



Aligning Archwires in Orthodontics: Exploring the Past, Present, and Future - A Comprehensive Narrative Review

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Abstract

Orthodontic wires facilitate the required dental adjustments in the context of orthodontic therapy. The archwire has played a crucial role in orthodontic treatment, and the increasing emphasis on aesthetic preferences from patients, as well as the development of composite and ceramic brackets, have prompted investigations into aesthetic archwires that complement these brackets. Orthodontic wires are produced using a diverse range of materials. The utilisation of all available wire types can improve patient comfort, decrease chairside time, and shorten the overall duration of treatment. The individual clinician must possess comprehensive knowledge and comprehension of the various requirements and alternatives throughout the therapeutic process. This article provides an overview of the history of materials utilised in producing orthodontic aligning archwires, the latest advancements in these materials currently accessible in the market, and the future of archwire production.

Introduction:

The principal objective of orthodontic treatment is to achieve proper positioning of the dentition through the application of forces while causing minimal damage to the dental and periodontal tissues. The optimal outcomes require considering biological and non-biological factors and utilising less force to avoid compromising the periodontal tissues. To achieve these outcomes, orthodontists must formulate a treatment plan based on adequate knowledge of the biomechanical properties and the clinical uses of orthodontic wires (1). Thus, choosing orthodontic wires is vital to fixed orthodontic therapy (2).

Material science has progressed dramatically in the past century, bringing about changes in treatment philosophy and the advancement in orthodontic materials. Orthodontic wires, which provide biomechanical stresses for tooth movement through brackets, are fundamental to the profession. Developing novel orthodontic procedures and improving wire manufacturing technologies have necessitated the quest for higher-quality alloys (3).

Material and Methods

A comprehensive online search was conducted across several databases, such as PUBMED, Google Scholar, and Cochrane, to gather relevant information from February to May 2023. Using the keywords "levelling and alignment" and "Archwires," data was retrieved from various articles. The authors examined the titles and abstracts of the collected literature, extracting pertinent data to summarise the topic comprehensively. The search was limited to articles written in English-language only.

The only inclusion criterion was that the article investigated aligning archwires (AWs), regardless of the study type. Excluded were articles examining applications of AWs outside of orthodontics first phase of treatment.

The total number of publications obtained through the search process was 198, only 67 articles met the criterion and were deemed suitable for data extraction, evaluation, and thorough compilation.

Types of Aligning Aws According to Material

The progression of AWs' chronological development was delineated into five distinct stages, with each phase being associated with a particular mode of force delivery (4):

Phase I: Linear force/deflection characteristics that change as a result of AW dimensional changes (e.g., diameter, length). Steel, gold, etc. are examples.

Phase II: Linear force/deflection characteristics that varies as a result of changes in AW material but keeping same dimensions (e.g., variable modulus orthodontics).Ex: Beta Titanium, Nickel-titanium, Stainless Steel).

Phase III: Non-linear force-deflection characteristics (superelasticity) due to stress-induced structural changes that Varies in AW diameter for Ex: Japanese NiTi and Chinese NiTi.

Phase IV: Non-linear force-deflection characteristics dictated by thermally induced structural change of the whole AW as a result of variation in the structural composition of AW material Ex: Thermally activated Nickel Titanium.

Phase V: Non-linear force-deflection characteristics dictated by different thermally induced structural changes in sections of the graded, thermally activated Nickel Titanium AW this occurs with Variation in AW material composition/structure with Ex: Bioforce and Smartarch AWs.

Figure 1 provides a summary of the archwires materials on their first appearance.

The following are most of aligning arch wires that are used in the first phase of treatment and these are summarized in Figure 2:

1)Gold AWs

The use of gold wires in orthodontics was reported in 1887. The material exhibits exceptional resistance to corrosion, excellent biocompatibility, and outstanding formability. Soldering is easy and produces corrosion-resistant solder connections. Their high cost compared to other wire options caused their discontinuation. (5)

2)Stainless steel AWs

Stainless steel was a cheaper substitute for gold, more resilient, and more resistant to failure when subjected to force. It is corrosion-

resistant, stiff, weldable, and has low friction. Despite the use of small cross-sectional wires, stainless steel wires generate significant levels of stresses. Stainless steel wires made of many strands are less rigid than a single strand wire with the same diameter; therefore, they are suitable for alignment. (6)

3)Titanium AWs

A) Nickel Titanium alloy wires

NiTi wires consist of two main phases: austenite, which is a high-temperature phase, and martensite, which is a low-temperature phase. Each phase possesses its distinctive lattice structure. The reversible phase transition between these two phases is responsible for the remarkable shape memory properties exhibited by NiTi wires. The phase transformation occurs when the austenitic phase changes temperature or stress beyond a specific threshold. The concept of hysteresis is defined as the numerical discrepancy between the temperatures at which the forward transformation from austenite (A) to martensite (M) occurs and the temperatures at which the reverse transformation from martensite (M) to austenite (A) takes place. Thermal hysteresis, appearing under a constant stress condition, can be attributed to the reverse transformation taking place at a temperature higher than that of the forward transformation; it's essential in understanding the temperature ranges involved during the conversion from martensitic to austenitic and vice versa. For a NiTi AW to exhibit shape memory, the phase transition must occur within the temperature range of the oral environment. However, the deformation of the wire through bending reduces its elastic recovery capacity, making it difficult for the wire to return to its original configuration. The term "superelasticity" is employed to characterise the characteristic of specific alloys to revert to their initial form upon unloading following a significant deformation. The phenomenon of significant elasticity discussed here is commonly referred to as pseudoelasticity due to its unconventional nature, or alternatively as transformational superelasticity, as it arises from a stress-induced phase transformation. Alloys exhibiting superelasticity undergo a thermoelastic martensitic transformation, which is a necessary condition for the occurrence of the shape memory effect.

Superelasticity and the shape memory effect exhibit a close relationship.(5, 7-10)

I. Martensitic stabilised nickel titanium:

The first nickel titanium alloy was known as Nitinol. The initial versions of this wire do not undergo phase transformation, so it lacks shape memory and superelasticity due to work-hardening during manufacturing. Nonetheless, they exhibited excellent springback characteristics. (11-13) The inability of Nitinol to withstand permanent wire bending and soldering presents challenges in clinical applications. (5, 7)

II. Austenitic active nickel titanium (superelastic):

a) Chinese NiTi AWs

Superelasticity and shape memory are present in Chinese NiTi wires. The austenite parent phase and low work hardening of this material result in notable distinctions in mechanical properties when compared to nitinol wire. Furthermore, it is noteworthy that the transition temperature of Chinese NiTi wire is significantly lower compared to nitinol wire. It has gained widespread clinical acceptance for initial tooth alignment due to its low stiffness and exceptionally high spring back compared to stainless steel and regular nitinol, the stiffness of this wire is 73% and 36%, respectively. (14, 15)

b) Japanese NiTi

This austenitic active NiTi alloy possesses properties such as springback, shape memory, and superelasticity. This unique behaviour is achieved through the martensitic transformation triggered by applied stress. In clinical practice, these wires provide a gentle and continuous force, promoting the natural movement of teeth and enhancing patient comfort. Sentalloy is the brand name for the Japanese nickel titanium alloy.(7, 16, 17)

III. Martensitic active (thermally activated) nickel-titanium:

Recent technological advancements have facilitated the ability to set the TTR (transition temperature range) at precise temperatures,

such as 27°C, 35°C, and 40°C. This can be achieved through heat treatment and pressure variations such as heat-activated nitinol and neo sentalloy or by modifying the atomic composition that partially substitutes copper for nickel in the copper-based alloy.(18)

Copper NiTi (CuNiTi)

This forthcoming generation of superelastic and shape-memory wires is geared towards reducing hysteresis and achieving precise transition temperatures. by incorporating copper into NiTi. The CuNiTi wires exhibit a loading force approximately 20% lower than conventional nickel-titanium wires. The adaptability of the wire in the bracket slot results in improved engagement and reduced trauma and pain for the patient. (19)

The CuNiTi AWs are calibrated at multiple transformation temperatures to cater to varying force levels, enabling orthodontists to manage diverse clinical scenarios effectively. They are categorised into four types with transition temperatures of 15 °C, 27 °C, 35 °C, and 40 °C (17, 20).

IV. Graded actuating force

a) Bioforce

This wire belongs to the first family of biologically compatible AWs. These AWs are made of thermodynamically graded nickel titanium and can generate varying AW forces through temperature transitions along the length of the wire. This wire exerts delicate forces in the front section, moderate forces in the premolar region, and higher forces in the molar region.(21, 22). Using a high-energy ion beam, this structure and chemistry of the wire surface were altered without changing its superelastic properties through a process called "ion implantation", which does not change the dimensions nor the properties of the AW. This enhances abrasion resistance, surface hardness, chemical attack resistance, and, most importantly, reduces friction.(23)

b) SmartArch

SmartArch® is a new type of CuNiTi wire manufactured using laser technology to generate multiple memory material transitions. These wires are meant to apply a good amount of force to each tooth's periodontal ligament (PDL) to make tooth movement easier and less painful. Transition zones were precisely

programmed in the cross-section of the shape-memory alloy wire using laser technologies. SmartArch® wires are a unique AW that is available in round and rectangular configurations of 0.016 inches and 0.018 inches x 0.025 inches..(24)

V. Multi-strands NiTi

a) Supercable AWs

This wire is a coaxial wire made of superelastic nickel-titanium and is called 'supercable.' The super cable AW has seven distinct strands that have been interwoven to enhance flexibility and minimize force transmission, providing mechanical advantages of multi-stranded and superelastic AWs. The malleable nature of this wire enhances treatment effectiveness by obviating the need for AW manipulation and allowing for more uncomplicated ligation, even in cases of dental crowding. Decreased frequency of visits is attributed to prolonged activation of AWs.(22, 25)

b) Biotwist NiTi AWs

The Biotwist AW is known for its remarkable elasticity. It is composed of several strands and possesses rectangular dimensions measuring 0.021x0.025. The distinctive structure of this wire confers a significant degree of flexibility through the provision of low force and rigidity. The Biotwist wire demonstrates a high level of suitability for the initial phases of orthodontic treatment, wherein the primary objectives revolve around attaining proper leveling, alignment, and torque control. Furthermore, it can also be employed in the final stages of the treatment procedure to sustain torque while simultaneously accommodating for certain degrees of mobility induced by external factors such as the application of vertical elastics.(26)

B) Titanium Molybdenum AWs

It is marketed as TMA. It is a titanium-based alloy that retains its beta structure at ambient temperature, thus, it is also known as beta-stabilized titanium. The modulus of elasticity of beta titanium is smaller than that of stainless steel and almost twice that of Nitinol. This makes it excellent for cases when a force smaller than that of stainless steel is required or when a material with a lower modulus, such as Nitinol, cannot achieve the needed force levels. Attaching active auxiliaries and hooks

to beta-titanium wires through welding enhances the applicability of the wire.(27)
Empirical evidence suggests that TMA wires exhibit surface roughness. In addition to the occurrence of cold welding or wire adhesion to the bracket slots in isolated areas, the presence of surface roughness contributes to the elevated levels of friction experienced during the sliding of AW brackets.(7)

C) Timolium Titanium AWs

Is a type of Alpha-beta NiTi. This alloy exhibits the advantageous characteristics of NiTi, such as flexibility, continuous force, and shape memory, while also possessing the high rigidity and malleability of stainless-steel wire, allowing for AW shaping through bending. There are stabilizing agents in the alloy, including aluminum and vanadium. At room temperature, aluminum stabilizes the alpha phase of titanium, and vanadium stabilizes the beta phase.(28)

Timolium, with its polished surface, decreased friction, low modulus, superior strength, and enhanced resistance to breakage, represents a potentially significant advancement in orthodontic clinical practice. The Timolium wire is appropriate for various stages of dental treatment, including the initial phase for gap closure, teeth alignment, and bite opening, the intermediate phase for early torque control, and the final phase for comprehensive control during detailing.(29)

D) Niobium–Titanium–Tantalum–Zirconium AW

It is a beta titanium alloy composed of titanium (Ti), niobium (Nb), tantalum (Ta), and zirconium (Zr), formability is one of the properties of the wire and can generate consistent light forces, while also being devoid of nickel content. The currently available wire is marketed as Gummetal. This wire exhibits exceptional properties when subjected to intensive cold working. These properties include an extremely low Young's modulus with non-linear elastic behavior, exceptionally high strength, high yield strain, remarkable ductility, and the ability to undergo superelastic deformability at room temperature. Gummetal currently offers orthodontists a pragmatic, cost-efficient, and efficacious tool to assist with orthodontic treatment. The remarkably low Young's modulus allows for precise three-dimensional

manipulation of teeth and the distribution of force in an optimal manner, resulting in gentle and stable tooth movement.(30)

4) Combined AWs

The utilization of combined wires is prevalent in straight wire systems owing to their capacity to deliver both soft tipping movements and inflexible translation. The methodology utilizes a triad of distinct combined wires, namely Dual Flex-1, Dual Flex-2, and Dual Flex-3 (fabricated by Lancer Orthodontics).(31)

The Dual Flex-1 that commonly utilized at the initiation of the treatment is composed of a front segment made of round Titanal measuring 0.016 inches and a rear segment made of round steel measuring 0.016 inches. The anterior teeth can be readily aligned by the flexible front section, while the rigid rear section ensures anchorage and molar control through a "V" bend located mesial to the molars. The Dual Flex-2, and Dual Flex-3 are utilized at the later stages of treatment.

5) Coated AWs

A) polytetrafluoroethylene (PTFE) coated AW

The wire is enveloped in a pliable elastomeric substance known as PTFE, which does not impact the superelastic characteristics of the wire. The PTFE coating exhibits strong adhesion to the wire and maintains a consistent force throughout a prolonged activation period. (32)

B) Epoxy Coated AWs

The AW coated with epoxy is intended to mimic the color of teeth and exhibits exceptional durability and color persistence for 6-8 weeks. It is known for its high esthetic appeal, owing to its composition of high-performance NiTi superelastic AWs. Additionally, it seamlessly integrates with ceramic or plastic brackets. The material exhibits resistance to staining, discoloration, and cracking.(33)

6) Non-metallic esthetic AW

A) Optiflex AW

Its non-metallic material composed of transparent optical fibers possessing distinctive mechanical characteristics that confer a

markedly pleasing visual aspect and resistance to discoloration. The wire consists of three distinct layers: a silicon dioxide core that facilitates tooth movement, a silicon resin middle layer that provides protection against moisture and enhances structural integrity, and a strain-resistant nylon outer layer that serves to prevent wire damage and bolster its strength. The Optiflex AWs are designed to facilitate effective dental realignment by applying gentle, sustained pressure. Their enhanced pliability enables them to accommodate a diverse array of bracket systems. It is recommended to avoid acute angles in the wire and refrain from employing metal ligatures, as they have the potential to induce fractures in the glass core. Utilizing a mini distal end cutter specifically designed to sever through all three layers of Optiflex when trimming the wire is recommended. One potential drawback of utilizing Optiflex AWs is their relatively high cost and the necessity for replacement every 4-6 weeks.(34)

B) Fiber reinforced composite AW

Composite AWs exhibit a higher coefficient of friction than stainless steel but a lower coefficient of friction when compared to nickel-titanium or beta-titanium AWs. Abrasive wear of the composite surface at the AW-bracket interface may occur at high forces and angles, leading to the undesirable release of glass fibers into the oral cavity. (34)

Fiber reinforced composite wires possess numerous advantages in comparison to traditional metal wires. Due to their translucence, the aforementioned characteristics comprise high elastic recovery, high tensile strength, low mass, exceptional malleability, and superior visual appeal. The wires under consideration facilitate the direct bonding of attachments, thereby obviating the necessity of soldering and welding. In certain instances, it is possible to form a direct bond between wires and teeth, which will obviate the necessity for brackets, especially when many teeth require anchorage. Furthermore, they represent a more secure alternative for individuals who suffer from nickel hypersensitivity.(35, 36)

C) Self-reinforced polymer (SRP) AW

A novel polyphenylene polymer with improved mechanical properties, including

increased rigidity, strength, and hardness, has been developed. The aforementioned superior characteristics are acquired through a process of molecular-level strengthening. Polyphenylenes exhibit enhanced hardness and elevated resistance to stress relaxation. This thermoplastic polymer exhibits desirable characteristics such as excellent formability, torque control, and translucency, which make it a potentially effective and esthetically pleasing option for a labial orthodontic wire. It has been observed that the incorporation of pliable segments into an otherwise inflexible all-phenylene framework can yield a polymer with exceptional durability and malleability. The nomenclature of SRP is attributed to the inflexible nature of the phenylene group blocks present in the backbone chain. The modulus of elasticity of polyphenylenes ranges from 5.5 to 8.3 GPa, while the strength ranges from 152 to 207 MPa. This substance exhibits properties that exceed those of polycarbonate by over two-folds and even surpass high-performance polymers like poly-ether-ether-ketone by a margin of one third. Despite the fact that the characteristics of polyphenylenes are currently inferior to those of beta-titanium or NiTi alloys, the properties of polyphenylene are satisfactory for implementation as orthodontic AWs.(37)

The efficiency of alignment and pain associated of different aligning Aws

In the early stages of treatment, orthodontists typically prefer to use wires that have a broad range of activation and deliver low levels of force in order to align and level the teeth. The first wire chosen should convey the maximum force that can be tolerated once attached at the maximum activation point bracket. (38)

Many studies have compared different AWs to evaluate the efficiency of these AWs in clinical scenarios, the summary of these studies can be found in supplementary table.(39-51)

In their recent Cochrane systematic review of aligning arch wires Wang et al. stated that “there is insufficient evidence in this review to determine whether any specific AW type is better than another in terms of rate of tooth alignment or pain experienced during alignment other than the moderate-quality evidence that suggests that initial arch wires made of coaxial superelastic NiTi can produce greater tooth movement over 12 weeks than

those made of single-strand superelastic nickel- titanium, and there is no difference in pain at day one between multistrand stainless steel and superelastic NiTi AWs. No studies assessed root resorption” (38) this summarizes that further studies are required in this field to determine the most appropriate leveling AW.

Future of aligning AWs

Future of aligning AWs can be summarized in three points:

- A) Future of AW material.**
- B) Future of AW shape.**
- C) Future of AW coatings.**

A) Future of AW material.

With advancement in the materials and increased demands of esthetics, several attempts have been made to introduce new esthetic arch wires that can surpass the drawbacks of the available AWs such as with FRP that demonstrated significant bending and distortion, resulting in interference with the fiber/polymer interface and a reduction in their mechanical characteristics. (52, 53) Recently, coated orthodontic wires have emerged as an additional option. The enhancement of the surface of the wire results in enhanced visual appeal. Nevertheless, there exist issues related to metal allergy and corrosion.(54)

Therefore, attempts have been made to construct AW using super engineering plastics (SEPs), these materials exhibiting enhanced mechanical strength and superior thermal and chemical stability, these materials includes: polyether ether ketone (PEEK), polyether sulfone (55) and polyvinylidene difluoride (PVDF).(56, 57) One study found promising results for the use of these materials as AWs especially with the high bending strength of PEEK material.(57, 58)

One study attempted to produce a novel thermoplastic polymer to use as AWs. The resin was synthesized through a combination of a liquid phase comprising of methylmethacrylate monomer and butyl acrylate, and a solid component consisting of benzoyl peroxide, tricresyl phosphate, and dichloromethyl silane. The polymer was subjected to an initial curing process at 40 °C for 2 hours, followed by a subsequent curing process at 60 °C for 14 hours. Subsequent to that, the substance underwent a post-curing

process involving exposure to high temperature for a duration of 1 hour at 130 °C. AWs with cross sections that are clinically relevant were produced by extruding the thermoplastic polymer. This study also showed a promising results to construct new AWs.(59)

B) Future of AW shape:

One of the recent AW designs is the MH-wire that serves all phases of treatment. This AW was constructed from NiTi coil springs that linked delta-shaped segments of 0.018" x 0.025" TMA segments to accommodate the 0.018" x 0.025" bracket slot, or 0.022" x 0.028" TMA segments to fit the 0.022" x 0.028" bracket slot. The coil spring was designed to be compact and tightly wound. The coil spring loops were fabricated utilizing a 3 mm lumen. The coil-spring loops' thread thickness varied over the arch. They delivered safe force while stretched to quadruple their lengths. Canines received 120 g and incisors and premolars 80 g. Upper molars received 240 g and lower molars 160 g.(60)

Another advanced technology in manufacturing AWs is the use of robotics industry with the aid of the CAD\CAM and digital dentistry in wire bending especially in lingual braces, such as the lingual arch wire manufacturing and design aid (LAMDA) established by Gilbert that only moves in the XY plane.(61)

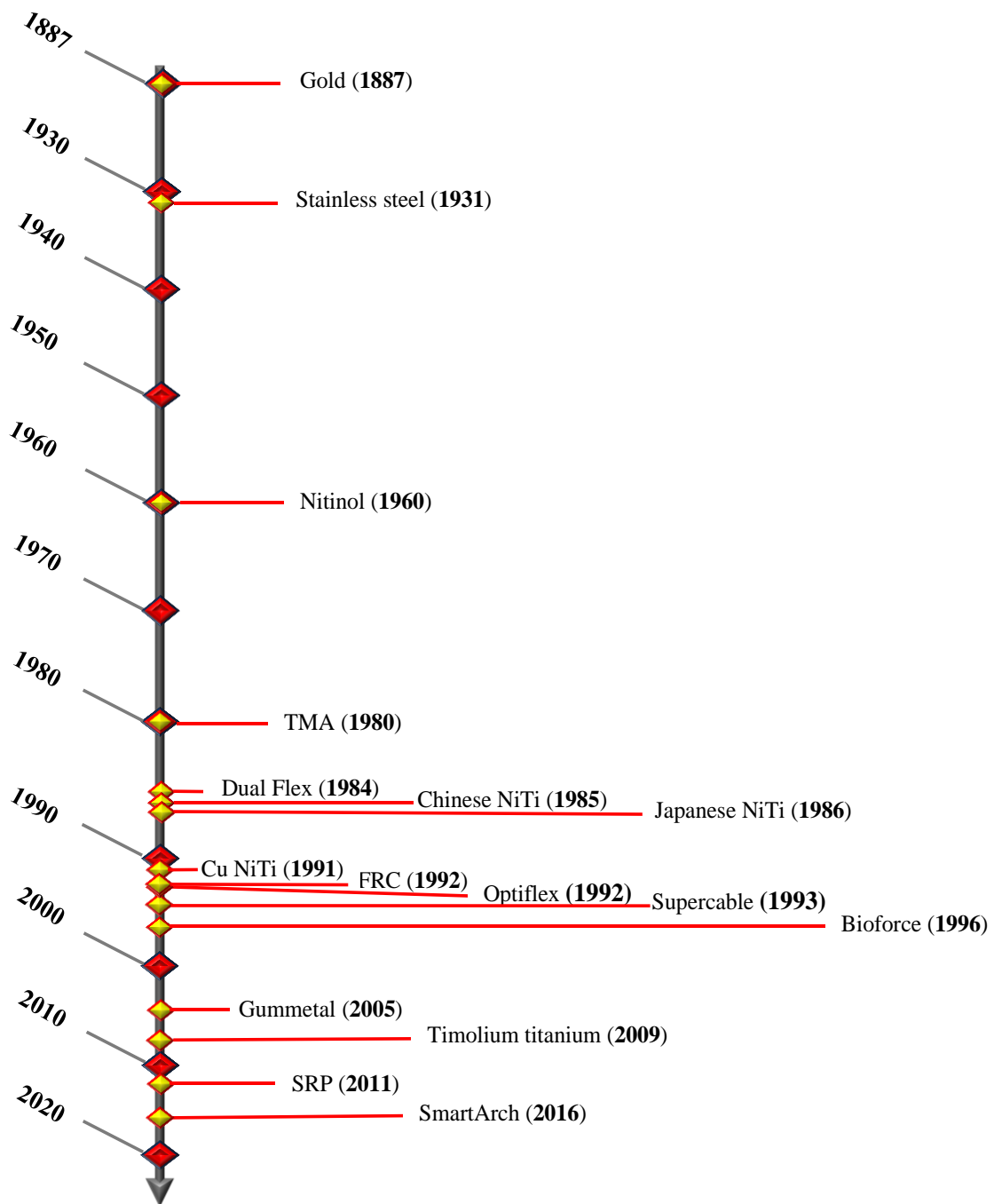
C) Future of AW coatings:

The complex oral cavity microstructure, which comprises electrolytes, proteins, and bacteria, can cause serious issues such bacterial adhesion, nickel release resulting in nickel allergy in supersensitive people, corrosion and ions release, mechanical weakness and tooth decay(62- 64). Coating of AWs have been advocated to solve the aforementioned issues also to produce esthetic AWs. Several materials for coating AWs have been developed recently, one study have developed a bioinspired superhydrophobic strategy that confers antibacterial adhesion, anti-Ni ion release, and corrosion resistance on Ni-Ti alloy AWs. The phenomenon of superhydrophobicity is widely observed in nature, such as on a lotus leaf, and is now employed in anti-biofouling applications. The superhydrophobic surface not only inhibits bacterial adhesion but

also suppresses Ni ion release. This is due to the fact that trapped air on the superhydrophobic surface significantly reduces the contact area between the AWs and bacterial suspension, from surface contact to point contact. Furthermore, the inherent mechanical properties of the AWs are not altered.(65) Also another new advancements in AWs coatings is the use of nanoparticles (NPs) technology, One study found that a novel salt of CHX-hexametaphosphate nanoparticles (CHX-HMP NPs) when exposed to an aqueous environment provides sustained discharge of the CHX component.(66)

Conclusions:

The acquisition of scientific knowledge pertaining to orthodontic wires empowers professionals to make informed decisions regarding the most optimal treatment protocol for their patients. It is evident that there does not exist an archwire that fulfils all the criteria specified by the orthodontist. There remains a considerable distance to be traversed in the pursuit of discovering the optimal archwire. However, given the rapid advancements in the field of science and technology, it is highly likely that notable enhancements in archwires will be observed in the foreseeable future (67).



TMA: Titanium Molybdenum Archwire, NiTi: Nickle Titanium, FRC: Fiber Reinforced Composite, SRP: Self Reinforced Polymer.

Figure 1: Timeline for archwires materials according to their first appearance

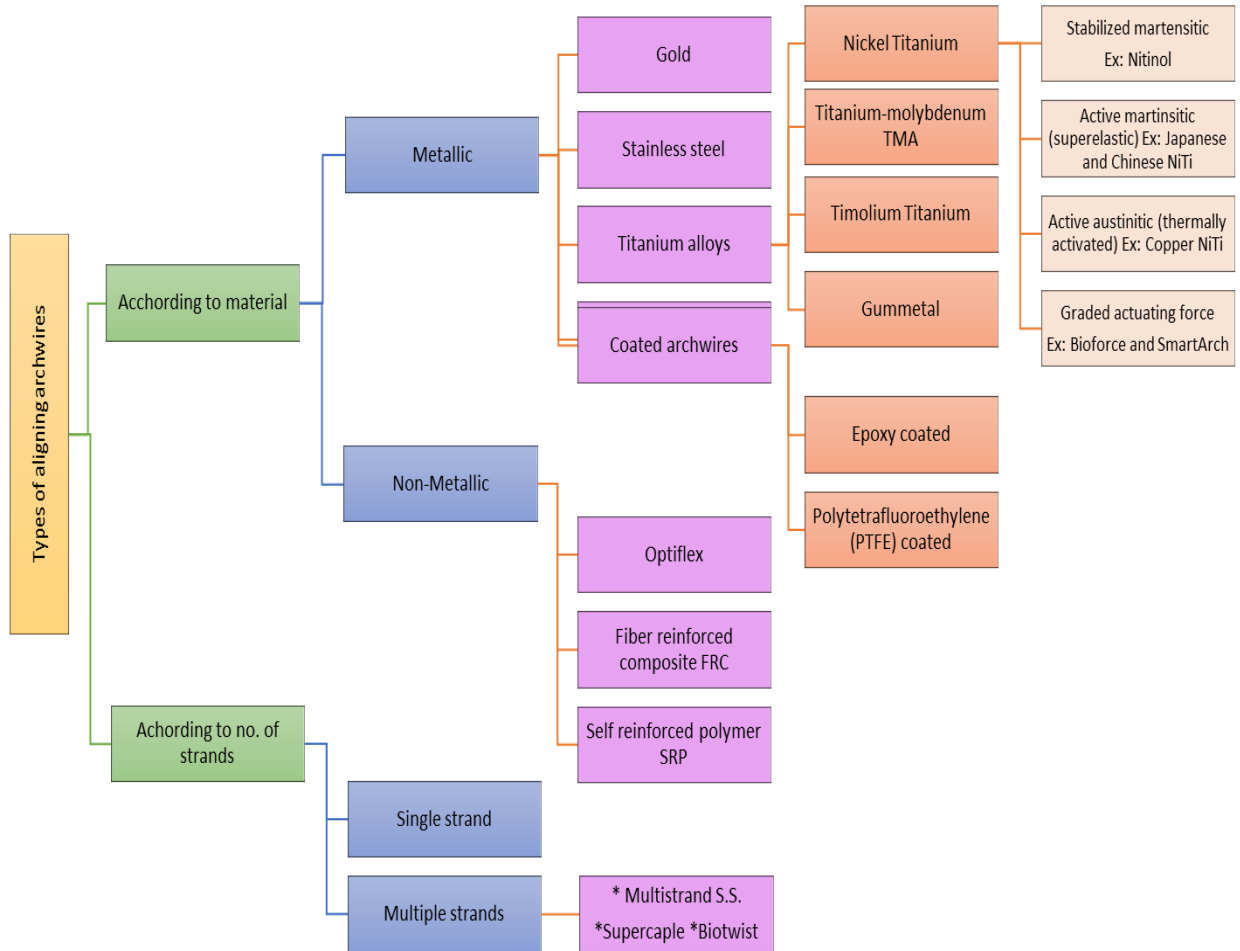


Figure 2: Summary of aligning archwires discussed in this review.

Supplementary table: Summary of the studies involving different aligning archwires.		
Author\ year	Type of archwire	Outcomes
Cobb et al., 1998.(39)	Multistranded S.S. and Superelastic NiTi	No significant difference in alignment rate between these archwires.
Quintao et al., 2005.(40)	S.S., multistranded steel, superelastic and thermoactivated NiTi	Results showed no significant difference in alignment rate between the different archwires.
Jones et al., 1992.(41)	Multistranded S.S. and superelastic NiTi	It was found that the prevalence, intensity, and duration of pain after the insertion of the two types of wire were similar.
Sandhu et al., 2013.(42)	Multistranded S.S. and superelastic NiTi	For overall pain, there was no statistically significant difference between the two wires.
West et al., 1995.(43)	Multistranded S.S. and superelastic NiTi	Superelastic NiTi performed better regarding alignment rate in the alignment of the mandibular anterior segment.
Evans et al., 1998.(44)	Multistranded S.S., thermally activated NiTi and graded actuating force NiTi.	This study showed no statistically significant difference in the aligning capabilities of these archwires after four and 8-week intervals.
Abdelrahman et al., 2015.(45)	Nitinol, superelastic NiTi and thermally activated NiTi	The three forms of NiTi wires were similar in terms of their alignment efficiency during the initial aligning stage of orthodontic fixed appliance therapy.
O'Brien et al., 1990.(46)	Nitinol and superelastic NiTi	No significant difference was found between the two wires assessed in the study.
Pandis et al., 2009.(47)	NiTi and Cu NiTi	Thermally activated NiTi produced the same effect in alignment efficiency.
Fernandes et al., 1998.(48)	Nitinol and superelastic NiTi	Both archwires were similar in terms of pain perception.
Cioffi et al., 2012.(49)	superelastic NiTi and thermally activated NiTi	Both archwires resulted in similar pain perception during study.
Sebastian, 2011.(50)	Coaxial and single-stranded superelastic NiTi	Coaxial superelastic NiTi wire proved superior to single-stranded NiTi in its efficiency in relieving lower anterior crowding over 12 weeks.
Nabbat et al., 2020(51)	SENT (0.014, 0.016) and HANT (0.014,0.016).	Both HANT and SENT AWs were equally effective in the aligning stage of orthodontic treatment in terms of crowding relief, root resorption and pain perception.

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