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REVIEW ARTICLE

Metallurgy of Rotary Files- A Review

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Abstract

Over the past three decades, the nickel–titanium (NiTi) rotary instruments have highly improved the quality of the cleaning and shaping of the root canals. Their unique super-elasticity and shape memory of these instruments reduce the possibility of the canal transportation along with saving the time for both the patients and the clinicians. Several commercial types of these instruments, produced by different manufacturers, have currently become available by modifying the characteristics of NiTi alloy and also the cross-sectional shapes, cutting edges, taper, numbers and distances between the flutes of the instruments. Five generations for NiTi rotary instruments have been introduced based on the properties, and method of application, till date with numerous advancements in their newer alloy microstructure with various surface treatments to improve its mechanical properties.
Keywords: NiTi, Austenite, Martensite, M-wire, R-phase, CM wire

1 | INTRODUCTION

The epitome of an endodontic treatment should satisfy the bio-mechanical principles of cleaning and shaping of the root canal system which is influenced by type and efficiency of endodontic instruments used for the procedure. (1) Hence there were advent of newer generations in endodontic files with several evolutions in terms of crystal characteristics or phase transformations (metallurgy) also surface treatment of endodontic instruments for improved mechanical properties. (2)

It appears to be necessary to select appropriate instruments for different cases due to the vastly prevalent complexities in the root canal morphology (curved canals, calcified canals, blunderbass canals). Therefore, a proper knowledge on the metallurgy of rotary instruments and its mechanical properties conclusively determines the treatment outcome. (3) Hence there was development of rotary files with varying crystal characteristics intended in minimising the unanticipated errors (instrument separation, ledge, canal transportation) resulted by the use of conventional rotary instruments. (4) This review is intended to summarize the unique properties of Nickel-Titanium (NiTi), various phases and mechanical properties of both traditional NiTi instruments and contemporary NiTi instruments.

History

Long before the advent of NiTi files into dentistry, endodontic instruments used to clean and shape root canals were made up of carbon steel and stainless-steel which were less flexible and produced procedural errors which were overcome by the introduction of NiTi instruments. (5)

NiTi alloy was first developed by W. F. Buehler, a metallurgist in 1960s, with unique properties of super-elasticity and shape memory which did not confine to normal metallurgic properties of alloys (6) . It was Harmeet Walia (7) who first fabricated an endodontic file from a NiTi arch wire in 1988. Since then, NiTi alloy has become an inevitable part of endodontics.

NiTi: metallurgical structure and phases

Nickel and titanium are transitional metals. Transitional metals or elements are those that have properties of both metals and non- metals. NiTi alloys are usually equiatomic in nature usually with a 1:1 atomic ration. Majority of endodontic instruments approximately contain about 55% of nickel and 45% of titanium by weight. (8)

The unique features of NiTi instruments are its super-elasticity and shape memory property which usually arises due its microstructural phase transformation. (9) NiTi can have 3 different forms: Austenite, Martensite and R-phase (intermediate phase). (10) The character and relative proportions of which determine the mechanical properties of the metal (11). The "Parent phase" or "Austenite phase" has a **body centred cubic** lattice structure that only occurs at high temperature and low stress exhibiting a strong and rigid characteristic. (11) The "Daughter phase" or "Martensitic phase" has a **face centred cubic** lattice structure that occurs at low temperature and high stress exhibiting a soft and ductile characteristic. (11)

The **super-elasticity** property of NiTi alloy is induced due to transformation from the stable austenitic to stress induced unstable martensite which tends to reverts back to its original shape on unloading (stress induced property). (12) Whereas, the **shape memory** property of NiTi alloy is induced due to a transformation from a stable austenite to a stable martensite phase (martensitic re-orientation) which is a specified heat-controlled property and will not regain its original shape on unloading. This allows the alloy to remember its original shape and retain to it when heated above its transition temperature. (12)

Properties:

When NiTi instrument is used, it undergoes a stress-strain behaviour (13) and this stress-strain behaviour best depicts the variations in the crystal configurations of the alloy which is responsible for their unique properties. When introduced into a root canal, there occurs an initial elastic deformation of NiTi instrument followed by a transformation from austenite phase to a martensite phase. After transformation, the instrument undergoes a state of both elastic and plastic deformation. On ceasing instrumentation, the sequence of events is reversed, there occurs a decrease in elastic strain, followed by transformation of martensite to austenite structure. Finally, as bending movement decreases the elastic strain reduces to zero. But a small amount of permanent angular deformation remains in instrument because a permanent deformation is induced during use of NiTi instrument which does not occur in cases of any other alloys. Other alloys may undergo permanent deformation and will not revert back to its original shape unlike NiTi alloy due to its **super-elasticity** property. (14)

Most of the NiTi instruments used for cleaning and shaping of root canals were heat treated during manufacturing and remain in a stable austenitic structure at both room and body temperature. When they are introduced into the canals, it produces a stress induced martensitic structure (unstable) and

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once the stress is relieved and when the instrument is back to room temperature, it reverts back to austenitic structure. This phenomenon is called **shape memory** property. (15) In general this mechanism of reversible transformation between austenitic and martensitic structures in NiTi which is of clinical significance. (16)

When stressed or upon cooling of NiTi the austenitic phase can transform into two phases namely, martensitic phase or an intermediate phase between the austenite to martensitic transformation called the R-phase, which has a rhombohedral crystal structure.

The temperature that induces conversion from twinned martensite to austenitic structure is termed a s **transformation temperature**. (11) There is specific transformation temperature for start and finish of each phase of NiTi alloy. Usually, transformation temperature range of NiTi is well below or close to body temperature. And transformation temperature influences the use of NiTi alloy in its different properties. If the austenitic transformation temperature is less than the body temperature, it produces the super-elastic effect of the NiTi alloy. (17) But if the body temperature is less than the martensitic transformation temperature it produces the shape memory property of NiTi alloy. (17)

Alloy microstructure of NiTi instruments

Conventional NiTi

Conventional NiTi instruments remain in a stable austenite phase but on instrumentation it produces a stress induced martensite phase which is unstable which tend to straighten during preparation leading to canal transportation. (18) They are usually manufactured by milling or grinding process tends to acquire surface imperfections or irregularities, milling marks or metal flash which remain vulnerable for crack propagation and ultimately fracture of the NiTi instrument. (19) Hence various studies aimed in improving the surface characteristics by thermomechanical treatments which may significantly alter the material properties.

M-wire

M-Wire (Martensitic wire), introduced in 2007 by Dentsply, is produced by applying a series of heat treatments to NiTi wire blanks (20) Here the austenite finish temperature (A_f) is higher (40-50^oC) than normal which gives rise to the phase composition of austenite with small amounts of R-phase and martensite that render the instrument more super elastic than conventional NiTi instrument. (21) Advantageous property is that these instruments need less stress for their martensitic transformation than the conventional NiTi instrument. They exhibit greater resistance to cyclic fatigue. (22) Instruments with M-with technology include ProFile Vortex, ProFile GT Series X, ProTaper Next.

R-phase

The R-phase was developed by Sybron Endo in 2008. R-phase is an intermediate phase (rhombohedral structure) that can form during forward transformation from martensite to austenite on heating and reverse transformation from austenite to martensite on cooling. (23) The phase composition of R-phase is purely austenite. It exhibits unique characteristics of low elastic modulus with less transformation strain which will require only less stress to produce plastic deformation in R-phase (24). Hence NiTi during manufacturing process the alloy will be brought to its R-phase for easy twisting or grinding and then back to the stable austenite phase. An instrument made from the R-phase wire would be more flexible (25). Instruments with R-phase technology are Twisted file, Twisted file Adaptive, K3XF.

CM wire

Controlled Memory (CM) wire was introduced in 2010. This novel NiTi alloy was found to have properties that controlled the memory making the files extremely flexible. (26) The phase composition of CM wire is completely made of martensite. Exhibits only shape memory property but not super-elasticity at body or root canal temperature. [(27)] But will exhibit super elastic property if it undergoes sterilisation cycles. The major advantage is that, no canal transportation occurs unlike conventional NiTi instruments, CM wire lacks super-elasticity property hence it tends to adapt to the canal morphology and they do not fully straighten during preparation of curved canals. (28) Instruments with CM Wire technology are Hyflex CM, Hyflex EDM, Protaper Gold, Waveone Gold, Vortex Blue, Reciproc Blue, V-taper 2H.

MaxWire

Max wire- Martensite Austenite electro polish file X, introduced by FKG Dentaire in 2015 is the most recent advancement in thermomechanical treated files. This is the first endodontic NiTi alloy that has both shape memory and super-elasticity effect in clinical application. (29)These instruments are straight at room temperature and exhibit a shape memory effect when inserted into the root canal (M-phase to A-phase) and possess super-elasticity during preparation. Instruments made of MaxWire are XP-endo Shaper and XP-endo Finisher. (30)

Conclusion

New endodontic files for root canal instrumentation are introduced just like older systems are updated. Today, the safest, most efficient, and simplest file systems utilize the most proven design features from the past, coupled with the most recent technological advancements currently available. The concept of shaping the root canal walls and maintaining the original canal curvature and shape has now become the prime motive of designing the new generation of NiTi rotary files. Thus, appropriate files for each situation defines the betterment of the endodontic treatment. Martensite files for severely curved canals, austenite files in cases of sclerotic or calcified canals with proper irrigation protocol and recommended speed and number of use of the files are highly recommended. However, each rotary system has its own advantages; so, a hybrid concept should be utilized to gain optimum advantage of the newer generation rotary systems.

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