steel.

1960: Cobalt–Chromium alloys were introduced. Their physical properties were very similar to stainless steel. However, they had the advantage that they could be supplied in softer and more formable state that could be hardened by heat treatment

1962: Buehler discovers Nitinol at Naval Ordinance laboratory.

1970: Andreasen brought this intermetallic composition of 50% Ni and 50% Ti to orthodontics through University of Iowa. **Unitek company** licensed the patent (1974) and offered a stabilized martensitic alloy that does not exhibit shape memory effect under the name NITINOL.

1977: Beta titanium was introduced to orthodontic profession by C.J **Burstone**and **Jon Goldberg.** This beta titanium alloy had a modulus closest to that of traditional gold along with good springback, formability and weldability.

1984: Mr. A.J Wilcock Jr. as per request of **Dr. Mollenhauer** of Melbourne Australia resulted in production of Ultra high tensile stainless steel round wires – The SUPREME GRADE.

1985: Burstone reported of analloy, Chinese NiTi developed by **Dr. Tien Hua Cheng** and associates at the General Research Institute for nonferrous metals in Beijing china.

1986: Miura *et al*reported on Japanese NiTi, an alloy developed at Furukawa Electric Company Limited Japan in **1978**.

1988: Mr. A.J Wilcock Jr. developed much harder- Alpha Titanium archwires.

1990: Neo-Sentalloy was introduced as a true active martensitic alloy.

1992: Optiflex a new Orthodontic archwire – developed by **M.F Talass-** Combined unique mechanical properties with a highly esthetic appearance.

1994: Copper NiTi, a new quaternary alloy containing Ni, Ti, Cu and Cr was invented by **Dr. Rohit Sachdeva**. Displays phase transition at 15 ° C ,27° C, 35° C, 40°C.

2000: Titanium Niobium – an innovative new arch wire designed for precision tooth to tooth finishing reported by **Dalstra*et al.*** Additional progress in orthodontic archwire materials including esthetic wires is being made.

Gold Alloys

1. Popular till 1940's
2. Noble metal
3. Type IV commonly used
4. Composition:

Gold	55-65%
Copper	11-18%
Silver	10-25%
Platinum	5-10%
Palladium	5-10%
Nickel	1-2%

Advantages

1. Good formability.
2. Inert
3. Biocompatible
4. Easily joined by soldering.
5. Excellent corrosion resistance.
6. Can be heat treated to variable stiffness (30%), which is comparable to today's beta-titanium alloy.

Disadvantages

1. High Cost.
2. Low yield strength ($50 \times 10^3 – 160 \times 10^3$ psi)
3. Limited springback

Uses

Only the Crozat appliance is still occasionally made from gold following original design of early 1900s.

Stainless Steel

Iron based alloysthat usually contain less than 1.2%carbon.

***Classification*:**Steels are classified according to the

American Iron and Steel Institute (AISI)system

Three types of stainless steel

1)	Ferritic
2)	Austenitic
3)	Martensitic

Ferrite: (α - iron)

1. Pure iron has body centered cubic (BCC) structure at room temp
2. Stable upto 912° C.
3. Carbon has a very low solubility in ferrite (0.02 wt %) – because spaces between atoms in body centered cubic structure are small and oblate.

Austenite: (γ - Iron)

1. Face centered Cubic (FCC) structure.
2. Exists between 912° C - 1394°C.
3. Maximum carbon solubility of 2.1 weight %.

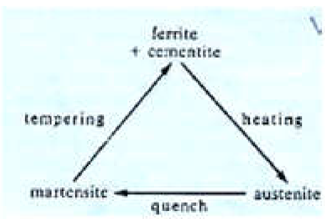
Martensite

1. When Austenite is cooled rapidly (quenched) it undergoes a spontaneous transformation to Body Centered tetragonal (BCT) structure.
2. Highly distorted and strained lattice.
3. Hard, strong, brittle.

Tempering

This process results in decreased hardness and increased toughness.

Martensite —Heat Treatment (525° C)→ Ferrite + Carbide



Composition and Types of Stainless Steel

1. Steel + 12-30% Chromium → STAINLESS STEEL
2. When at least 10-12% Chromium is present.A Coherent oxide layer formed that passivated the surface rendering the alloy **'STAINLESS'**

TYPE (Space lattice)	CHROMIUM	NICKEL	CARBON
Ferritic (BCC)	11.5 – 27	0	0.20 max.
Austenitic (FCC)	16 –26	7 – 22	0.25 max.
Martensitic (BCT)	11.5 – 17	0 – 2.5	0.15 – 1.20
BALANCE is Iron			

Ferritic Stainless steels – AISI 400 series

1. Provide good corrosion resistance at a low cost provided that high strength is not required.
2. Not readily work hardenable.
3. Finds little application in dentistry.

Martensitic Stainless steels – AISI 400 Series

1. High strength and hardness.
2. Less corrosion resistant and less ductile.
3. Used for surgical and cutting instruments

Austenitic Stainless Steel – AISI 300 series

1. Most used for orthodontic materials. Most corrosion resistant of the stainless steels.
2. Three Types:

AISI 302
AISI 304
AISI 316 L

AISI 302:18% Chromium, 8% Nickel, 0.15% Carbon, balance iron

AISI 304: Similar Composition. Chief difference → Carbon content (0.08%)

Both 302 and 304 stainless steel are designated as **18-8 stainless steel**.

Type 316 L: 'L'→ Low Carbon Content. Carbon content → 0.03% max. carbon. Used for implants.

Austenitic Stainless Steels

1. The addition of nickel to the iron-chromium-carbon composition stabilizes the austenite phase on cooling.
2. Type 18-8 stainless steel, which contains 18% chromium and 8% nickel by weight, is the most commonly used alloy for orthodontic stainless-steel wires and bands.

Austenitic stainless steel is preferable to ferritic stainless steel for dental applications because it has the following properties

1. Greater ductility and ability to undergo more cold workwithout fracturing
2. Substantial strengthening during cold working (sometransformation to martensite)
3. Greater ease of welding
4. Ability to overcome sensitization

5. Less critical grain growth
6. Comparative ease of forming

General properties of stainless steel

Stiffness:Relatively stiff material

1. Stiffness altered by altering carbon content, cold working and annealing.
2. Produce high forces which dissipate over a short amount of deactivation. Can be used in later stages of treatment, to maintain tooth position.

Spring back:lower spring back than those of newer titanium-based alloys.

Cannot be deflected to a greater extent

Resilience or stored energy:less than that of Beta titanium and Nitinol wires.

Clinical Relevance: SS wires produce higher forces that dissipate over shorter periods of time than either beta titanium or nitinol wires, thus requiring more frequent activation or archwire changes.

Formability: Excellent formability

***Weldability:* C**an be soldered, welded.

Friction:Low levels of bracket / wire friction have been reported with experiments using stainless steel wires. This signifies that stainless-steel arch wires are the ideal choice during space closure with sliding mechanics

Various sizes and cross sections

1. Round → 0.012, 0.014, 0.016, 0.018, 0.020 etc.
2. Rectangular → 0.016x0.022, 0.017x0.025, 0.018x 0.025, 0.019x 0.025 etc.
3. Square → 0.016 x 0.016, 0.017 x 0.017

Sensitization of 18-8stainless steel**:**18–8 stainless steel may lose its resistance to corrosion if it is heated b/w 400° C-900°C. The reason for decrease in corrosion resistance is:

1. Precipitation of Chromium Carbide (Cr_3 C) at the grain boundaries.Formation of Cr_3C is most rapid at 650°C. Chromium is depleted adjacent to grain boundaries.
2. When chromium combines with carbon its passivating qualities are lost. Chromium is depleted adjacent to grain boundaries. Alloy becomes susceptible to intergranular corrosion.

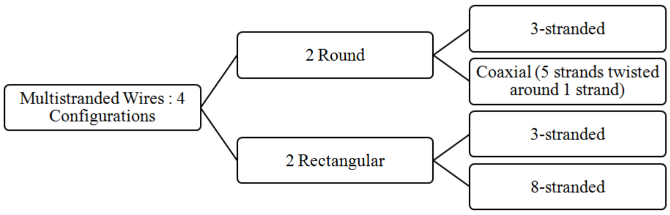
Stabilization of stainless steel

Objective:To make Carbon unavailable for sensitizing action

1. Introduction of some element that precipitates as a carbide in preference to chromium.
2. e.g- Titanium.
3. Titanium is introduced in an amount approximately six times the carbon content.
4. Stabilized steel is less susceptible to Intergranular corrosion, but it is still not 100% safe.

Multistraned Stainless Steel Wires

1. Composed of specified number of thin wire sections coiled around each other to provide round or rectangular cross section.
2. Improved strength,stiffness and range.



Advantages

1. Flexible
2. Sustain large deflections
3. Apply lower forces when deflected
4. Good working range

Clinical applications

1. Can be alternative to more expensive titanium wires for initial levelling aligning.
2. Braided rectangular steel wires are available in variety of stiffness and the stiffest of theseis 0.021 x 0.025 – useful in 0.022 slot for finishing.

Australian Arch Wires[4,5,6]

Mainstay of Begg technique.In 1940, **Dr. Begg**met **Mr. Arthur J. Wilicok Sr**. of Whittlesea, Victoriawho was directing metallurgical research projects at University of Melbourne.After many years of research and development Mr. Wilcock produced high tensile wires that combined the balance between hardness and resiliency with unique property of zero stress relaxation.

Various grades

1. Regular(white)
2. Regular plus(green)
3. Special(black)
4. Special plus(orange)
5. Premium(blue)
6. Premium plus(blue)
7. Supreme(lavender)

RegularGrade

1. Lowest grade and
2. easiest to bend.
3. Used for practice bending and auxiliaries.
4. Can be used when arch form distortion and bite opening is not required

Regular plus Grade

1. Relatively easy to form
2. More resilient than regular
3. Used for making auxiliaries
4. Used for making an archform when more pressure and resistance to deformation is required.

Special Grade

1. 0.016 is often used asstarting arch wire in many techniques.
2. Highly resilient.
3. Can be formed to intricate shapes with little danger of breaking.

Special plusGrade

1. Hardness and resiliency of 0.016 is excellent for supporting anchorage and reducing deep overbites.

2. Must be bent with care.
3. Chances of fracture is more.

Recent advances in Australian wires

1. New series of wire grades and sizes.
2. The fundamental difference for the superior properties for these new wires is use of new manufacturing process called pulse straightening.

Wires are straightened by use of 2 processes

1. Spinner straightening.
2. Pulse straightening.

Spinner straightening

1. Mechanical process of straightening materials usually in cold drawn condition.
2. Wires are straightened by process of **reverseStraining.**
3. Flexing in a direction opposite to that of original bend. (This is what is done manually in clinical setting).
4. In conventional manufacturing wire is pulled through high speed rotating Bronze rollers or spinners which torsionally twist the wire into straight condition. This process is called as work softening due to reverse straining or bauschinger effect.

Disadvantage

1. Resultant deformation.
2. Decreased yield strength in tension and compression as compared to that of the "as drawn" material.

***Pulse straightening**: (figure 2)*

1. This process was developed to overcome the mentioned difficulties.
2. The wire is pulsed in special machines that permit high tensile wires to be straightened.

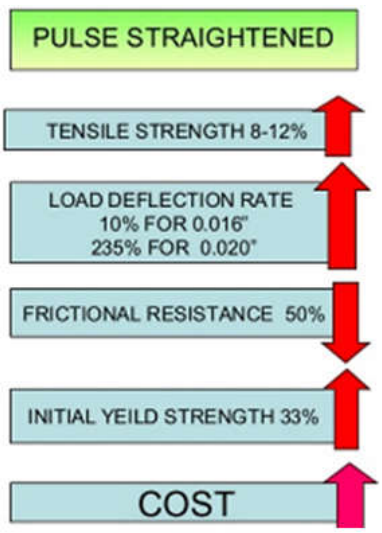


Figure 2 Factors associated with pulse straightening

Has several advantages over other straightening methods

1. Permits higher tensile wires to be straightened.Material yield
2. strength is not diminished in any way.
3. Wire has smoother surface and hence less bracket friction.
4. Available in

Special plus
Premium
Premium plus
Supreme

Availability of newer wires

WIRE SIZE (INCH)	.008	.009	.010	.011	.012	.014	.016	.018	.020
PREMIUM	*	*	*	*	*	*	*	*	*
PREMIUM PLUS	*	*	*	*	*	*	*	*	
SUPREME	*	*	*	*					

Properties:**Higher yield strength** of newer grade wires influences following properties:

1. ***Springback (YS/E):***Better springback than lower grade wires. It can be deflected more without deformation.
2. ***Resiliency:***Greater resiliency
3. ***Zero stress relaxation:***Ability of wire to deliver a constant force over long periods when subjected to an external load. Newer wires maintain their configuration over long periods against deforming forces (forces of occlusion).
4. ***Formability:***Lesser formability. More brittle than lower grade wires, need to be bent in specific way.

Clinical usage of new grades of Australian wires

When relatively high load deflection rate is required

For generating relatively lighter forces in stage I (for incisor intrusion and lateral contraction or expansion of post teeth).

- 0.016 or 0.018 Premium + or Premium wires are used.

Large resistance to deformation is required. e.g: Maintaining arch from

- 0.018 Premium + or Premium or 0.020 Premium wires are indicated.
- Similarly, for overcoming undesired reactions of a torquing auxiliary or uprighting springs in IIIrd stage-0.020 Premium wire is employed.

When a low load deflection rate is required

Supreme grade arch wires of sizes 0.008 – 0.011 are used for

1. Unravelling of crowded anterior teeth.
2. MAA (Mollenhauer aligning auxiliary)
3. Miniuprighting springs.

0.010 Supreme: Used to form Reciprocal torquing auxiliaries.

0.011 /0.012 supreme: Used for aligning second molars towards and of stage III.

0.012 Supreme: Torquing Auxiliary in stage III because of its high resiliency and springback.

Method of bending Australian wires: Warm the wire by pulling through fingers before bending because these wires have a ductile brittle transition temperature slightly above room temperature.Bend the wire around square beak of birdbeak pliers. (figure 3)

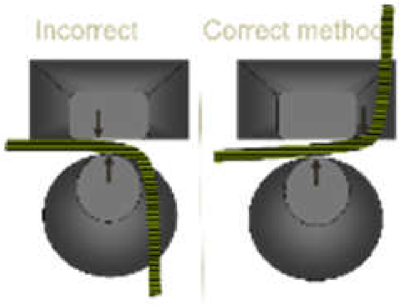


Figure 3 Bending Australian wires

Recent advances in stainless steel metallurgy

Nickel free stainless steel

Composition

1. Stainless steel is fabricated in a high-pressure melting process where Manganese and Nitrogen replace allergic components of Ni.
2. Ideal for Ni sensitive patient.
3. Corrosion resistant and durable.

15 – 18%	Chromium.
3 – 4%	Molybdenum
10 - 14%	Manganese.
0.9 %	Nitrogen – To compensate for Ni.

Orthodontic wires: **Menzanium** (Scheu Dental), **Noninium** (Dentaurum)

Cobalt Chromium Arch Wires[2,7]

1. Patented in 1950's by Elgin National Company as the mainspring of their analog watch.
2. Originally used for watch springs. It was marketed as **ELGILOY** by Rocky Mountain Orthodontics.

Types of elgiloy: Manufactured in 4 tempers

1. Soft (blue)
2. Ductile (yellow)
3. Semiresilient (green)
4. Resilient (red)

Cobalt	40%
Chromium	20%
Nickel	15%
Iron	15.8%
Molybdenum	7%
Manganese	2%
Carbon	0.15%
Beryllium	0.04%

Composition

Blue Elgiloy

1. It can be bent easily with fingers and pliers.
2. It is recommended for use when considerable bending, soldering, or welding is required.
3. Heat treatment of blue Elgiloy increases its resistance to deformation.

Yellow Elgiloy

1. Relatively ductile and more resilient than blue elgiloy.
2. It can also be bent with relative ease.
3. Further increase in its resilience and spring performance can be achieved by heat treatment.

Green Elgiloy

1. More resilient than yellow elgiloy
2. can be shaped with pliers before heat treatment.

Red Elgiloy

1. Most resilient of elgiloy wires
2. Careful manipulation with pliers is recommended when using this wire because it withstands only minimal working.
3. Heat treatment makes red Elgiloy wire extremely resilient.
4. Since this wire fractures easily after heat treatment, all adjustments should be made before this precipitation hardening process.

***Heat treatment*: (figure 4)**

1. At that time practitioners particularly welcomed the formability before heat treatment in order to bend loops into wires and to enhance the working *ranges* of their otherwise somewhat rigid appliances.
2. Once the appliance was fabricated, however, the practitioner no longer required the formability. Instead, he or she desired resilience in order to capitalize on the inherent elasticity of the material.
3. **Precipitation hardening**[1]heat treatment increased the ultimate strengthand resilienceof these arch wires without changing the stiffness.
4. Clinicians can easily perform heat treatment using an electrical resistance welding apparatus and a special paste provided by the manufacturer to indicate the optimal period.
5. Alternatively, furnace heat treatment at approximately 480 °C for 7 to 12 minutes can be employed.

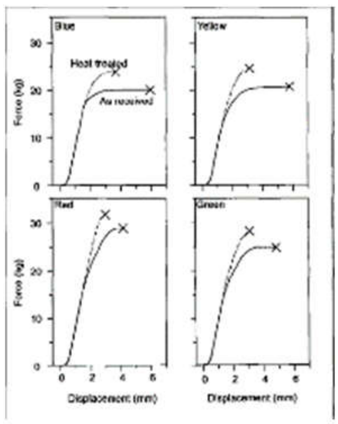


Figure 4 Influence of heat treatment on the ultimate strength and resilience of cobalt chromium alloys

Properties:[7]

*- soldered with some difficulty
+ - blue and yellow eligiloy only

Springback	*Stiffness*	*Formability*	*Stored energy*	*Biocompatibility and environmental stability*	*Joinability*	*Friction*
Low	High	Good	Low	Good	*Soldered +welded	Low-moderate

Advantages of Co-Cr wires over stainless steel wires:[7]

1. Greater resistance to fatigue and distortion
2. Longer function as a resilient spring.
3. In most other respects, the mechanical properties of Co-Cr wires are very similar to those of stainless-steel wires.
4. The high moduli of elasticity of Co-Cr and stainless-steel wires suggestthat these wires deliver twice the force of beta-titanium wires and four times the force of nitinol wires for equal amounts of activation.
5. The resultant undesired force vectors are therefore greater with Co-Cr and stainless-steel wires than with both types of titanium alloys.
6. Clinically, this may translate into faster rates of mesial movement of posterior teeth, thus placing greater demandson intraand extraoral anchorage.
7. Co-Crandstainless-steel wires have good formability and can be bent into many configurations relatively easily.
8. Caution should be exercised when soldering attachments to these wires since high temperatures cause annealing with resultant loss in yield and tensile strengths.
9. Use of Low-fusing solder is recommended for this purpose.
10. Because of the "soft feel" (low YS) during manipulation, Orthodontists can mistakenly believe that the as-receivedelgiloy blue wires have substantially lower elastic force delivery than stainless steel wires.
11. But in reality, they have similar force delivery and joining characteristics.

Clinical applications:[2]

1. Elgiloy: Easier to bend than SS, NiTi and β-Ti in its "as received state".
2. Preferred in techniques in which loops are used.
3. Ideal and economical finishing wire.
4. Utility arches
5. Quad helix

Alpha and Beta-Titanium Alloys[1,2,8]

Commercially pure titanium (CP Ti) exists in a stable hexagonal closed packed crystal structure at temperatures below 882 °C and a stable body centered cubic structure above that temperature. These structures are referred to as α-titanium and β-titanium, respectively.

Titanium	88.9%
Aluminum	7.86%
Vanadium	4.05%

Alpha Titanium

Developed by **A.J Wilcock Jr**.

Composition

1. Less ductile than beta titanium owing to the hexagonal closed packed structure.
2. At oral temperature (37 degree C) it tends to harden by absorbing intraoral free hydrogen ions to form Ti hydride therefore becoming brittle.

Clinical Application

1. Rectangular wires in the sizes of 0.022" x 0.018" (ribbon mode) or 0.020" x 0.020" (square) can be used for finishing stage.
2. Braking mechanics in the second stage of Begg treatment- anterior ribbon (0.022"x0.018") and posterior round (0.018").

Beta Titanium

1. In 1980,**Burstone and Goldberg** developed Beta titanium alloy for orthodontic use.
2. Sold as TMA wire (Titanium Molybdenum Alloy) – By Ormco Corporation.
3. For orthodontic use,one of Dr.Burstone's primary objectives was to produce an alloy whose deactivation characteristics were about one-third that of stainless steel or twice that of a conventional martensitic stabilized nitinol.
4. This led to Ormco Corporation's introduction of the low stiffness beta-phase titanium-molybdenum alloy known as TMA

Titanium	77.8%
Molybdenum	11.3%
Zirconium	6.6%
Tin	4.3%

Composition

1. Molybdenum: stabilizes body centered cubic lattice structure beta phase.
2. Zirconium and tin: increases strength and hardness.
3. Titanium: passivating effect.

Properties:[9]

1. ***Stiffness:***β-titanium has modulus of elasticity which is less than ½ that of stainless steel and approximately twice that of Nitinol. Its stiffness makes it ideal in applications where less force than steel is required but where lower modulus materials would be inadequate to develop required force magnitudes. Full bracket engagement and a resultant greater torque control than smaller stainless-steel wire.
2. ***Spring Back:***β-titanium can be deflected twice as much as SS wire without permanent deformation.
3. ***Formability:*** It has been shownthat the formability of the beta titanium orthodontic wire, is like that of stainless steel. However, the titanium alloy cannot be bent over as sharp a radius as stainless steel, so that some care in the selection of pliers and bending procedures is required.
4. ***Corrosion Resistance:***titanium dioxide has passivating effect.
5. ***Friction:***Demonstrate highest levels of friction.As titanium content of alloy increases its surface reactivity increases.
6. ***Weldability:***The β-titanium wires are the only orthodontic wire alloy type that demonstrates true weldability, and clinically satisfactory joints can be made by electrical resistance welding. Such joints need not be reinforced with solder, which is necessary for welded joints in stainless steel and Elgiloy wires. Titanium alloys are highly reactive with oxygen at high temperature. Because of their high melting temperatures

and this reactivity, soldering of these alloys with torches is not advisable. To prevent the potential reaction of titanium alloys with the oxygen in ambient air during the metal joining process, these procedures are often performed in a vacuum or in an argon environment.

7. ***Heat Treatment:*** Not recommended for TMA wire by the clinician. Heat treatment by the manufacturer between 700 °C to 730 °C followed by water quenching yields a nearly all-beta microstructure. Recent research has shown that Ti-15V-3Cr-3Al-3Sn β-Titanium may have improved formability and springback, but this new alloy does not seem to have commercial application.

Advantages of TMA over Nitinol: [1]

1. Smoother
2. Can be welded
3. Good formability

Advantages of TMA over stainless steel:[1]

1. Gentler linear forces per unit of deactivation
2. More range
3. Higher spring back
4. **Drawback:** High coefficient of friction

Ion implantation:[8]

1. The surface roughness of the TMA wires is much greater than that of the stainless steel and Elgiloy wires.
2. Surface treatment of nickel-titanium and beta-titanium orthodontic wires with nitrogen ion implantation has been performed to decrease adhesion between wires and brackets.
3. Additional research is required to ascertain whether hard titanium nitride near-surface phases are formed during ion implantation.

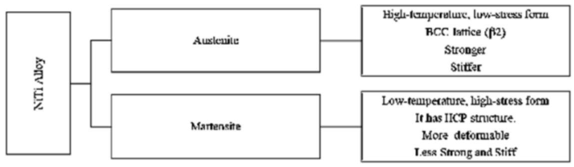
Clinical Application:[9]

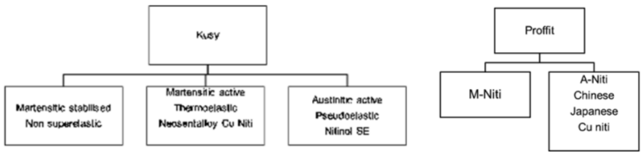
1. Greater range of action for either initial tooth alignment or finishing arches.
2. Beta titanium is ductile, which allows for placement of tie-back loops or complicated bends.
3. Formed into arches or segments with complicated loop configurations.
4. Springs or auxiliaries
5. Unique in comparison to commonly used orthodontic wire in that it allows direct welding of auxiliaries to an arch wire without reinforcement by solder.

Nickel Titanium Wires:[2]

1. Invented in early 1960's by **William F. Buehler**-research metallurgist at the Naval Ordinance Laboratory.
2. Around 1970, **Dr. George Andreasen** recognized the potential of this alloy.
3. Largely through his efforts and those of the Unitek Company, the first nitinol alloy was marketed to Orthodontists as Nitinol™.
4. The alloy name "Nitinol" originally came from the two elements nickel (Ni) and titanium (Ti) and the **Naval Ordnance Laboratory** (NOL) where these alloys were developed.
5. It has much lower elastic modulus and much wider elastic working range than those of stainless steel and Co-Cr-Ni wires.
6. Ironically, this first 50:50 composition of nickel and titanium was a shape memory alloy in composition only.
7. Indeed, this alloy was passive, as the SME had been suppressed by cold working the wire during drawing to more than 8 to 10%. (martensite- stabilized alloys).
8. Attractive about this alloy- low stiffness, light force, springy, equal loss of force per unit deactivation.
9. Later the drawback was realised-low fomability which remains today.
10. Nickel Titanium exhibits two unique properties: related to phase transition within NiTi alloy that occur at relatively low TTR.

1. Shape memory (SME)
2. Superelasticity (SE)





Shape Memory:Ability of a material to 'remember' its original shape after being plastically deformed while in the martensite form.Through deflection and repeated temperature cycles, the wire in austenitic phase is able to memorize a preformed shape including specific orthodontic arch forms.

Shape memory process/ Twinning*:* The austenite crystal is stable at a higher temperature and can be plastically deformed to some desired shape without altering its crystalline structure. When austenite is cooled to room temperature, it converts to a twinned martensite without undergoing a shape change. When the twinned martensite is deformed plastically under a stress, the structure detwins and takes up a new shape. Note that the overall shape of the object has changed but the relative position between atoms did not change. Upon heating to body temperature (for orthodontic wire), the deformed martensite (detwinned martensite) will revert back to austenite and regain its original shape, since there is no change in the relative position of the atom arrangement. Heating of twinned martensite will also recover the austenite structure. (figure 5)

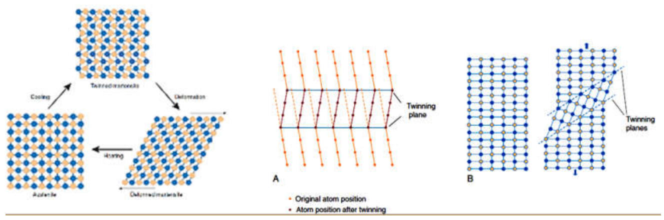


Figure 5 Twinning

Superelasticity: is when one deforms the alloys at a temperature above the transformation temperature. Above the transformation temperature, the material is in the high temperature or austenitic phase. When stress is applied, the deformation causes a stress-induced phase transformation from austenite to deformed martensite. When the applied stress is removed, the material immediately springs back, and the crystal form returns to the austenite phase. (figure 6)

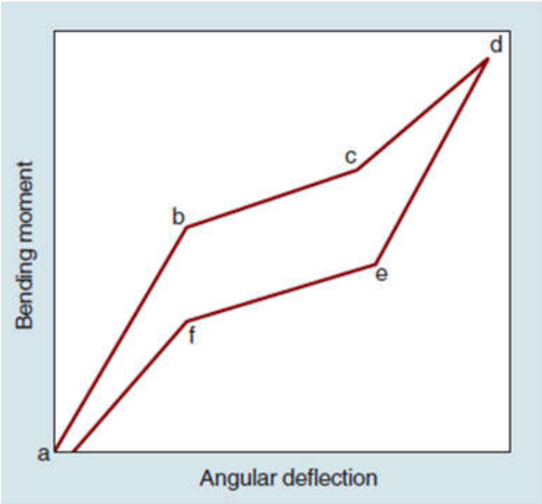


Figure 6 A small amount of permanent angular deflection remains in the wire because of the permanent deformation induced in segment c-d. This phenomenon is called superelasticity or pseudoelasticity in engineering materials science.

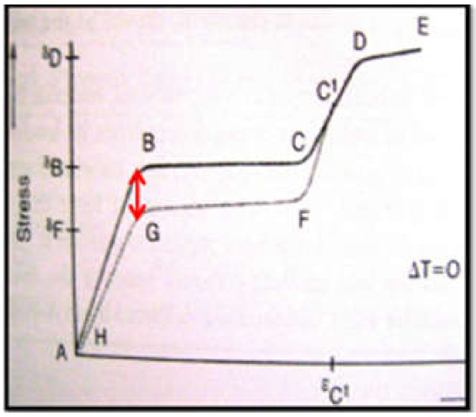


Figure 7 Hysteresis

Hysteresis

Linear region corresponding to the deactivation plateau and is lower than activation plateau i.e. reversibility has energy loss associated with it.

Clinical importance: force delivered to periodontal structures is lower than the force necessary to activate it.

Martensitic Stable: Nitinol and other nonsuperelastic NiTi[2] Substantial quantity of heavily cold worked and Martensitic stable. The A_s temperature are much higher than the room temperature and oral environment temperature. The martensitic-stabilized alloys do not possess shape memory or superelasticity, because the processing of the wire creates a stable martensitic structure. These are the nonsuperelastic wire alloys such as Nitinol.M-NiTi remains useful, primarily in the later stages of treatment when flexible but larger and somewhat stiffer wires are needed.

Martensite Active: Shape memory NiTi[2]

The martensitic-active alloys employ the thermoelastic effect to achieve shape memory. This thermoelastic shape memory can be observed by the clinician if a deformed archwire segment is warmed in the hands. A_f temperature below the temperature of oral environment, so that wires have austenite structure completely in-vivo. These are the shape-memory wire alloys such as Neo Sentalloy and Copper Ni-Ti.

Austenitic Active: Superelastic NiTi[2]

The austenitic-active alloys undergo a stress-induced martensitic (SIM) transformation when activated. These alloys display superelastic behavior (termed pseudoelastic in the materials science literature). Does not exhibit thermoelastic behavior when a deformed wire segment is warmed in the hands. These alloys are the superelastic wires that do not possess thermoelastic shape memory at the temperature of the oral environment, such as Nitinol SE.

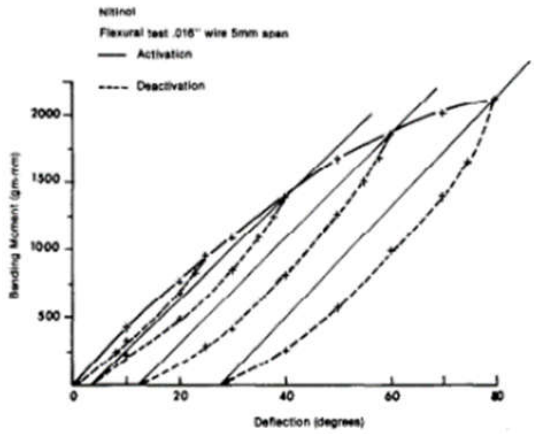


Figure 8 Activation and deactivation curves for nitinol wire. The average unloading stiffness is the same for all activations.[10]

Properties:[7]

:j: - some corrosion and failures noted

Springback	*Stiffness*	*Formability*	*Stored energy*	*Biocompatibility and environmental stability*	*Joinability*	*Friction*
High	Low	Poor	High	:j:	Not joinable	Low-moderate

1. ***Springback and Flexibility****:* Excellent with low stiffness.
2. ***Formability:***poor formability. Bending of loops and stops in nitinol is not recommended.
3. ***Biocompatibility****:* some concern
4. ***Joinability:***Not joinable. Since hooks cannot be bent or attached to Nitinol, crimpable hooks are recommended for use.
5. ***Corrosion Resistance:***Corrosion resistance feature of NiTi alloys is due to presence of large proportion of Titanium (48% - 54%). Titanium dioxide forms a thin film that protects the metal. Irregularities on surface of Nitinol wires produced by manufacturing process predisposes wire to corrosive attack in mouth and not due to corrosion of alloy.[11]
6. ***Friction:***Noted that bracket wire frictional forces with nitinol wires are higher than those with stainless steel wires and lower than those with β-titanium, in 0.018 slot.In 0.022 slot, NiTi and β-titanium wires demonstrated similar levels of friction.NiTi has greater surface roughness.[12,13]

Cinch backs:By flame annealing/ resistance annealing the end of wire. This makes the wire dead soft and it can be bent into the preferred configuration. **A dark blue color indicates the desired annealing temperature**.Care should be taken not to overheat the wire because this makes it **brittle(cherry red color- overheat).**

Limitations

1. By its very nature nitinol is not a stiff wire which means that it can easily be deflected.
2. Low stiffness of nitinol provides inadequate stability at completion of treatment.
3. Expensive
4. Poor formability.
5. Poor joinability.
6. Biocompatability

Chinese Niti[10]

1. Developed by**Dr. Tien Hua Cheng and associates** at the General Research Institute for Non-Ferrous Metals in Beijing, China.
2. Because of its high range of action or springback, Chinese NiTi wire is applicable in situations where large deflections are required.

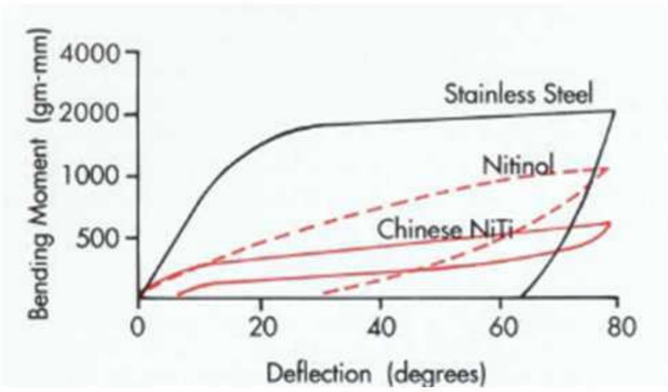


Figure 9 Springback- Chinese NiTi wire has 1.4 times the springback of nitinol wire and 4.6 times the springback of stainless-steel wire for 800 of activation

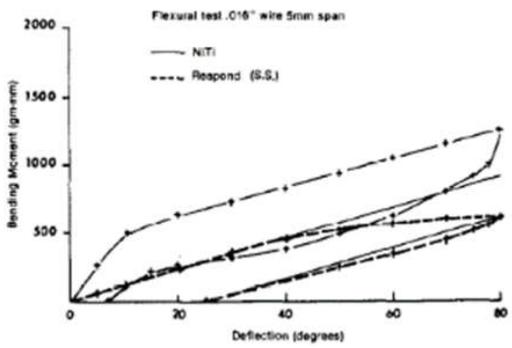


Figure 10 At 800 of activation the average stiffness of Chinese NiTi wire is 73% that of stainless-steel wire and 36% that of nitinol wire.[10]

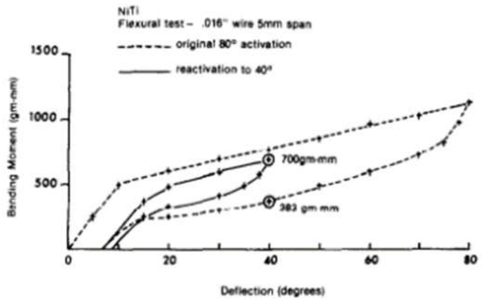


Figure 11 Activation (original 800) and reactivation (to 400) curves for NiTi wire. The moment decreases to 383 gm-mm after 400 of deactivation. If the wire is untied and retied into a bracket (reactivation), the moment increases to 700 gm-mm. [10]

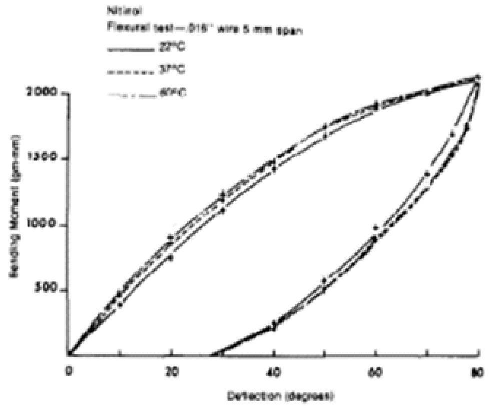


Figure 12 Chinese NiTi wire, on the other hand, exhibits some small differences at varying temperatures because material components have lower transition temperatures.[10]

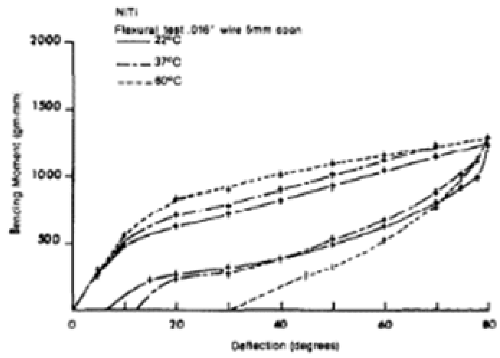


Figure 13 Very small reduction in springback at mouth temperature. Higher temperature (600 C) reduces springback and increases stiffness. Higher temperatures are beyond usual clinical range.[10]

Unlike wires of other orthodontic alloys, the characteristic stiffness is determined by the amount of activation. The load-deformation rate at small activations is considerably higher than that at large activations.

Clinical application

1. Chinese NiTi wire is highly suitable if low stiffness is required and large deflections are needed. Its higher stiffness at small activations make it more effective than wires of traditional alloys whose force levels may be too low (as teeth approach the passive shape of the wire).
2. Applications include straight-wire procedures when teeth are badly malaligned and in appliances designed to deliver constant forces during major stages of tooth movement.

Japanese NITI[14]

1. In 1978, Furukawa Electric Co., Ltd. of Japan pro-duced a new type of the Japanese NiTi alloy, possessing all three properties (excellent springback,shape memory, and super-elasticity).
2. The newly developed Japanese NiTi alloy wire does exhibit super-elastic properties indicating an area of definite amount of stress in spite of the changes in the strain rate.By contrast, the stainless steel, Co-Cr-Ni, and Nitinol wires showed that therelationship between the stress and strain is proportional. (figure 14)

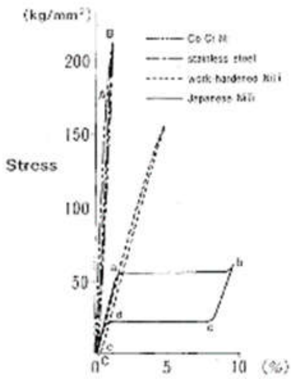


Figure 14 Stress-strain curve for orthodontic wires[14]

3. The Japanese NiTi alloy wire possessed super-elastic properties whereby the load became almost even when the deflection was decreased in the bending test. This feature provides a light continuous force so that an effective physiologic tooth movement can be delivered. (figure 15)

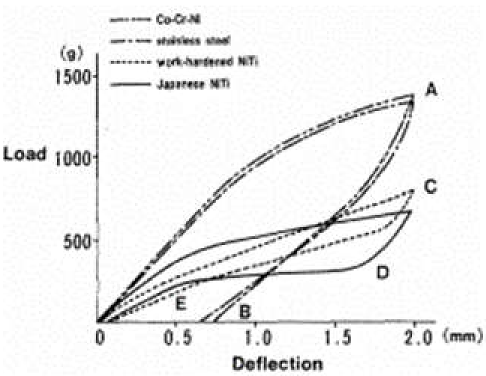
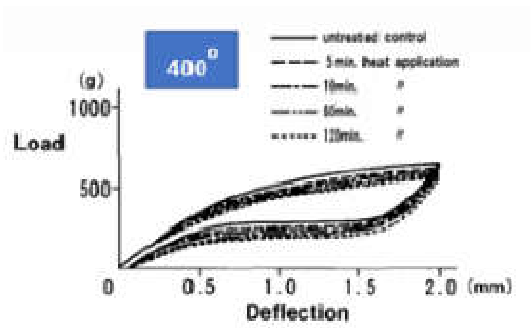


Figure 15 load deflection curves produced by three-point bending test[14]

4. When the heat application is raised to 500 ° C, the force level indicating the super-elastic property could be reduced. Thus, arch wires providing a different magnitude of force can be fabricated from the wires of the same diameter. In addition, in the preformed arch wire, different magnitudes of force can be produced by controlling the temperature and time in the desired section of the arch wire. (figure 16)



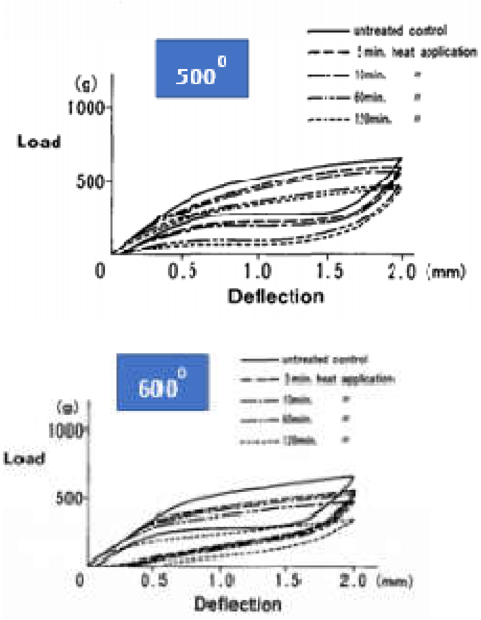


Figure 16 results of heat application of 0.016 Japanese NiTi wire[14]

Direct Electric Resistance Heat Treatment Method (DERHT):[15]

1. Japanese nickel titanium (NiTi) alloy wire possesses excellent spring-back properties,shape memory and super-elasticity.
2. In order to adapt this wire to clinical use, it is necessary to bend as well as to control its super-elastic force, and so a direct electric resistance heat treatment (DERHT) method was developed.
3. An electric current is passed directly through the wire, thus generating enough heat to make it possible to bend it as well as to impart a change in the super-elastic force of the wire.
4. The DERHT method utilizes the electric resistance of the wire to generate heat. In spite of the resulting molecular rearrangement,the mechanical properties of the wire are unchanged.
5. The equipment involved in the DERHT method is small and light in weight. One distinct advantage is that with a pair of electric pliers and an electric arch holder, it is possible to heat-treat only the desired section of the arch wire. (figure 17,18)

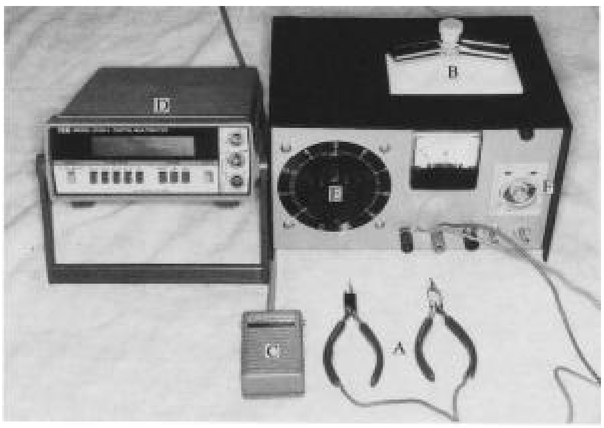


Figure 17 The equipment for DERHT method, (a) electric pliers, (b) electric arch holder, (c) foot switch, (d) electric current meter, (e) transformer, (f) timer.[15]

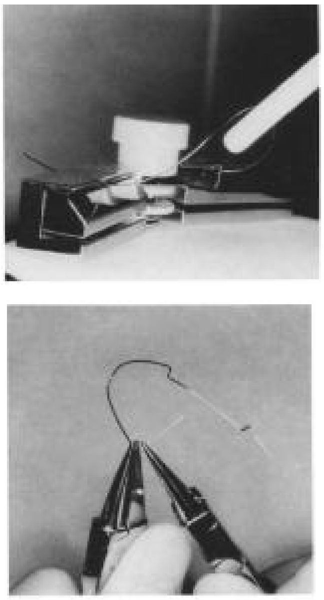


Figure 18 The super-elastic Japanese NiTi alloy wire can be bent without any loss of the mechanical properties, (a) utility archwire form, (b) reverse curve form. [15]

Copper NITI [16]

Invented by **Dr. Rohit Sachdeva** and **Shuichi Miyazaki** in 1994.

Composition:Quaternary alloy

Copper: Increases strength, reduces hysteresis. These benefits occur at expense of increasing temperature transition range (TTR) above that of oral cavity.

- To compensate for the above-mentioned unwanted effect 0.5% chromium is added to return TTR close to oral temperature
- For very small activations, it generates a near constant force. It is more resistant to permanentdeformationandexhibitsexcellentspringback characteristics.
- Itexhibitsasmalldropinunloadingforce than is true with other NiTialloys.
- Addition of Copper combined with more sophisticated manufacturing and consistent transformation temperatures, i.e. **15, 27, 25 and 40ºC.**

Type I – Af - 15℃:Not frequently used. Generates very heavy forces.

Type II – Af - 27℃:Generates highest forces of 3 types (II, III and IV). It has superelastic property.

Indications:average or higher pain threshold, normal periodontal health, mouth breathers

Type III Af 35℃:Generates forces in mid range.

Indications:low to normal pain threshold, periodontium is normal to slightly compromised, when relatively low forces are desired.

Type IV Af - 40℃:Generate forces only when mouth temperature exceeds 40°C. it can produce intermittent forces. True thermoelastic wire as Af above oral temperature.

Indications: Patients who are sensitive to pain, have compromised PDL conditions, where tooth movement is deliberately slowed down i.e when the patient may not be able to visit the orthodontist regularly or poor patient cooperation.

Not to be used in mouth breathers.

Clinical applications of Niti

1. Alignment of malposed teeth.
2. Distalize the molar.
3. Expansion of arch.
4. Gain/ close space.
5. Periodontally compromised patients.

Nomograms:[17]

1. A more graphic and efficient method for comparing different wire materials and sizes is the use of nomograms-fixed charts that display mathematical relationships via appropriately adjusted scales.
2. Nomograms developed by Kusy to provide generalized comparisons of stainless steel, M-NiTi, and beta-Ti in bending and torsion.
3. In the preparation of a nomogram, a reference wire is given a value of 1, and many other wires can then be located appropriately in reference to it. (figure 19)

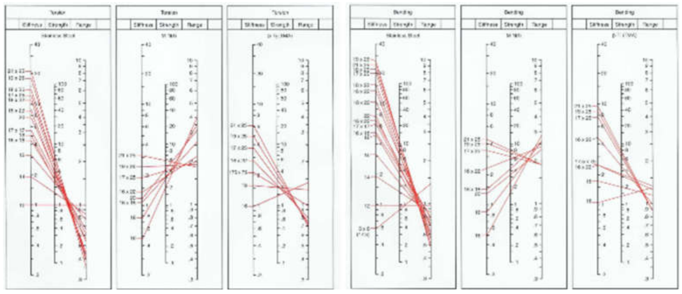


Figure 19 Nomograms

As the description of the wide variety of wires was beyond the scope of this article, they have been included in the part II of the same article so that the clinician is aware of all the wires at his dispense and can choose appropriate wire based on its properties.

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