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Review Article

NiTi rotary system in endodontics – An overview

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ABSTRACT

Success of root canal treatment depends on complete removal of microorganisms which is done through chemomechanical instrumentation of root canal system. To achieve this, earlier stainless steel files were used which had inherent disadvantages of excessive tooth cutting as well as straightening of the canal curvature. This Eventually led to introduction of NiTi alloy which has proven to be a valuable adjunct in root canal preparation. These NiTi files are highly flexible and elastic due to their Metallurgical properties like Austenite, Martensite, Intermediate R phase. It has got greater strength and modulus of elasticity making them more beneficial in curved canals. Over the evolution various changes have taken place within the NiTi rotary systems and various generations too. Thus the Objective of this Review article is to completely discuss about Evolution, Metallurgy, Mechanical properties, Generations of NiTi rotary system.

1. Introduction

Biomechanical preparation is one of the fundamental step in root canal treatment. This can be achieved by proper cleaning and shaping of the root canal, by following Schilder's biological and mechanical objectives. That is continuous tapering, conical shape with the narrowest crosssectional diameter apically and the widest diameter coronally. In the past few years, various innovations in NiTi have taken place making them more convenient and befitting for all kinds of canal anatomies.

The main aim of this literature is to enlighten the various aspects of NiTi used in endodontics including their evolution, properties, design features, different generations which have revolutionised dentistry.[1] The information review is based on the search information in journals indexed from 2000 in Medline, Scielo, Pubmed with the use of description such as root canal preparation, NiTi alloys, generation of NiTi alloys, mechanical properties and various textbooks.

Evolution – In 1963, a Metallurgical Engineer William Buehlerin introduced Nickel Titanium alloy in Dentistry, it was named as Nitinol [Ni-nickel, Ti- titanium, NOL- Naval Ordnance Laboratory] Ever since, it has revolutionized dentistry.[2] First hand held NiTi endodontic instruments, which were made of orthodontic wire was introduced by Walia, Brantley and Gerstein in 1988[2] nearly eliminated iatrogenic instrumentation complication. Later these instruments were fabricated by different manufacturing methods, variations in tapers, length, tip

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size, cutting properties, cross section. Its been almost four decades since their debut, still various changes in design seen considerably and forge in manufacturing and alloy processing.

1.1. Metallurgy and mechanical properties of NiTi

Ever since NiTi was introduced it changed the concept of traditional stepback technique to crowndown technique in chemo mechanical preparation of root canal. NiTi is a combination of Nickel alloy (55 wt%) and Titanium alloy (45 wt %) and some amount is substituted by Cobalt(2 wt %). This composition is known as 55 Nitinol. Another type is 60 Nitinol (5% more nickel) but most commonly used is 55 nitinol because of its better shape memory effect.[3]

The lattice organization of NiTi alloys are austenitic, martensitic, intermediate R phase.

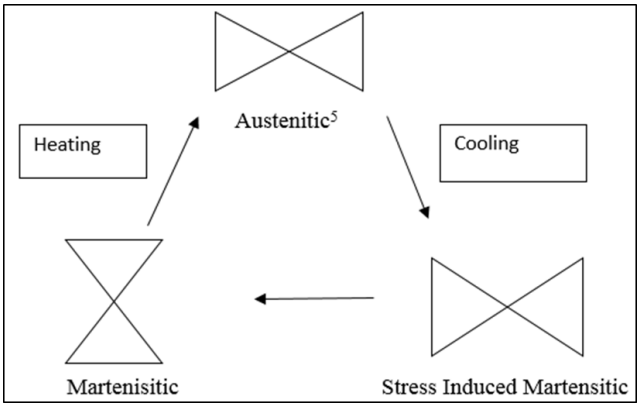
Austenitic phase – It is a body centered cubic lattice, stable, also called parent phase. Elastic modulus is 80-90 GPa. It possess superelastic property.[4,5]

Martensitic phase – It is a hexagonal lattice, unstable, also called daughter phase. Elastic modulus is 30-40 GPa. It possess shape memory property.[4,5]

Intermediate R phase –It is rhombohedral distorted phase which is formed when transition occurs from austenite to martensitic phase. Elastic modulus is less than martensitic.[4]

Mechanical properties and crystallographic arrangement of the alloy can be altered by temperature and stress. The distinctive feature of NiTi are shape memory, superelasticity, biocompatibility. These features are the reason for popularity of NiTi in clinical dentistry compared to other metals which are less popular.[4,5]

The shape memory effect, allows NiTi instruments to "memorize" a certain form and return by heating to its original form because of transition between two crystallographic phases: a crystalline phase (called martensitic phase) which is stable below a certain critical temperature, and an austenitic phase that is stable above that critical temperature (critical temperature range is in the range of -50 to 100 degree Celsius). The superelasticity, allows NiTi alloy, when introduced into the canal (austenite phase), upon stress (example: curved canals) it changes to stress induced martensite phase, allows complete recover of strain upto 8% (Thompson 2000). This stress induced martensitic is not stable at the present temperature of the canal, on unloading (removal of instruments from canal) it retransforms to its original shape.[4]



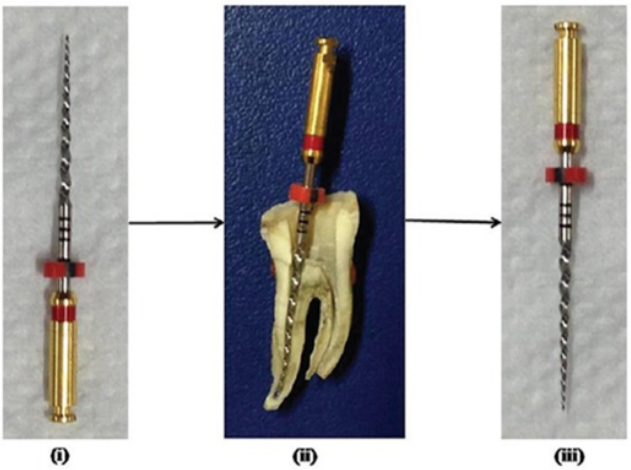


Fig. 1: Properties ofNiTi file:(i) conventional rotary NiTi file (ii) superelasticity (when stressed in the canal) (iii) shape memory (when stress is released)[6]

Table 1: Mechanical properties of NiTi[7]

	Austenite	**Martensite**
Ultimate tensile strength (MPa)	800–1500	103-1100
Tensile yield strength (MPa)	100-800	50-300
Modulus of elasticity (GPa)	70-110	21-69
Elongation at failure(%)	1-20	Up to 60

2. Various Advances in NiTi Alloy

2.1. Conventional NiTi alloy

Consist of 56 wt % Nickel and 44 wt % Titanium. It consist of austenite phase which possess superelastic properties. It is manufactured by grinding process not by twisting or machining.[4,8]

Disadvantages –It leads to an surface defects, reduced fracture resistance, cutting efficiency.

Examples – first generation NiTi files(Quantec System (Kerr-United States), ProFile (Dentsply Maillefer,

Ballaigues, Switzerland), Light speed files (Kerr, Brea, CA, USA),Greater Taper (Dentsply Maillefer).[9]

2.2. *Electropolishing*

Advantages -helps to remove the surface irregularities, cracks. Increase in fracture resistance, cutting efficiency, resistance to corrosion.[4]

Disadvantages- presence of micro fracture (Herold et al 2007).

Examples – second generation NiTi files(Protaper (Dentsply tulsa), K3 system (Sybron Endo-United States), Endosequence (Brasseler, savannah,GA, USA),Biorace (FKG dentaire, Switzerland), RaCe (FKG Dentaire).[4,9,10]

2.3. *M -wire*

Introduced in 2007 by Dentsply Tulsa. Objective of M wire is to make more flexible NiTi alloy with enhanced cyclic fatigue resistance. Consist of 55 % nickel, 44% titanium with trace elements of less than 1 wt%. It exist in austenite, small amounts of martensite, R phase at body temperature.[4]

Advantages - resistant to cyclic fatigue, super elasticity, flexibility.

Examples -Third generation NiTi files (HyFlex CM (HyFlex; Coltene Whaledent), K3XF (SybronEndo, Orange, CA), ProFile GT Series X (GTX; Dentsply Tulsa Dental Specialties, Tulsa, OK), ProFile Vortex (Vortex) and Vortex Blue (Dentsply Tulsa), TYPHOON™ Infinite Flex NiTi (TYP CM; Clinician's Choice Dental Products, New Milford, CT), Twisted Files (SybronEndo) Fourth generation niti files (Reciproc (VDW) and WaveOne (Dentsply Sirona), Self-adjusting file (SAF) (ReDent Nova), Fifth generation NiTi files (Revo-S, One Shape®(Micro-Mega®) ProTaper Next (Dentsply Tulsa Dental /Dentsply Maillefer).[1,10]

2.4. *R phase*

Also called twisted files introduced by Sybron endo in 2008. It is manufactured by subjecting it to 2 rounds of grinding process followed by twisting. It is an intermediate phase between austenite and martensite.[4]

Advantages -higher resistance to cyclic fatigue, canal centering, flexibility.

Disadvantage – decreased maximum torque compared to M wire.

Example – seventh generation NiTi files [k3 XF, TF adaptive (Sybron endo)].[1,10,11]

2.5. *CM wire*

Thermomechanically treated NiTi alloy introduced in 2010. It exist in mixture of Austenite , Martensite ,small amounts of R phase at room temperature. It doesn't possess superelastic properties (Zhou et al).[4]

Advantages – greater flexibility, cyclic fatigue resistance, errors during preparation.

Disadvantages – decreased cutting efficiency.

Examples – Hyflex CM (Coltene, Switzerland), Typhoon CM(clinicians choice dental products, USA), ProDesign R and ProDesign logic system (easy dental equipments, Brazil).[10]

2.6. *Electrical discharge machining (EDM)*

Developed from CM wire by Coltene known as Hyflex EDM. The main objective was to overcome the disadvantage of Hyflex CM wire that is to enhance fracture resistance and cutting efficiency. It is produced by noncontact process by electric discharge in electric fluid. It consist of martensitic and less amount of R phase. Absence of austenite formation.[4]

Advantages – enhance fracture resistance, cutting efficiency compared to Hyflex CM and other NiTi instruments.

2.7. *MAX wire (martensitic, austenitic electropolished file -X).*

Introduced by FKG, it consist of both super elasticity and shape memory. These files can be adapted to different root canal morphologies. It changes from martensitic to austenitic phase.[4]

Examples – XP endo finisher (XP -F), XP endo shaper(XP-S), XP endo retreatment (XP -R)

2.8. *T -wire*

Introduced by MicroMega. New generation file system obtained by heat treatment. Main objective is to enhance the flexibility and cyclic fatigue. It has unique cross section with triple helix, that is 2 main cutting edge and 1 secondary cutting edge. Features are similar to single file system. cyclic fatigue resistance of 40% given by manufacturer. Used in complex root canal morphology.[4]

Examples -2 shape file system

2.9. *C -wire*

Introduced by micromega. Based on single file system and manufactured by C wire heat treatment. Enhanced cyclic fatigue resistance, flexibility, canal centering ability and controlled memory. used in complex root canal system.[1,4]

Examples – One Curve

2.10. *Gold and blue heat treated NiTi files.*

Dentsply Sirona introduced this system in 2012, by repeated heating and cooling resulted in changes in surface colour resulted in formation of titanium oxide layer. In NiTi blue wire alloy, thickness of oxide layer is 60-80 nm

and in NiTi gold wire its 100-140 nm. The significance of these is to compensate for loss of hardness during instrumentation. Which has led to Better cyclic fatigue resistance, flexibility, controlled memory. Used in complex root canal morphology. [1,4,10]

Examples – Vortex Blue and ProTaper Gold (Dentsply Sirona), Sequence rotary file and X1 Blue file (MK Life, Brazil), Reciproc blue (VDW), WaveOne gold.

Table 2: Design feature if NiTi [1,3,12]

Taper	Increase of 2mm diameter from file tip to handle of the file No taper – Quantec, greater taper – profile (constant taper with different apical tip), odd taper - Quantec, orifice shaper, Protaper universal (both varying tip and tapers)
Flute/groove	Groove on working surface, collects debris out of root canal
Cutting edges	Working area of the file which cuts root dentin.it is directly proportional to sharpness and angle of incidence.
Land	It is formed between flutes, which projects from centre of core to tip of the cutting edge axially. Prevents canal transportation
Pitch	Number of spirals or threads per unit length and measures the distance from one cutting edge to next cutting edge. consists of variable pitch (greater taper files), constant pitch (Profile)
Tip designs	Tip of instrument, consists of cutting tip (flexmaster), partial cutting tip (ProTaper Universal) and noncutting tip or passive tip (Profile System)
Helix angle	Angle formed by the cutting edge to long axis of file. It ascertains the cutting efficiency of the file.
Rake angle	Angle formed by leading edge to the radius of file. It consists of positive rake angle or obtuse (ProTaper, Hero 642, RaCe, k3, Quantec), negative rake angle or acute (Profile), neutral angle (light speed ,GT rotary system)

Precautions to be taken, while using rotary files OR factors to be considered in rotary NiTi file

1. Instrument factors
   (a) Torsional stress - Fracture of NiTi files occurs because of following reasons when instrument tip is larger than the canal shape, taper lock and when operator exerts extravagant pressure on the instrument.
   (b) Torque – Torque is a measure of how much force acting on an object cause that objects to rotate. When higher torque values is used, it might lead to instrument locking or fracture and lower torque values leads poor cutting but less fracture is

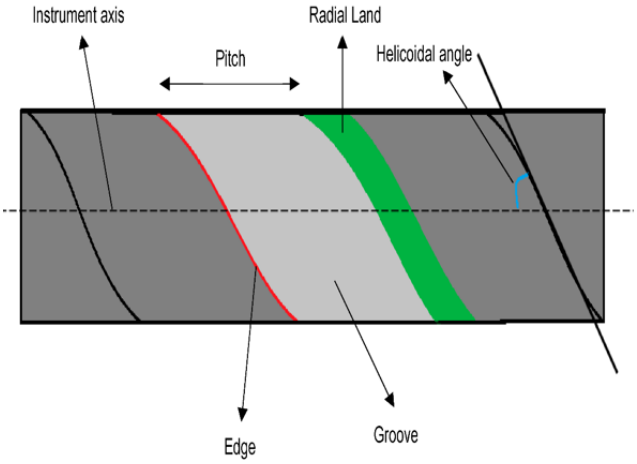


Fig. 2: Design feature of NiTi file system. [13]

Table 3: Generations of NiTi rotary system. [1,4,10,14]

First generation files	Rounded noncutting tip, U shaped - radial land, step back technique, crown down technique, fixed taper, negative rake angle
Second generation files	Based on design of instrument, actively cutting without radial lands (except -k3), multiple tapers, positive rake angle, variable pitch-Mtwo, alternate cutting edge-RaCe
Third generation files	Based on advancement in alloy, thermomechanical treatment, cyclic fatigue resistance, M wire, R phase, CM wire -blue and gold surface conditioning
Fourth generation files	Based on different kinematics, reciprocating motion, single file system and single use concept, adaptive motion, reduces working time, instrument fracture, cross contamination. SAF-hollow reciprocating instrument with simultaneous irrigation
Fifth generation files	Based on changes of instrument design, offset (center of rotation), reduces taper lock and noncontact space for better debris extrusion, swaggering effect. Revo-S - snake like motion, One shape - continuous rotation and cutting action in three zones
Sixth generation files	Incorporation of engine driven instruments for glide path, innovation in irrigation (SAF, XP finisher) retreatment
Seventh generation files	Based on new manufacturing process, twisted file, shape setting (TRUshape, XP shaper), electric discharge machining (EDM)

noticed. To prevent this always use lower or equal torque values as given by manufacture.[15]

(c) Speed – speed refers to revolution per minute. cyclic fatigue is inversely proportional to speed.[16] Greater speed leads to lots of disadvantage like canal transportation, breakage of instruments, loss of tactile sensation.

2. Anatomy of the canal – Greater the curvature of canal, more is the instrument fracture. It is most commonly seen in the apical one third compare to middle and coronal third.[17]
3. Skill and experience of operator – Undeniably operator experience, skills, techniques in dental procedures can prevent file separation and other iatrogenic errors. Following points to be considered while operating
   (a) Always examine the instrument before and after use
   (b) Do not use in dry canals
   (c) Excessive forces on files to be ignored[17]
4. Manufacture instruction –It is the key factor to be considered. By following proper instruction given by manufacture like proper torque, speed, frequency of use, conspicuously, all the iatrogenic errors can be avoided.
5. Sterilization – Most accepted theory is that thermocycling may result in metal fatigue. But there are studies reported that sterilisation doesnot adversely affect the endodontic instruments. still its controversial further studies are required to evaluate the influence on NiTi files.[3,5]
6. Corrosion – Earlier body temperature of mouth, saliva (electrolytes) were considered to be reason for corrosion of NiTi alloys. There was no difference was seen in the surface characteristics of NiTi alloy under scanning electron microscope (Edie et al). United States Navy tests found that NiTi had very good corrosion resistance and performed well in marine environment.[3,5]
7. Allergy – Nickel was boundlessly used in fashion jewellery and consumer products. It is a common allergen, prevalence of 28.5%. Titanium was considered as no allergy potential but some others suggest allergies exist. Research on titanium allergies is essential.[3,5,18]

3. Conclusion

With advancement of technology major progress in endodontic therapy has taken place, from earlier stainless steel to NiTi rotary file system. An exceptional feature of NiTi that is shape memory, superelasticity has positive impact towards outcome of root canal shaping. With integration of various advances like M wire, CM wire, Max wire, EDM, Gold and Blue coated NiTi files led to improved durability, reliability and clinical performance of treatment. New endodontic files keeps on upgrading in the market since from first generation to current seventh generation. Many variables like mechanical properties, cross section, manufacturing, designs, tapers, cutting edge, tip designs which has also influenced more favourable outcomes in flexibility, fatigue resistance, resistance to fracture.[1,8,12]

4. Conflict of Interest

The author declares no relevant conflict of interest.

5. Source of Funding

None.

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