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RECENT ADVANCES IN ENDODONTIC INSTRUMENTS – A LITERATURE REVIEW

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Abstract-
Numerous adaptations to endodontic instruments have emerged following the introduction of nickel-titanium tools, simplifying the results of endodontic procedures, less time-consuming, and successful. This review article gives an account of recent advancements in nickel-titanium instruments along with the evolution of various generations of Nickel-Titanium instruments.

INTRODUCTION-
Endodontics deals with the prevention, diagnosis, and treatment of pathosis of the dental pulp and its sequelae. An endodontic treatment involves access preparation, shaping and cleaning, and obturation. Cleaning implies removing debris that could accommodate bacterial growth and shaping is developing a unique shape concerning the position and curvature of each root. Proper cleaning and shaping promote sterilization and 3-dimensional obturation of the root canal system.
The field of dentistry has witnessed remarkable advancements with the continuous evolution of science, leading to innovative instruments and materials at the disposal of dentists. A significant breakthrough occurred in late 1988 when "Walia et al" introduced nickel-titanium instruments, marking a pivotal moment in dental technology [1]. Prior to 1988, clinicians relied on rigid stainless steel hand files that were characterized by aggressive cutting action. The utilization of these files was both tedious and time-consuming for dental professionals [2]. Instruments employed prior to 1988 were

associated with limitations, including the propensity to induce ledge formation and zip perforation while preparing curved root canals. In contrast, nickel-titanium instruments demonstrate shape memory and super elasticity, enhancing overall flexibility. This characteristic allows them to respect the curved and complex anatomy of root canals, mitigating the issues associated with rigid stainless steel files [3].
From the 1990's until now Nickel titanium rotary instruments have undergone revolutionary changes with respect to construction and physical characteristics [4]. The sole objective of it being able to preserve as much dentin after shaping the canal without separating the instrument Additionally, these nickel-titanium instruments contribute to preserving the original shape of the prepared canal.[5]

HISTORY –
The discovery of Nitinol dates back to 1959 when W.H. Buehler, a metallurgist at the US Naval Ordnance Laboratory, identified this shape memory alloy while investigating alloys for the space program[6][7].
The term "Nitinol" finds its origin in the alloy's elemental components: "Ni" for Nickel, "Ti" for Titanium, and "nol" for Naval Ordnance Laboratory, the place of its discovery. Initially recognized for its significance in naval and military applications, Nitinol's application was visionary expanded into the medical field, particularly in orthodontics and endodontics.

Ni-Ti ALLOY –
"Nitinol is 55% nickel and 45% titanium. Biocompatibility, corrosion resistance, shape memory effect, and elasticity make this alloy the material of choice for the production of endodontic instruments" [9][10].

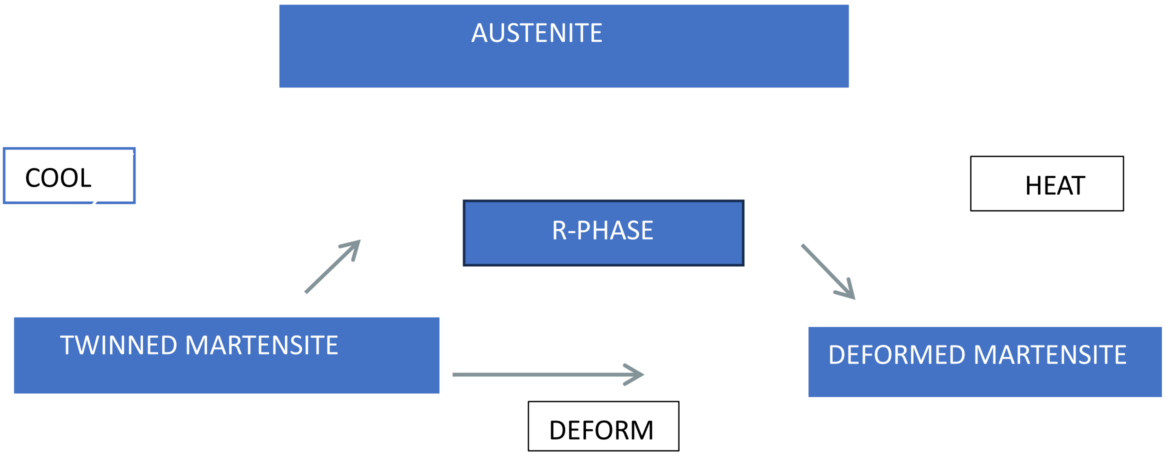
The property of shape memory enables the material to memorize a specific form and return to its original shape upon heating. Moreover, super elasticity permits nickel-titanium to undergo reversible deformation at exceptionally high strain levels. Upon the removal of load, nickel-titanium returns to its original shape. Hence, these instruments can be placed into curved canals, can be stressed more than stainless steel, and upon autoclaving, they would return to their parent phase [11][12].

However, these instruments have certain limitations. They are susceptible to separation, often caused by flexural and torsional fractures. Flexural fractures result from cyclic fatigue within curved canals, as the files undergo repeated loading and unloading, inducing phase transformations. Additionally, torsional fatigue occurs due to the repeated phase transformations during the process.

To overcome these challenges, thermomechanical treatments have been utilized to enhance the mechanical properties of nickel-titanium alloys. This has resulted in the development of rotary endodontic instruments with improved performance and durability.[13]

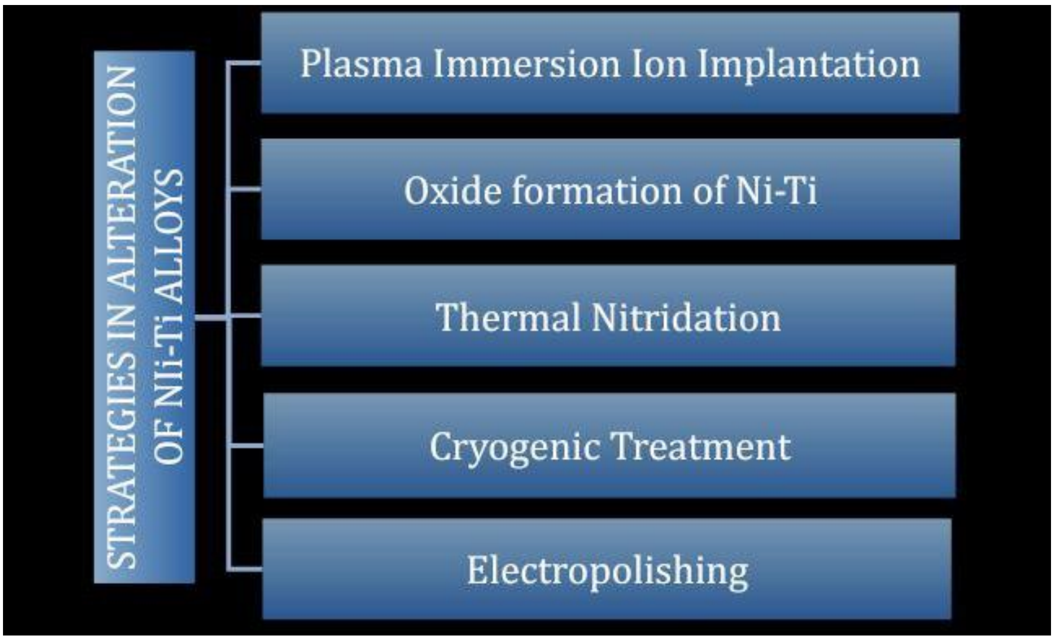
METALLURGY –
Nickel-titanium alloys exhibit two phases that depend on temperature and stress. The parent phase is identified as the "Austenite" phase, distinguished by a more flexible nature compared to stainless steel and a body-centered cubic lattice structure. The daughter phase is the "Martensite" phase, which occurs upon cooling or application of stress. The stress-induced transformation from the austenitic to martensitic phase, either through cooling or stress application, is referred to as "super elasticity" [3].

Conversion of the parent phase to the martensitic phase-



Nickel-titanium alloys demonstrate the shape memory effect, wherein they revert to their original shape from the martensitic phase upon heating or when stress is relieved.
"The austenite phase is stronger and stiffer than the Martensite phase."
The transformation between martensite and austenite involves the formation of an intermediate R-phase [14]. This R-phase exhibits the characteristics of shape memory and super elasticity. Furthermore, the R-phase has extremely good cyclic stability [15].
The R-phase transformation takes place with precipitates in the crystalline structure. Incorporating the R-phase into the design of Nickel-titanium holds the potential for developing advanced endodontic instruments [1].
"Twisted files are manufactured using a twisting method with R-phase alloy" [16].
With years passing there have been different strategies in use to obtain Nickel titanium endodontic instruments with better Mechanical properties.

STRATEGIES IN ALTERATION OF Ni-Ti ALLOYS



1. Plasma Immersion Ion Implantation
"In the late 1980s, Conrad et al. and Tendys et al. pioneered the introduction of this technique., This method elevates the surface characteristics, cutting efficiency, and wear resistance of endodontic instruments.[17]"

2. Oxide formation of Ni-Ti / Titanium Oxide
The endodontic instrument is coated with a flexible titanium oxide protective layer by using the dip coating sol-gel method. This improves the cutting efficiency corrosion behavior and failure fatigue resistance [18].

3. Thermal Nitridation
This involves Powder Immersion Reaction Assisted Coating (PIRAC) which is a nitriding process that produces Titanium nitride on Nickel-Titanium.
The placement of Titanium nitride on a Nickel titanium endodontic instrument produces increased corrosion resistance on files against sodium hypochlorite [8].

4. Cryogenic Treatment
This provides improved resistance to corrosion and wear along with better strength and microhardness of metals [19].

5. Electropolishing / Reverse Plating
During the final finish of Nickel titanium instruments, a typical surface treatment is done which is known as electropolishing this removes surface imperfections as dissolved metal ions and causes a reduction in surface irregularities which may later cause stress concentration and crack initiation [8].
Anderson et al reported electropolishing improved resistance to cyclic fatigues and poor static torsional loading resistance [20].

MODIFICATION IN MICROSTRUCTURE OF ALLOY BY THERMO-MECHANICAL TREATMENT –

Thermal processing during manufacturing of alloy –
As the nickel-titanium becomes martensitic, the flexibility increases and so does fatigue resistance.
To achieve this phase, heat treatment is done. This entails heating a material to a specific temperature and subsequently cooling it for a predetermined duration under controlled conditions [17].
Below are some of the newer endodontic instruments that have employed heat treatment for enhancing the material management area.

- M-Wire –In 2007, Tulsa Dental introduced the revolutionary thermomechanical process called M-Wire. This innovative wire remains in the martensite phase even at room temperature, showcasing improved durability and flexibility. The process entails drawing raw Ni-Ti wire in the martensite phase to its final diameter, followed by heat treatment and annealing cycles under strain. The resulting M-Wire incorporates not only the M-phase but also the A-phase and R-phase, contributing to its advanced properties in the field of endodontic instrument [21]."

Various Instruments are - Dentsply's ProFile GT Series X, ProFile Vortex, and ProTaper Next files, Path Files, WaveOne, and Reciproc (VDW, Munich, Germany) Profile GTX was launched in 2008 with better flexibility and resistance to cyclic fatigue. Wave One had better cyclic fatigue and torsional properties.

- R-Phase – Treating Ni-Ti wires with heat modifies them to rhombohedral crystal. This structure is R-Phase and is between Austenite and martensite. As mentioned earlier in this article, the R-Phase embraces better shape memory, super elasticity, and cyclic stability.

Twisted Files – In 2008, Sybron Endo introduced this phase and branded it as Twisted Files. The files are twisted into shape while in the R-Phase before undergoing a series of heating and cooling. This process aids in preserving a new shape and transforming it into the austenite phase, making it super elastic when subjected to stress [21].
On the contrary, according to Park et al, this method of manufacturing does not elicit any benefits in regards to torsional fracture [22].

K3 XF Files – In 2011, Sybron Endo introduced K3XF Files, leveraging R-Phase technology. Unlike Twisted Files, K3XF involves grinding rather than twisting during manufacturing. A specialized heat treatment, applied after grinding, enhances flexibility and alters the crystalline structure of the alloy to accommodate the stress induced by the grinding process [17].
K3 and K3XF share a similar shape, with the only distinction being that K3XF undergoes a post-machining treatment.

- Controlled Memory Ni-Ti Alloys-

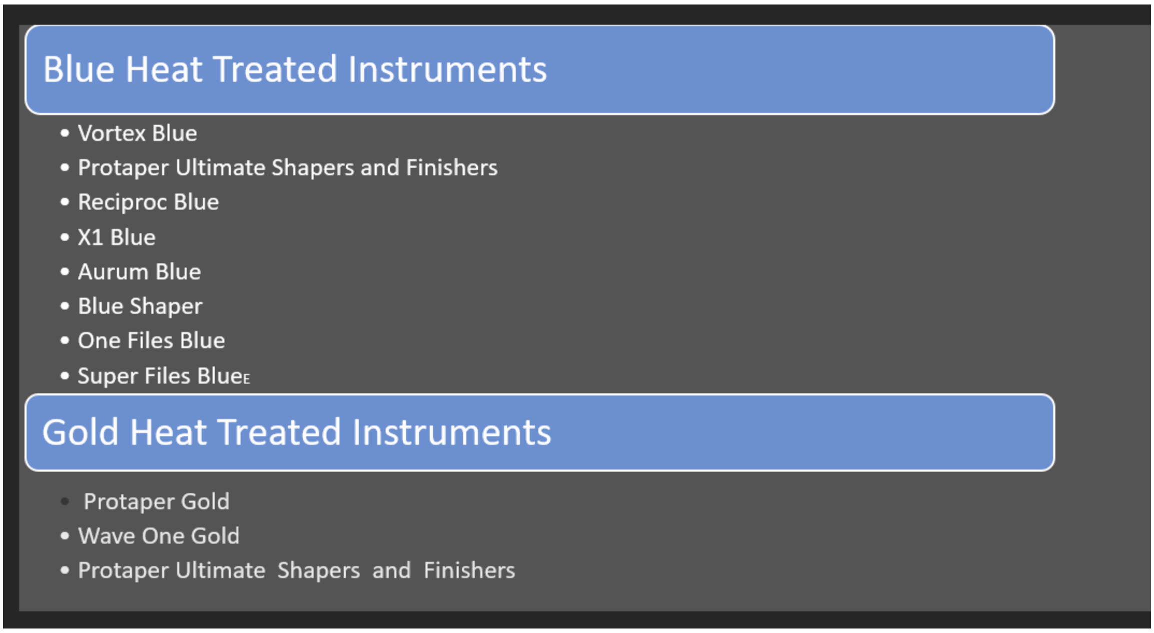
Introduced in 2010, CM Wire is produced through a thermomechanical process designed to enhance flexibility, decreases shape memory, raises transformation temperature and stays at a stable martensite phase.
CM Wire can be processed before placing it within the curved canal. However, on sterilization, these get back to their original shape.
In 2011, Hyflex CM and Hyflex EDM were commercialized which were made from CM Wire. Grinding the CM Wire produces Hyflex CM whereas usage of EDM technology produced Hyflex EDM [17].
"According to manufacturers, HEDM is 700 % more resistant to cyclic fatigue compared to HCM."
The Typhoon Infinite Flare introduced in 2011, exemplifies CM Wire technology. These instruments are exceptionally flexible at room temperature, owing to a significant proportion of martensite in their composition [21].
Another CM Wire example is V-Taper 2H.

THERMAL PROCESSING AFTER MACHINING OF FILES/POST-MACHINING HEAT TREATMENT–

Post-machining treatment is a newer process that overcomes the defects during machining and also makes the martensitic transformation occur in two stages instead of one.
The Austenite to R-phase to Martensite phase can only occur if additional heat treatment is done.
Finely dispersed Ti3Ni4 is formed as a result of heat treatment in the austenitic matrix.
In consequence, due to the presence of Ti3Ni4b "R-Phase "is formed [21].

GOLD AND BLUE HEAT-TREATED INSTRUMENTS –

"Not long ago, with post grinding process there were newer thermomechanical treatments. These treatments elicit a blue or gold-colored oxide layer as a result of which Blue or Gold heat-treated files were introduced.



The gold and blue treated instruments exhibit a controlled memory effect, allowing the operator to prebend the instrument as needed [17]."

- **Vortex Blue and Reciproc Blue**

Vortex Blue and Reciproc Blue are manufactured using M-wire as the foundational material. There is a complex proprietary heating-cooling treatment that elicits a blue color. This blue color as mentioned above is due to the presence of TiO2.

Vortex Blue, renowned for its superior fatigue resistance, cutting efficiency, flexibility, and canal-centering ability in comparison to M-Wire, derives its advantage from the increased presence of unstable martensite in M-Wire. In a comparison between Profile Vortex M-Wire and Vortex Blue, the latter demonstrated lower hardness than Profile Vortex M-Wire. A 2012 study by Gao et al. An assessment of the impact of various materials on the fatigue resistance of rotary instruments within a stainless-steel canal revealed that Vortex Blue demonstrated the highest fatigue life and flexibility, followed by M-Wire, super elastic nickel titanium, and stainless steel [17][21]."

- **Protaper Gold**

Protaper gold is also manufactured on the basis of M-wire. With repeated heating and cooling, a characteristic gold appearance is seen on the raw wire, giving the instrument a gold color.

Protaper Gold has a geometry similar to Protaper Universal. They both have a triangular cross-section with progressive taper. Protaper Gold has more resistance to cyclic fatigue when compared with Protaper Universal, and has lesser shape memory than Protaper Universal which further results in following the anatomy of the canal on removal of the instrument from the curved canal[17][21].

- **Wave One Gold**

Similar to Protaper Gold and Vortex Blue, the manufacturing of Wave One gold is also based on M-Wire. It is also formed as a result of heat treatment before and after the manufacturing process. The gold technology in Wave One Gold, according to manufacturers provides better flexibility and strength to the instrument. Wave One Gold has a parallelogram-shaped cross-section design, which improves its torsional resistance.

- **Hyflex EDM**

The manufacturing of Hyflex EDM is based on the electrical discharge machining technique. This is a non-contact thermal erosion technique that uses controlled electrical discharge to machine electrically conductive materials.

According to manufacturers, the fatigue resistance of Hyflex is 300% more as compared with other rotary nickel-titanium instruments. Mostly, they regain their shape after sterilization. According to Peters et al, more than half of the instruments which have undergone plastic deformation got back to their original shape after sterilization. Precautions need to be taken while using small instruments as they may get permanently deformed.

GENERATIONS OF NICKEL-TITANIUM INSTRUMENTS –

First Generation Nickel-Titanium Alloys –

The initial generation of nickel-titanium instruments, launched in the mid-1990s, incorporated passive cutting radial lands with a constant taper of 0.04-0.06 across the entire working length. While these instruments produced smooth root canal walls, a drawback was noted in that achieving this outcome necessitated the use of numerous files. While these instruments produced smooth root canal walls, a drawback was the need for multiple files to achieve this outcome [23][24].

Examples of First-generation Nickel Titanium instruments are Light Speed Endodontics (1992), Profile Dentsply (1993), Quantec-SybronEndo (1996) and GT System-Dentsply.

Second Generation of Nickel-Titanium Alloys –
"The second-generation nickel-titanium instruments, introduced in 2001, featured active cutting edges, enhancing cutting efficiency. This advancement resulted in the need for fewer instruments compared to the first-generation counterparts. Studies have demonstrated the system's efficiency in rapidly preparing root canals while preserving the original shape, even in curved and calcified canals. However, some studies noted instances of transportation and instrument breakage with this system."
Examples of Second generation Nickel Titanium instruments are Race, Protaper, K3, Hero shaper, Biorace, Enosequence[23][24].

Third Generation of Nickel-Titanium Alloys –
In 2007, the introduction of third-generation Nickel Titanium alloys marked a significant advancement in endodontic instruments. Utilizing advanced heating and cooling technologies, these alloys aimed to enhance instrument safety by focusing on improving metallurgical properties. The incorporation of M-Wire and R-Phase technology played a crucial role in reducing the risk of cyclic fatigue and file separation.
Examples of Third-generation Nickel Titanium instruments are K3XF Files, Sybron Endo, Profile GTX series, CM Files, and Vortex Blue [23][24].

Fourth Generation of Nickel-Titanium Alloys-
"The fourth generation of Nickel-Titanium alloys adopts reciprocation theory, involving back-and-forth or up-and-down motion in canal preparation. This approach, initiated by Blanc in the late 1950s, has influenced the development of the single-file method within this generation."
Examples of Fourth Generation Nickel Titanium instruments are WaveOne-Dentsply, Self-Adjusting Files, and Reciproc-VDW [23][24].

Fifth Generation of Nickel-Titanium Alloys –
The fifth generation of Nickel-Titanium alloys features an innovative design with an offset center of mass or center of rotation. This design translates mechanical rotation into a wave motion, aiming to minimize file engagement with dentin.
"Examples of fifth-generation nickel-titanium instruments are Hyflex/Electrical discharge machining (EDM)-Coltene, Revo-S-Micro-Mega, One Shape Micro-Mega, Protaper Next – Dentsply" [23][24].

CONCLUSION-
A proper understanding of Nickel-Titanium instruments with respect to their properties, metallurgy, and generations has benefitted endodontic treatments by making them easier, less time-consuming, and more successful. Intracanal separation of endodntic instruments is still a noticeable concern. Further improvements in metallurgy can lead to lesser instrument failure.

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