REVIEW ARTICLE

ROOT CANAL INSTRUMENT MATERIALS-METALLURGIC PROSPECTIVE: A MINI REVIEW

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ABSTRACT:
Root canal procedures are very common these days and so is the increasing demand of better root canal instruments. NiTi are one of the most common and better alloys used for manufacturing of these instruments. These instruments have better thermodynamic properties producing a shape memory effect under suitable conditions. Therefore, this review elaborates the metallurgic prospects of NiTi instruments.
Key words: Nickel, Root canal, Titanium

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INTRODUCTION

The first useable Nickel titanium (NiTi) alloy was developed in 1960, at the U. S. Navy Ordinance Lab in Silver Spring, Maryland by William Buehler, a metallurgist who was investigating nonmagnetic, salt resisting, waterproof alloys for a space program. The thermodynamic properties of this alloy were found to be capable of producing a shape memory effect when specific, controlled heat treatment was undertaken. Initially it was used for military purposes, but it soon became apparent that NiTi was also useful for other applications, such as orthodontic wires and dental burs.[1-3]

NICKEL – TITANIUM STRUCTURE

The crystal structure of NiTi alloy at high temperature ranges (100°C) is a stable, body-centred cubic lattice which is referred to as the austentic phase. NiTinol has the particular characteristic that when it is cooled through a critical transformation temperature range (TTR), the alloy shows dramatic changes in its modulus of elasticity (stiffness), yield strength and electric resistivity as a result of changes in electron bonding. The transformation induced in the alloy occurs by a shear type of process to a phase called the Martensitic or daughter phase, which gives rise to Twinned martensite that forms the structure of a closely packed hexagonal lattice. Almost no macroscopic shape change is detectable on the transformation, unless there is application of an external force. The martensite shape can be deformed easily to a single orientation by a process known as de-twinning to detwinned martensite , when there is a 'flipping over' type of shear.[2]

The deformation can be reversed by heating the alloy above the TTR (reverse transformation temperature range or RTTR) with the result that the properties of the NiTi alloy revert back to their previous higher temperature values. The alloy resumes the original parent structure and orientation as the body-centred cubic, high temperature phase termed austenite with a stable energy condition. This phenomenon is termed shape memory and allows the alloy to return to its previous shape, by forming strong, directional and energetic electron bonds to pull back displaced atoms to their previous positions; the effect of this transformation is instantaneous.[4]

STRESS - INDUCED MARTENSITIC TRANSFORMATION

The transition from the austensitic to martensitic phase can also occur as a result of the application of stress, such as occurs during root canal preparation. In most metals, when an external force exceeds a given amount, mechanical slip is induced within the lattice causing permanent deformation; however, with NiTi alloys a stress-induced martensitic transformation occurs, rather than slip. This causes:

- A volumetric change associated with the transition from one phase to the other and an orientation relation is developed between the phases.

• The rate of the increase in stress to level off due to progressive deformation even if strain is added due to the martensitic transformation. This results in the so-called super-elasticity, a movement which is similar to slip deformation.
• Spring back occurs when the stress decreases or stops without permanent deformation occurring. Spring back is defined as load per change in deflection to the previous shape with a return to the austenite phase, provided the temperature is within a specific range.[3]
This quality is not unique to NiTi because cuzn, cual, aucd, and ninb alloys also show it, but these alloys are less biocompatible. The superelasticity is most pronounced at the beginning, when a first deformation of as much as 8% strain can be totally overcome. After 100 deformations, the tolerance is about 6% and after 100,000 deformations, it is about 4%.[3,4]

MANUFACTURE OF NITINOL ALLOY

Nickel–titanium alloy production is a very complex process that consists of:
• vacuum melting/casting
• press forging
• rotary swaging
• rod/wire rolling
Two methods for manufacturing process of nickel titanium :

a) Arc melting
- Requires multiple remelts to ensure homogenicity
- Produces minimum contamination

b) Induction melting
- Current technique
- Use of vacuum induction melting in graphite crucibles
- Ensures effective alloy mix
- Carbon contamination forming tic which are uniformly distributed

The double vacuum melting manufacturing process ensures purity and quality and maintains the mechanical properties of the alloy.[3]

CONSTRUCTION OF ROOT CANAL INSTRUMENTS

The manufacture of NiTi endodontic instruments is more complex than that of stainless steel instruments, as the files have to be machined rather than twisted. The super-elasticity of the alloy means that it cannot maintain a spiral as the alloy undergoes no permanent deformation. The instrument profile has to be ground into the NiTinol banks. Further difficulties during production include elimination of surface irregularities (milling marks) and metal flash (roll-over) on the cutting edges that may compromise the cutting ability of these instruments and potentially cause problems with corrosion.[4]

EFFECT OF STERILIZATION

Recent studies on endodontic instruments indicate that there are changes, but that they are not seen as clinically relevant. Dry heat and steam autoclave decreased the flexibility of stainless steel and NiTi files, but the values satisfied International Standards Organization specifications. Clinical use with sodium hypochlorite (naocl) and repeated sterilization ‘‘did not lead to a decrease in the number of rotations to breakage of the files’’.[3]

ADVANTAGES OF NITI INSTRUMENTS

Superelasticity- The superelasticity of NiTi allows deformation of as much as 8 per cent strain to be fully recoverable, in comparison to a maximum of less than 1 percent with alloys such as stainless steel. The improved flexibility allows better control of root canal shape.[5]
Centering ability- One of the objectives of optimal instrumentation is that the apical foramen should remain in its original position. The centering ability of an instrument refers to the dimension and direction of canal transportation during root canal preparation. Displacement of canal towards the furcation or towards the outer curvature increases the risk of perforation.[8]
NiTi shows good centering abilities with only minor deviations from the main axis of the root canals. The use of NiTi instruments decreased the prevalence and the degree of transportation and straightening when compared with hand instruments. Nevertheless, these effects could not be entirely eliminated. The straightening and centering ability vary amongst the different NiTi systems possibly due to the flexibility (size and taper).[6,7]
Cleaning ability- Tan and Messer found that instrumentation to larger file sizes using rotary NiTi instruments resulted in significantly cleaner canals in the apical 3mm than hand instrumentation. However, neither technique was totally effective in cleaning the apical canal space. After instrumenting curved root canals of extracted human teeth with either rotary NiTi or stainless steel hand files, Schafer et al. Discovered uninstrumented areas with remaining debris in all areas of the canals irrespective of the preparation technique. Cleanliness was found to decrease from

the coronal to the apical part of the root canal. Peters et al. used micro-CT data to analyse preparation of root canals of maxillary first molars after instrumentation using K-type hand files and three rotary NiTi file systems. They found that all instrumentation techniques left 35 per cent or more of the canal's dentine surface untouched, with very little difference found between the four instrument types.

These findings highlight the limited ability of endodontic instruments to clean the root canal and reinforce the importance of antibacterial irrigation for enhanced disinfection of the canal system.[6]

BIOCOMPATIBILITY

Nickel is used in fashion jewellery and is known as a widespread allergen. Nickel hinders the mitosis of fibroblasts but NiTi seems to lack that effect and shows good biocompatibility. In the alloy, the Ni is chemically joined to Ti in a strong intermetallic bond and the alloy surface shows a thin tio_2 layer which acts as a barrier for the Ni release, so the risk of reaction, even for patients with Ni sensitivity, is extremely low.[7] Less preparation time- While some comparative studies have shown evidence for shorter working times for rotary NiTi preparations when compared with manual instrumentation, other studies have shown no difference. It is likely that working time is more dependent on operator factors and the preparation technique used rather than the instruments themselves. For example, NiTi systems using only a small number of instruments, e.g., protaper (Dentsply Maillefer) will prepare canals faster than systems using a large number of instruments, e.g., Lightspeed (Lightspeed Inc., San Antonio, Texas, USA). Better anticorrosive properties than stainless steel- NiTinol wires showed better resistance to corrosion so were felt more appropriate for intraoral use than stainless steel. The NiTinol alloy exhibits a pitting type corrosion attack seen as numerous, round-bottomed, corrosion pits interspersed with corrosion products rich in titanium. This was presumed to be a mixed oxide of titanium and nickel. There were no differences in the clinical performance of the two wires, in terms of corrosion.

DISADVANTAGES OF NICKEL TITANIUM

Canals with wide oval- or ribbon-shaped cross sections present difficulties for rotary files, and other techniques, such as circumferential filing and ultrasonics, are sometimes used in those canals. Oscillating files that have been recommended for these canal types do not perform as well as NiTi rotaries, particularly in curved canals. Instrument fracture- Rotary NiTi files may undergo fracture due to fatigue without prior evidence of plastic deformation. Clinically, deformation and fractures of endodontic files do occur, but Spili *et al.* Showed that rotary files fractured in a specialist practice only slightly more frequently compared to stainless-steel hand files.[2]

Fractured rotary NiTi instruments have been classified into those that fail as a result of cyclic flexural fatigue or torsional failure or a combination of both.[8]

Torsional load is transferred into the file through friction against the canal wall while cyclic fatigue occurs with rotation in curved canals. Both factors work in concert to weaken the rotary file. Fine and flexible files are vulnerable to torsional load but are resistant to cyclic fatigue. Conversely, more rigid and larger files can withstand more torque but are susceptible to cyclic fatigue. The greater the amount and the more peripheral the distribution of metal in the cross section, the stiffer the file. Therefore, a file with a greater taper and larger diameter is more susceptible to fatigue failure.[2]

Occurrence of fractures can be prevented by:

- Use of gel based lubricants
- Flooding the chamber with copious irrigation
- Low motor speeds
- Preparation technique
- Replacing used files sooner[8]

Single-use of these instruments has been advocated by some, and there is currently no agreement as to a recommended number of uses of these instruments. The most important influence on defect rate was found to be the operator, which may be related to clinical skill or a decision to use instruments a specified number of times.[5]

With NiTi instruments there has been a considerable improvement in the file designs but challenges of instrument separation due to cyclic fatigue has led researchers to continue their endeavor to prevent it. The mechanical performance of NiTi alloys is extremely sensitive to their microstructures and associated thermomechanical treatment history. The martensitic phase of NiTi has some unique properties that have made it an ideal material for many applications. The martensitic form of NiTi has remarkable fatigue resistance. Instruments in the martensite phase can easily be deformed, yet they will recover their shape on heating above the transformation temperatures. Therefore, one of many promising solutions to improve fatigue resistance of rotary instruments is to optimize the microstructure of NiTi alloys through novel thermomechanical processing or new manufacturing technologies.[9]

M WIRE

In 2007 a new NiTi wire was launched (termed M-Wire) which has been developed through a proprietary thermomechanical processing procedure and showed significantly improved cyclic fatigue resistance on endodontic rotary instrument products GT series X and profile Vortex in comparison with those made of conventional superelastic NiTi alloys. According to the latest study on the metallurgical characterization of M-Wire by Alapati et al, M-Wire contains all 3 crystalline phases, including deformed and microtwinned martensite, R-phase, and austenite.[10]

M-wire offers greater advantages than traditional NiTi.

• Greater flexibility than traditional NiTi
• Greater resistance to cyclic fatigue[11]

M-Wire with a profile design exhibited nearly 400% more resistance to cyclic fatigue than SE wire instruments of the same size.[9]

Ye J and Gao Y, in 2011, investigated the Metallurgical Characterization of M-Wire Nickel-Titanium Shape Memory Alloy Used for Endodontic Rotary Instruments during Low-cycle Fatigue. Results suggested that endodontic instruments manufactured with M-Wire are expected to have higher strength and wear resistance than similar instruments made of conventional superelastic NiTi wires because of its unique nano-crystalline martensitic microstructure.[10]

R PHASE

In 2008, another innovative manufacturing process was also developed to create a NiTi endodontic instrument—Twisted files(tfs). TF instruments were developed by transforming a raw NiTi wire in the austenite phase into the R-phase through a thermal process. The R-phase is an intermediate phase with a rhombohedral structure that can form during forward transformation from martensite to austenite on heating and reverse transformation from austenite to martensite on cooling. It occurs within a very narrow temperature range.[9] In R-phase, nickel titanium cannot be ground, but it can be twisted. Once twisted, the file is heated and cooled again to maintain its new shape and convert it back into the austenite crystalline structure which is superelastic once stressed and which can be used in endodontic function.[12]

CM Wire is a novel NiTi alloy with flexible properties that was introduced in 2010. CM NiTi files have been manufactured using a special thermomechanical process that controls the memory of the material, making the files extremely flexible but without the shape memory of other NiTi files, as opposed to what is found with conventional SE forms of NiTi. Both hyflex and Typhoon (TYP) are made from CM Wire.[9]

CM WIRE

Instruments made from CM Wire were nearly 300%–800% more resistant to fatigue failure than instruments made from conventional NiTi wire with the same design in a dry condition in a 3-point bending device.[9]

Shen Y et al, in 2011, examined the phase transformation behavior and microstructure of NiTi instruments from a novel controlled memory NiTi wire (CM wire). From the results they concluded that the TYP CM and Vortex instruments with heat treatment contribute to increase austenite transformation temperature. The CM instrument has significant changes in the phase transformation behavior, compared to conventional superelastic NiTi instruments.[13]

Shen Y et al. studied the fatigue of controlled memory wire nickel titanium instruments and concluded that instruments made from CM Wire had a significantly higher Nf and lower surface strain amplitude than the conventional NiTi wire files with identical design.[14]

CONCLUSION

NiTi alloys are increasingly used for the manufacturing of root canal instruments. They provide more advantages than other alloys because of certain additional properties including shape memory, thermodynamic control etc. ongoing research in endodontic aim on improving the quality and efficiency of these instruments for better success of root canal therapy.

REFERENCES:

1. Crumpton BJ, McClanahan S. Endodontic rotary nickel-titanium instrument systems. Clinical update 2003;25(8):15-17.
2. Rotary instrumentation: an endodontic perspective. Endodontics: AAE; Medivisuals: clinical topics.
3. Thompson SA. An overview of nickel–titanium alloys used in dentistry. Int Endod J 2000;33:297–310.

4. Walsch H. The hybrid concept of nickel–titanium rotary instrumentation. Dent Clin N Am 2004;48:183–202.
5. Young GR, Parashos P, Messer HH. The principles of techniques for cleaning root canals.
6. Vaudt J, Bitter K, Kielbassa AM. Evaluation of rotary root canal instruments in vitro: A review. Quintessence Int 2007;1(3):189-203.
7. Torrisi L, Marco GD. lnvestigations of endodontic instruments in NiTi superelastic alloy. Metallurgical Science and Technology 1999;17(2):59-64.
8. Parashos P, Messer HH. Rotary NiTi instrument fracture its consequences. J Endod 2006;32(11):1031-43.
9. Peters OA, Paque F. Current developments in rotary root canal instrument technology and clinical use: A review. Quintessence Int 2010;41:479–488.
10. Ye J, Gao Y. Metallurgical characterization of M-Wire nickel-titanium shape memory alloy used for endodontic rotary instruments during low-cycle fatigue. J Endod. 2012;38(1):105-7.
11. Jia ye et al Metallurgical Characterization of M-Wire Nickel-Titanium Shape Memory Alloy Used for Endodontic Rotary Instruments during Low-cycle Fatigue. J Endod 2012;38(1):105–107.
12. Mounce R. A clinically relevant review of nickel titanium canal enlargement; Penwell dental CE digest.
13. Shen Y et al. Metallurgical Characterization of Controlled Memory Wire Nickel-Titanium Rotary Instruments. J Endod 2011;37:1566–1571.
14. Shen Y, Qian W, Abtin H, Gao Y, Haapasalo M. Fatigue testing of controlled memory wire nickel-titanium rotary instruments. J Endod. 2011;37(7):997-1001.

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