RESEARCH PAPER

Evolving science of Nickel-titanium archwires in Orthodontics - A review

Dr. Kavya B R[1*], Dr. Jansiya Thangavelu[2]
[1*]Assistant Professor, Department of Orthodontics & Dentofacial Orthopedics, Dayananda Sagar College of Dental Sciences, Bangalore, Karnataka, India.
ORCID ID: 0009-0008-4819-6555
[2]Assistant Professor, Department of Orthodontics & Dentofacial Orthopedics, Vinayaka Mission's Sankarachariyar Dental College, A Constituent College of Vinayaka Mission's Research Foundation (Deemed to be University), Ariyanoor, Salem, Tamil Nadu, India.
ORCID ID: 0000-0001-9334-0204

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Abstract

Nickel–titanium (NiTi) alloys have played an important role in the development of modern orthodontic biomechanics because of their distinctive shape-memory and superelastic properties. Since their introduction into orthodontics, NiTi archwires have progressed from relatively simple cold-worked alloys to a diverse range of superelastic, thermoactivated, copper-containing, low-hysteresis and functionally graded systems. They are used particularly during the initial stages of treatment, when considerable archwire deflection may be required to engage irregularly positioned teeth. The characteristic behaviour of NiTi is related to reversible solid-state transformations between austenitic, martensitic and, in some alloys, R-phase structures. As a result, factors such as alloy composition, thermomechanical processing, transformation temperature, wire dimensions and intraoral temperature can influence clinical performance.

This review examines the metallurgical basis, classification, mechanical properties, thermal behaviour, clinical applications, advantages, limitations, biocompatibility and recent developments associated with NiTi orthodontic archwires. Although NiTi wires offer important biomechanical advantages during the initial stages of orthodontic treatment, current clinical evidence does not demonstrate consistent superiority of one NiTi formulation over all others. Archwire selection should therefore be guided by the required biomechanical response, stage of treatment and individual patient requirements rather than by the commercial classification of the alloy alone.

Keywords: nickel–titanium; NiTi; orthodontic archwire; Nitinol; superelasticity; shape memory; thermoelasticity; heat-activated archwire; CuNiTi; orthodontic biomechanics.

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Introduction

Orthodontic archwires are fundamental components of fixed appliance systems and are responsible for transmitting forces and moments to the teeth. Their clinical performance depends on several factors, including alloy composition, cross-sectional geometry, dimensions, surface characteristics, manufacturing process and the interaction between the wire and bracket system.

The introduction of nickel–titanium alloys into orthodontics during the 1970s represented an important advancement in orthodontic materials science. Compared with conventional stainless-steel wires, NiTi alloys offered greater flexibility and springback, allowing substantial activation while maintaining comparatively low force levels.[1,2]

The clinical value of NiTi is largely related to two characteristic properties: shape memory and superelasticity. Both are associated with reversible phase transformations within the alloy. However, NiTi should not be considered a single, uniform material. Commercially available wires can differ considerably in their transformation temperatures, stress–strain behaviour, hysteresis and force delivery.[3,4]

A sound understanding of the metallurgical and biomechanical characteristics of individual NiTi systems is therefore important when selecting an appropriate archwire for clinical use.

Historical Development

The development of NiTi alloys originated from research into shape-memory materials. Their subsequent introduction into orthodontics provided clinicians with a wire capable of undergoing considerable deflection while recovering toward its original configuration.

Early orthodontic NiTi wires were valued primarily for their flexibility and shape-memory behaviour. Further developments in alloy processing and heat treatment subsequently led to superelastic, thermoactivated and copper-containing systems with more controlled transformation characteristics[2,5,6]

The development of NiTi technology has progressively moved towards superelastic austenitic alloys, thermoactivated alloys, copper-containing

NiTi alloys, low-hysteresis systems; and functionally graded or multi-force archwires. These developments represent a broader shift in orthodontic wire design—from simply producing highly flexible materials toward achieving greater control over the magnitude, duration and temperature dependence of force delivery.

Metallurgical Basis of NiTi Behaviour

Austenitic and Martensitic Phases

The characteristic properties of NiTi arise from reversible transformations between different crystallographic phases. Austenite is generally the higher-temperature phase, while martensite is the lower-temperature phase. Under certain compositional and thermomechanical conditions, an intermediate R-phase may also occur.[7]

When an appropriately conditioned NiTi alloy is mechanically loaded, it may undergo a stress-induced transformation from austenite to martensite. On unloading, the reverse transformation can occur, allowing a considerable amount of the deformation to be recovered.

This behaviour distinguishes NiTi from conventional orthodontic alloys, where deformation within the elastic range is primarily associated with conventional elastic lattice strain.

Transformation Temperatures

The transformation behaviour of NiTi is commonly described using four characteristic temperatures: martensite start temperature (Ms), martensite finish temperature (Mf), austenite (As) start temperature; and austenite finish temperature (Af).

The relationship between these temperatures and the intraoral environment is particularly important for thermoactivated wires. Changes in alloy composition and thermomechanical processing can substantially alter the transformation temperatures of the material.[7,8]

Differential scanning calorimetry is commonly used to characterize these transformations and can provide useful information about the thermal state and expected behaviour of a particular NiTi alloy.

Types of NiTi Orthodontic Archwires

Conventional NiTi

Conventional NiTi archwires were developed primarily to provide greater flexibility and springback than conventional stainless-steel alloys. Their mechanical behaviour is influenced by factors such as manufacturing history and phase composition.

Although the term “conventional NiTi” is commonly used in clinical practice, wires within this category should not automatically be assumed to have identical mechanical characteristics.

Superelastic NiTi

Superelastic NiTi undergoes stress-induced transformation between austenite and martensite under appropriate loading conditions. During unloading, this transformation can produce a relatively broad unloading plateau, allowing the wire to remain active over a substantial range of deflection.

However, independent investigations have shown considerable variation among commercially available superelastic NiTi wires. Some products demonstrate pronounced superelastic behaviour, whereas others show considerably less evidence of such transformation.[3]

Thermoactivated NiTi

Thermoactivated NiTi alloys are designed so that their phase transformation behaviour is strongly influenced by temperature. At lower temperatures, these wires may become relatively flexible and easier to engage in the brackets. As the temperature approaches the transformation range, the alloy progressively returns toward its programmed configuration. This temperature-dependent behaviour has made thermoactivated NiTi particularly useful during the initial alignment phase of orthodontic treatment.[8]

Copper–Nickel–Titanium

Copper-containing NiTi alloys were developed to modify the transformation behaviour of conventional NiTi and provide more controlled thermal characteristics. The addition of copper influences transformation temperatures and hysteresis, allowing manufacturers to develop wires with different activation temperatures for specific clinical applications.[9]

CuNiTi should therefore be regarded as a distinct metallurgical formulation rather than simply a stronger form of conventional NiTi.

Functionally Graded and Multi-Force NiTi

More recent developments have produced archwires in which different regions of the same wire possess different mechanical characteristics. Localized thermomechanical treatment can modify transformation temperatures and force delivery along the length of the archwire. These systems represent a move toward functionally graded orthodontic materials capable of providing region-specific biomechanical behaviour.[10]

Mechanical Properties

Superelasticity

Superelasticity is one of the most clinically relevant properties of NiTi. A superelastic alloy can undergo considerable deformation through stress-induced phase transformation and subsequently recover its original configuration during unloading. This allows the wire to provide relatively sustained force over a comparatively wide activation range.[2,3]

The clinical significance of superelasticity, however, depends on the actual unloading characteristics of the individual wire rather than simply on whether the manufacturer describes it as “superelastic.”

Shape-Memory Effect

The shape-memory effect describes the ability of an appropriately processed NiTi alloy to recover a predetermined configuration following suitable thermal activation. In orthodontic applications, this property allows thermoactivated wires to be deformed or engaged at lower temperatures and subsequently recover toward their programmed arch form as they reach intraoral temperature.[8]

Load–Deflection Characteristics

The load–deflection relationship is important clinically because it determines the force generated for a particular amount of wire activation. NiTi wires generally demonstrate favourable load–deflection characteristics compared with stiffer conventional alloys, particularly when considerable activation is required. However, the force delivered clinically is affected by several factors, including wire dimensions, cross-sectional geometry, interbracket distance, temperature, degree of deflection, alloy composition, bracket interaction and ligation method.[3,4]

For this reason, laboratory measurements obtained under controlled conditions should not automatically be regarded as exact representations of the forces delivered in the oral environment.

Springback

Springback refers to the ability of a wire to return toward its original configuration after being deformed. NiTi demonstrates considerably greater springback than many conventional orthodontic alloys. This makes it particularly useful during initial alignment, when a wire may need to accommodate substantial tooth displacement without undergoing permanent deformation.

Hysteresis

NiTi exhibits mechanical hysteresis, meaning that its loading and unloading pathways are not identical. The difference between the loading and unloading stresses reflects energy dissipation during phase transformation. Clinically, the unloading portion of the stress–strain curve is particularly relevant because it more closely represents the force available to move teeth as the wire deactivates.[3]

Influence of Temperature

Temperature is an important factor in the behaviour of thermoactivated NiTi systems. The oral environment is not maintained at a completely constant temperature. Intraoral temperature can change with environmental conditions and the consumption of hot or cold substances. Since the transformation temperatures of thermoactivated wires can be positioned within clinically relevant ranges, these changes may influence their phase state and mechanical behaviour.[8]

Consequently, force values measured at room temperature should not necessarily be assumed to represent the exact forces generated by the same wire under intraoral conditions. This temperature dependence is one of the key biomechanical differences between conventional superelastic and thermoactivated NiTi systems.

Clinical Applications

NiTi archwires are predominantly used during the initial stages of fixed orthodontic treatment.

Initial Alignment and Leveling

The combination of flexibility, springback and favourable load–deflection behaviour allows NiTi wires to accommodate considerable tooth displacement.

They are therefore commonly used for initial alignment, leveling;, correction of rotational irregularities, early arch coordination and selected cases involving substantial archwire deflection.

Sequential Archwire Protocols

NiTi wires may be incorporated into a progressive archwire sequence in which wire dimensions and stiffness are gradually increased as alignment improves. The decision to progress to larger or stiffer wires should be based on the biomechanical requirements of the individual treatment rather than on a rigid sequence applied to every patient.

Clinical Evidence

The theoretical mechanical advantages of NiTi should be distinguished from evidence demonstrating actual clinical superiority. A Cochrane systematic review evaluating initial archwires used during orthodontic treatment with fixed appliances concluded that the available evidence remains limited and that there is insufficient evidence to identify a particular archwire material or dimension as universally superior.[5]

The review found that superelastic and thermoelastic NiTi wires may produce broadly similar alignment outcomes over short periods, although the certainty of evidence for several outcomes was low or very low.[5]

Evidence concerning patient discomfort is also not entirely consistent. Some studies have reported differences in early pain between archwire systems, but such findings need to be interpreted in the context of the overall treatment protocol and individual patient response.[5,11]

Therefore, claims that a particular NiTi technology necessarily provides faster alignment, reduced pain or superior biological outcomes should be supported by well-designed randomized clinical trials rather than inferred solely from laboratory measurements of mechanical properties.

NiTi and Root Resorption

Orthodontically induced inflammatory root resorption is a multifactorial process influenced by factors such as force magnitude and duration, individual susceptibility, treatment duration, tooth morphology and other biological variables.

Although different orthodontic force systems have been investigated as potential contributors, current evidence does not support the conclusion that a particular NiTi formulation can reliably eliminate the risk of root resorption.[5]

The description of an archwire as "low force" should therefore not be interpreted as a guarantee against root resorption.

Friction and Surface Characteristics

The interaction between an archwire and bracket is influenced by several factors, including alloy composition, surface roughness, bracket material, wire dimensions, angulation and ligation technique.

Experimental studies have demonstrated differences in frictional behaviour among orthodontic alloys and surface conditions. However, translating laboratory friction measurements directly into clinical treatment efficiency remains difficult because tooth movement is influenced by numerous interacting mechanical and biological factors.[12]

Surface modification and improvements in manufacturing techniques therefore remain important areas of ongoing research.

Corrosion and Biocompatibility

The relatively high nickel content of NiTi alloys makes corrosion and biocompatibility important considerations. Orthodontic alloys are exposed to saliva, changes in pH, temperature fluctuations and mechanical stresses during clinical use. These conditions can influence the surface characteristics of the alloy and may affect ion release.

Systematic investigations of orthodontic metals have shown that the intraoral environment can influence alloy surfaces and corrosion behaviour.[13]

In patients with documented nickel hypersensitivity, appropriate clinical consideration should be given to the selection of orthodontic materials.

Effects of Clinical Use and Recycling

The mechanical properties of NiTi can change following clinical exposure, deformation and recycling. During clinical use, archwires are subjected to repeated loading, corrosion and temperature fluctuations. Subsequent sterilization or recycling may further influence their mechanical behaviour.

Recent experimental research has demonstrated changes in the load–deflection characteristics of superelastic and thermal NiTi wires following different recycling procedures.[14]

These findings highlight the difference between the mechanical properties of unused laboratory specimens and those of wires that have already undergone clinical service.

Contemporary Developments

Low-Hysteresis NiTi

Low-hysteresis systems are designed to reduce the difference between loading and unloading stresses and may provide more controlled force delivery.

Thermally Activated Systems

Thermoactivated alloys continue to be developed with increasingly specific transformation-temperature ranges designed around clinically relevant intraoral conditions.

Copper-Containing NiTi

CuNiTi remains an important development because copper can be used to modify transformation temperatures and influence the thermal response of the alloy.[9]

Functionally Graded Archwires

Functionally graded archwires represent a more advanced approach in which different regions of the same archwire can demonstrate different force characteristics.[10]

Despite their advantages, NiTi archwires have several limitations. Their relatively high flexibility can make precise permanent bends and chairside adjustments more difficult than with stainless steel. Their mechanical characteristics can also vary considerably between manufacturers and between different generations of NiTi technology.[3] Thermoactivated systems may exhibit temperature-dependent variability, while laboratory testing cannot always reproduce the complex mechanical environment present in the oral cavity.

Most importantly, current clinical evidence does not establish that newer or more technologically sophisticated NiTi systems consistently produce clinically superior outcomes compared with established alternatives.[5]

Future Directions

Future research should increasingly focus on clinically meaningful outcomes rather than relying solely on laboratory measurements. Further studies should emphasize the standardization of mechanical testing protocols for commercially available NiTi products and establish better correlations between laboratory force measurements and actual clinical tooth movement. Long-term evaluation of phase transformation behaviour following intraoral exposure is also necessary, along with investigation of intraoral temperature fluctuations and their clinical significance. Independent verification of manufacturer claims and larger randomized clinical trials comparing contemporary NiTi systems would provide stronger evidence regarding their clinical performance.

Future developments should also focus on patient-specific force systems, functionally graded archwires, and digitally customized archwires. Continued advances in thermomechanical processing and materials engineering may ultimately enable orthodontic archwires to deliver increasingly precise, predictable, and individualized force systems

Conclusion

Nickel–titanium archwires remain an essential component of contemporary orthodontics because of their superelasticity, shape memory, high springback, and favourable force delivery. As different NiTi systems exhibit distinct thermomechanical properties, archwire selection should be individualized according to the treatment stage and desired biomechanical response. Future advances in materials engineering and digital customization may further improve the precision, predictability, and individualization of orthodontic treatment.

References

1. Andreasen GF, Hilleman TB. An evaluation of 55 cobalt substituted Nitinol wire for use in orthodontics. *J Am Dent Assoc.* 1971;82:1373–1375.

2. Miura F, Mogi M, Ohura Y, Hamanaka H. The super-elastic property of the Japanese NiTi alloy wire for use in orthodontics. *Am J Orthod Dentofacial Orthop.* 1986;90:1–10.

3. Bartzela TN, Senn C, Wichelhaus A. Load-deflection characteristics of superelastic nickel-titanium wires. *Angle Orthod.* 2007;77:991–998.

4. Yoneyama T, Doi H, Hamanaka H, Okamoto Y, Mogi M, Miura F. Super-elasticity and thermal behavior of Ni-Ti alloy orthodontic arch wires. *Dent Mater J.* 1992;11:1–10.

5. Papageorgiou SN, et al. Initial arch wires used in orthodontic treatment with fixed appliances. *Cochrane Database Syst Rev.* 2024.

6. Nakano H, Satoh K, Norris R. Mechanical properties of several nickel-titanium alloy wires in three-point bending tests. *American Journal of Orthodontics and Dentofacial Orthopedics*, 115, 390-395.

7. Al-Horini O, Hajeer MY, Baba F. Evaluating the Elemental Composition, Transformation Behavior, Crystalline Structure, and Mechanical Properties of Three 0.016-Inch by 0.022-Inch Nickel-Titanium Archwires: An In Vitro Study. Cureus. 2022 Jul 24;14(7):e27206

8. Stoyanova-Ivanova A, Petrov V, Martins JNR, Andreeva L, Georgiev V. Multi-Force Bio-Active™ Archwires and Various Contemporary NiTi Multi-Force Archwires: Properties and Characteristics-A Review. Materials (Basel). 2024 May 28;17(11):2603.

9. Atik E, Gorucu-Coskuner H, Akarsu-Guven B, Taner T. A comparative assessment of clinical efficiency between premium heat-activated copper nickel-titanium and superelastic nickel-titanium archwires during initial orthodontic alignment in adolescents: a randomized clinical trial. *Prog Orthod.* 2019;20:38.

10. Abutayyem, Huda & Alam, Mohammad & Kanwal, Bushra & Alswairki, Haytham & Alogaibi, Yahya. (2023). Metallurgy in orthodontic—A systematic review and meta-analysis on the types of metals used. *Journal of Orthodontic Science*. 12. 50. 10.4103/jos.jos_52_23.

11. Nabbat, Sarah & A. Yassir, Yassir. (2020). A clinical comparison of the effectiveness of two types of orthodontic aligning archwire materials: a multicentre randomized clinical trial. *European Journal of Orthodontics.* 42. 626-634. 10.1093/ejo/cjz102.

12. Alemran MA, Abbassy MA, Zawawi KH. Frictional resistance in orthodontic archwires: A comprehensive review. *J Orthod Sci.* 2025 Sep 29;14:43. doi: 10.4103/jos.jos_9_25.

13. Fróis, António & Santos, Ana & Santos (Louro), Cristina. (2023). Corrosion of Fixed Orthodontic Appliances: Causes, Concerns, and Mitigation Strategies. Metals. 13. 1955. 10.3390/met13121955.

14. Shukla P, Kapoor S, Jaiswal RK, Sharma VK, Shashtri D, Bhagchandani J. The effect of different clinical recycling methods on load deflection properties of super-elastic and thermal nickel-titanium orthodontic arch wires: A comparative assessment. J Orthod Sci. 2024 Sep 17;13:27.