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Review Article

# Nitinol advancements in endodontics: Heat treatment and surface functionalization of NiTi instruments

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A B S T R A C T

Nitinol, a nickel-titanium alloy known for its exceptional properties of shape memory, superelasticity, and biocompatibility, has revolutionized the field of endodontics. This article explores the evolutionary journey of Nitinol in endodontics, highlighting its historical inception and subsequent integration into dental instruments. The article delves into pivotal advancements such as heat treatment and surface functionalization, showcasing their transformative effects on the mechanical properties and biocompatibility of Nitinol instruments. The discussion encompasses terms related to NiTi file design, including helical flute angles, pitch, cutting edges, rake angles, radial lands, cross-sectional shapes, and taper. Moreover, the article elucidates the modes of movement employed by NiTi files, including continuous rotary motion, reciprocating motion, and axial motion, emphasizing their significance in enhancing precision and minimizing risks. Through an exploration of Nitinol's evolution and its impact on endodontic procedures, this article underscores the symbiotic relationship between innovative materials and the evolving landscape of dentistry.



## 1. Introduction

The inception of nickel-titanium alloy, famously known as nitinol (NiTi alloy), traces back to its successful development by the U.S. space program at the Naval Ordnance Laboratory in 1963. This alloy, distinguished by its remarkable properties such as superelasticity (SE), shape-memory effect (SME), and biocompatibility, emerged as a pivotal material in various domains. Initially finding its application in orthodontic wires in 1971,[1] it garnered the moniker shape memory alloy (SMA) owing to its exceptional characteristics. The potential of NiTi alloy in endodontic applications was proposed by Civjan in 1975, further igniting exploration in this direction.[2]

The progressive integration of NiTi alloy into endodontic instruments gained substantial momentum in subsequent years. Notably, a significant milestone was achieved in 1988 with the introduction of the first NiTi hand file, characterized by its taper (#15) and orthodontic wire composition.[3] The 1990s marked a turning point with the advent of commercial rotary NiTi files. Key figures in this trajectory include John McSpadden and Johnson, recognized as pioneers in the development of rotary NiTi files. In 1992, they engineered a file boasting a taper of

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0.02, laying the foundation for subsequent advancements. The subsequent introduction of the ProFile Orifice Shaper (Dentsply Sirona, USA) in 1994, featuring tapers of 0.04 and 0.06, respectively, showcased the rapid evolution in the field.

Presently, the landscape boasts a plethora of over 160 distinct rotary NiTi systems that have permeated clinical practice. However, in stark contrast to the standardized international norms that govern stainless steel instruments, a consistent and unified standard remains elusive for the design of rotary NiTi systems. Variability persists in parameters such as tip diameters, tapers, and blade lengths, reflecting the ongoing diversity and exploration that defines the domain.

In the realm of dentistry, where precision and innovation intersect, the field of endodontics stands as a testament to continuous advancements. The treatment of dental pulp and root canal-related issues has evolved significantly, thanks to the integration of cutting-edge materials and technologies. One such groundbreaking development is the incorporation of Nitinol (Nickel Titanium Naval Ordnance Laboratory) alloy in endodontic instruments. These instruments, such as files and reamers, play a crucial role in root canal treatments and other dental procedures. Nitinol's exceptional characteristics, including shape memory and super elasticity, have revolutionized the field by enhancing the efficiency and precision of endodontic procedures. Renowned for its unique properties, Nitinol has introduced a new era of efficiency and precision in endodontic procedures, significantly impacting patient outcomes. This article delves into the two pivotal aspects of Nitinol advancements in endodontics: the transformative effects of heat treatment and the revolutionary potential of surface functionalization in Ni-Ti instruments.[4]

## 2. Simplifying Terms Related to NiTi File Design

NiTi files, the tools used for dental procedures, have certain parts that are crucial for their effectiveness. These include the cutting edge, the depth of the flute, the tip, the cross-sectional shape, rake angles, and radial lands.

### *2.1. Helical flute angle and pitch.*[5]

The helical flute angle is formed by a cross-section taken across the file, and the pitch is the distance between two cutting edges. NiTi files usually have 5 to 15 flutes. The tips of these tools are usually blunt to guide them through teeth without causing damage.

### *2.2. Impact of flute angle and pitch.*[6]

If the flute angle and pitch are the same throughout the tool, it can hold debris, increasing the risk of getting stuck in the teeth. Changing these parameters can help remove debris better, but it might also make the tool more prone to breaking.

### *2.3. Depth of the flute.*[7]

This is the distance from the tip to the bottom of the groove. It affects how stress is distributed in the tool. A deeper groove can help remove debris, but it might also make the tool weaker and more likely to break.

### *2.4. Cutting edge and rake angle.*[8]

The angle at which the cutting edge meets the tool affects how well it cuts. A positive angle is good for efficient cutting but leads to quicker wear. A neutral or negative angle is better for shaping and planning but not as efficient at cutting.

### *2.5. Radial land.*[9]

This is a surface behind the cutting edge that supports the tool's movement in the tooth. A wider land makes the tool stronger but increases friction and can create a layer on the tooth.

### *2.6. Cross-sectional shape.*[10]

The shape of the tool affects how it behaves during procedures. Different shapes have different mechanical properties.

### *2.7. Taper.*[9]

Taper refers to how the tool's diameter changes with its length. Tools with larger tapers cut quickly, while those with smaller tapers help maintain the shape of the tooth. Some tools have a constant taper, while others change taper at different points.

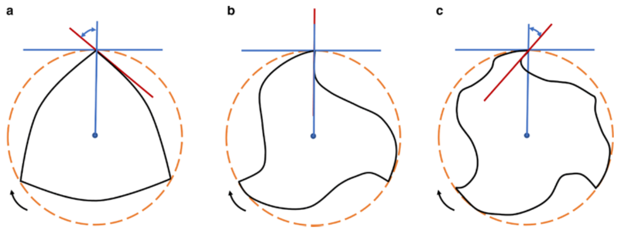


**Fig. 1:** https://media.springernature.com/full/springer-static/image/art%3A10.1038%2Fs41368-021-00154-0/MediaObjects/41368_2021_154_Fig4_HTML.png?as=webp

## 3. Endodontics and Nitinol

### *3.1. Symbiotic relationship*[11]

Endodontics, a specialized branch of dentistry, concentrates on the treatment of dental pulp and the intricate network of root canals within teeth. In recent years, the amalgamation of Nitinol, a nickel-titanium alloy, with endodontic instruments has given rise to remarkable advancements in the field. The exceptional characteristics of Nitinol, including shape memory and superelasticity, have brought about a paradigm shift in endodontic procedures, offering enhanced precision, efficiency, and ultimately, superior patient outcomes.

Nitinol's ability to revert to its original shape when exposed to specific conditions has revolutionized the field of endodontics. This unique property allows Nitinol instruments to adeptly navigate the complex twists and turns of root canals, minimizing the risk of procedural errors. These instruments retain their form and functionality even after multiple uses, leading to increased durability and reducing the likelihood of instrument separation, a common challenge in traditional instruments. As a result, dental professionals can now approach complex root canal anatomies with heightened confidence, knowing that Nitinol instruments will maintain their integrity and effectiveness throughout the procedure.

## 4. Heat Treatment

### *4.1. Enhancing mechanical properties:* [12]

The cornerstone of Nitinol advancements lies in the strategic heat treatment of endodontic instruments. Heat treatment involves subjecting the Nitinol alloy to controlled heating and cooling cycles to attain specific crystalline structures. These structures, in turn, influence the alloy's shape memory and superelastic behaviors, effectively enhancing its mechanical properties.

Heat-treated Nitinol instruments exhibit remarkable flexibility and resistance to cyclic fatigue. This enhanced flexibility allows for smoother negotiation of curved root canals, reducing the risk of canal transportation and maintaining the natural anatomy of the tooth. Additionally, the increased torsional strength of heat-treated Nitinol instruments enables dental professionals to exert greater control during procedures, reducing the chances of instrument fracture and minimizing procedural complications.

The application of heat treatment to Nitinol instruments marks a significant leap in the realm of endodontics. It empowers practitioners with instruments that not only endure the demands of intricate procedures but also provide a more efficient and accurate means of treating various dental pathologies. This advancement not only elevates the quality of endodontic care but also translates into improved patient experiences and outcomes.

## 5. Surface Functionalization

### *5.1. Pioneering precision and biocompatibility:*

Beyond the mechanical enhancements brought about by heat treatment, surface functionalization has emerged as a cutting-edge approach to optimizing Nitinol instruments. The surfaces of these instruments play a critical role in their cutting efficiency, debris removal, and interaction with the surrounding oral environment. Innovative techniques such as electropolishing, coating, and laser etching have redefined the way Nitinol instruments interact with dental tissues and enhance overall procedural outcomes.

Electropolishing, a surface treatment method, smoothens the surface of Nitinol instruments, reducing the likelihood of microcracks and enhancing corrosion resistance. This process not only increases the longevity of the instruments but also contributes to the precision and predictability of procedures. A smoother surface translates into reduced friction during use, allowing for smoother movements within the root canal while also reducing the risk of instrument fracture.

Coating Nitinol instruments with biocompatible materials, such as hydroxyapatite, holds promise for improved biocompatibility and enhanced healing. This coating promotes faster tissue integration and reduces the risk of adverse reactions, making it an invaluable tool in promoting patient comfort and recovery post-procedure. [13]

Laser etching, another surface functionalization technique, introduces micro-textured surfaces on Nitinol instruments. These textures enhance cutting efficiency by creating micro-abrasions that aid in debris removal during root canal procedures. This innovative approach not only enhances the instruments' ability to clean and shape the root canals effectively but also contributes to better outcomes and reduced patient discomfort. [13]

## 6. Modes of Movement for NiTi Files

### *6.1. Enhancing precision and minimizing risks*

NiTi files, crucial tools in dentistry, exhibit diverse modes of movement that impact their effectiveness and safety (Yared, 2008).

### *6.2. Continuous rotary motion*

Engine-driven NiTi systems predominantly employ 360° full rotation for optimal cutting efficiency. Root canal walls are continuously cut through both centric and eccentric rotary motion using electric motors and reduction contra-angle handpieces (ProTaper Universal, K3 systems). [14] Centric rotary motion, seen in systems like ProTaper Universal and K3, enhances cutting efficiency but can easily bind in dentin, bear high torque, and be susceptible to torsional failure. Innovative designs such as ProTaper Next and XP-endo Shaper introduce asymmetrical rotary motion, bolstering contact with the canal, and debris removal efficiency (Genius, Pro Design S, Reciproc).

### *6.3. Reciprocating motion*

A balanced-force technique introduced by Yared in 2008 revolutionized motion in engine-driven NiTi systems.[15] Reciprocating motion involves preparing the root canal with different angles in clockwise (CW) and counterclockwise (CCW) rotations. Systems like Reciproc, Reciproc Blue, Wave One, Wave One Gold, Pro Design R, Unicone, and X1 Blue File rotate with 120°–270° in CCW to cut dentin and 60°–90° in CW to relieve torsion stress and intermittently buffer. The Reciproc blue CM system withstands cyclic fatigue and flexes well post-heat treatment, while WaveOne Gold uses a similar approach with a CCW rotation of 170° and CW rotation of 50°. This mode's advantages include reduced apical pressure, taper lock prevention, lower torsional fracture incidence, and deformation compared to continuous rotary motion.[16]

### *6.4. Axial motion*

The SAF system uniquely employs axial motion. Operating with a handpiece at 3,000–5,000 vibrations per minute and an amplitude of 0.4 mm, this system uses a cylindrical meshwork hollow file to engage in a gentle in-and-out motion. Coupled with an irrigation device, dentin is removed via abrasion.[17] This approach adapts to irregular root canal spaces, adjusting the file to fit ovoid root canal walls, and ensuring thorough cleaning and shaping.

By understanding these distinct modes of movement, dental professionals can make informed decisions, optimizing their procedures for precision and safety in various clinical scenarios (SAF system.).[18]

## 7. Conclusion

### *7.1. Shaping the future of endodontics*

The convergence of Nitinol advancements, including heat treatment and surface functionalization, has heralded a new era of possibilities in endodontics. As dental professionals continue to explore the potential of Nitinol, the boundaries of what is achievable in root canal treatments and other endodontic procedures continue to expand. The integration of Nitinol's exceptional mechanical properties, coupled with innovative surface modifications, has propelled the field forward, fostering more predictable outcomes, enhanced patient comfort, and a higher standard of endodontic care.

As the dental community embraces the transformative potential of Nitinol in endodontics, ongoing research, and technological innovation are poised to push the boundaries even further. With each advancement, the gap between traditional dental procedures and minimally invasive, patient-centric approaches narrows, offering a future where Nitinol-powered instruments become synonymous with precision, efficiency, and excellence in endodontic practice.

## 8. Conflicts of Interests

The author has no financial interests or conflicts of interests.

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None.

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