The History, Evolution and Metallurgical Innovations in NiTi Endodontic Rotary File System

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Abstract: ***The quality of cleaning and shaping root canals has significantly improved thanks to nickel - titanium (NiTi) rotary instruments. These instruments' super elasticity and shape memory lessen the possibility of canal transportation while also saving time for patients and medical professionals. The cross - sectional shapes, cutting edges, taper, number, and spacing of the flutes of these instruments, as well as the properties of the NiTi alloy, have all been altered to create a variety of commercial types of these instruments that are currently on the market. The objective of this literature review is to present and discuss the latest innovations of the NiTi alloys used in the major instrumentation systems available in the market, as well as the historical journey through which the Endodontic NiTi Rotary systems have formed and the Evolution of file system, to enable clinician better understand the correct selection of the rotary file for predictable planning of root canal preparation.***

Keywords: Metallurgy of NiTi alloy, Thermomechanically Treatment of NiTi Alloy, Rotary File Innovations, History of Rotary Files

1. Introduction

Like many other dental and medical specialties, endodontics has developed over time and undergone changes. It primarily consists of root canal treatment, which involves preparing the access cavity, cleaning and reshaping the root canal, and then sealing the prepared pulp space in three dimensions. From the beginning of contemporary endodontics, there have been several ideas and methods for shaping the root canals. To reach till the latest advancements which we are observing today many files and alloys have been developed over the years. It is important to learn from the past historical events that took place which lead to the Modern Endodontic Era.

History

It all started by finding solutions for the purpose of cleaning and enlarging the root canal space. **Edward Maynard** invented the first endodontic device in **1838** using the spring from a watch clock and subsequently of piano wires (1–5). These first endodontic **files were made of carbon steel**, whose hardness was higher than that of dentin. Due to which there was an increased filing on the curved wall. This prevented their use in curved canals and also increased the risk for iatrogenic errors like perforations and transportation of the apical foramen. (6, 7).

The most often used hand files in endodontics were manufactured by the **Kerr company in 1904**which can be considered the first true endodontic instruments. These instruments werenumbered from one to six, where each consecutive number was larger in size than the earlier one.

The standardization of instruments was first proposed in **1955** by John Ingle, who was a professor at the University of Washington in the United States. Together with Levine they published the first work on standardized instruments, **in 1961**as well as the gutta - percha and silver cones accordingly (4, 6, 7) Nearly at the same time Dr. Herbert Schilder from the Boston University School of Graduate Endodontics had outlined the mechanical objectives for the Root canal preparation in 1960s (14)

On the other hand the birth of NiTiNol was about to happen, In 1958William Buehler a metallurgist at the Naval Ordnance Laboratory (White Oak, Maryland, USA) and his associates (Dr. Harold Margolin) had carried out some studies on phase changes of nickel - titanium alloys for Space Missions. This alloyexhibited considerably more fatigue, impact, Corrosion and heat - resistance. In 1959 henamedthe alloy NITINOL (which is an acronym of “Nickel Titanium Naval Ordnance Laboratory”).

In the early 1960s Buehler created a long, thin (0.010 - inch thick) strip of nitinol to use in tests of the substance's exceptional fatigue - resistant qualities. **.** In 1962 Dr. Frederick E. Wang joined Buehler’s group at the Naval Ordnance Laboratory, The commercial applications of Nitinol that were to come would not have been possible without Wang’s discovery of how the shape memory property of Nitinol works (10)

The A. A. E. accepted the proposal of Ingle and Levine by altering itslightly and resulting to what is now known as International Standard Organization (ISO). In **1976**, the American Standardization Association approved Specification No.28 which presents the standards for the manufacture of files and reamers (4, 12).

The Kerr Manufacturing Co. Industry was the first to build instruments that were according to the ISO standardization known as K - type instruments, also being the most copied in the world (4, 12).

In **1971,** Andreasen and Hilleman, introduced nickeltitanium (NiTi) wires to orthodontics, as a replacement for the steel wires. (9)

In **1988**HarmeetWalia for the 1st time introduced NiTi in Endodontics by making NiTi Rotary instruments from NiTi Wires, this started the era of Niti Rotary file systems. (8)

In **1992Dr. John McSpaddendesigned t**he first NiTi rotary instruments with theISO - standard.02 taper were introduce. During the same year in 1992, at the second International Federation of Endodontic Associations (IFEA) meeting in Paris, France, **Schilder** proposed the Profile Serie 29.02 hand files (Tulsa Dental), featuring a constant 29% increase between tip diameters. (13)

Two years laterDr. Johnson introduced the ProFile.04 and Profile.06 NiTi rotary systems, breaking the long standing paradigm of manufacturing endodontic instruments exclusively with the standard.02 taper. (10)

Evolution

The Classification of the Generations of File Systems by Clifford J. Ruddle in April 2013 [(11)] and again in Oct 2013 Haapasalo reviewed the 5 generations of NiTi instruments, [(12)] which were: -

- 1stGeneration has passive radial lands
- 2ndGeneration has active cutting edges
- 3rdGeneration had improvements in Ni - Ti metallurgy
- 4thGeneration utilizes reciprocation,
- 5th Generation instruments have offset design

But the latest innovations not only rely on the cross section and the design of the files but primarily the upgradationseen in through the Metallurgical changes done to take advantage of the phase transformation done by Proprietary heat treatments.

Metallurgy and Mechanical properties of nickeltitanium

The traditional NiTi alloy, contains roughly 56 wt% nickel and 44 wt% titanium, which is almost one to one in atomic ratio (equiatomic), is used to make endodontic instruments. This equiatomic NiTi alloy has the typical properties of superelasticity (SE) and shape memory effect (SME) and can exist in two different temperature - dependent crystal structures known as austenite (high - temperature or parent phase, with a body centered cubic crystal structure) and martensite phase. [5]

Super elasticity is the fully recoverable elastic deformation up to 8% strain as a result of the phase transition from the stress - induced martensite phase to the stable austenite phase. [15]

The ability of Niti alloy to return to its original shape from deformation when heated to a certain temperature is known as the "shape memory effect. " This is caused by the phase transition from stable martensite to stable austenite. [16]

Innovations in NiTi alloy processing techniques

The most popular metal processing technique “thermal treatments” involves repeatedly heating and cooling a given material under particular circumstances in order to produce a particular property, like the SE and SME of the NiTi alloy. Thermal treatments aim to affect the transition temperatures of the NiTi alloys and subsequently increase its fatigue resistance, whether it is torsional or cyclic fatigue (20). Other processing techniques are have also been used such as Electropolishing: which enables the controlled electrochemical removal of surface material to produce a smoother surface (17) and surface treatments by adding layers of oxides to reduce corrosion.

Following are the proprietary thermal treatments applied to the alloy to enhance its properties

M wire

It is a new NiTi alloy created by Tulsa Dental in 2007 and made of Super ElasticNitinol SE508 (containing 55.8% Ni wt) which goes through special thermal treatments at different temperatures before the instruments are machined. The pseudoelasticity of this material allows it to contain both the martensite and the R phases. Instruments made from M - Wire technology have better mechanical properties and higher cyclic fatigue resistance than instruments made from conventional NiTi alloys. (18, 19)

R phase

A line of NiTi instruments that underwent a special heat treatment was introduced by Sybron Endo in 2008. The alloy's crystal structure undergoes a phase change as a result of this treatment, which also reduces internal stress from machining while boosting flexibility and strength. The R - phase is essentially is a rhombohedral distortion of the cubic austenite phase. This phase occurs between the austenite and martensite phases.

Only in the R - phase, materials such as twisted files or R - phase files, allow for the twisting of Ni - Ti wire. Since R - phase has a lower Youngs modulus than austenite, it is more flexible and exhibits good super elasticity. (18)

Control Memory (CM) Wire

DS Dental introduced Control memory wire thermal treatment technique (Johnson City, TN, USA). After Nitinol SE508 is machined, a heating and cooling process giving rise to NiTi CM alloys, for eg: In Hyflex CM: - **NiTi CM 495 alloys**was used, which causesthe austenite finish temperature of the CM wire to be around 55 °C. So that the crystal structure at room temperature is mainly in Martensite phase which does not reverse back to the austenite phase and also allows the instruments to be pre bent. at the same time increasing the fatigue resistance and flexibility, contributing to a more centered canal preparation and lower rates of transportation as the instruments are in the martensite phase (18)

Gold & Blue Wire

DentsplySirona unveiled a brand - new heat treatment method for NiTi CM alloys in 2012. This method involves repeatedly heating and cooling instruments, which gives the finished product a surface color that reflects the thickness of the titanium oxide layer. The titanium oxide layer is formed on the CM - wire alloy through repeated heating and cooling processes, and the titanium oxide layer's thickness affects the alloy's surface color. The CM - Blue wire has a surface color of blue between 60 and 80 nm, and the CM - Gold wire has a surface color of golden between 100 and 140 nm. The titanium oxide layer boosts cutting effectiveness and wear by making up for the hardness lost during CM - wire alloy processing. (17, 18)

Electrical Discharge Machining (EDM)
The Hyflex EDM system, which was also made from **NiTi CM 495 alloy** but produced using spark - erosion technology also known as Electrical discharge machining (EDM) technique, was introduced by Coltene/Whaledent in 2016.

EDM is a controlled electrical discharge machining technique that produces thermal erosion without contact. This process depends on electrical sparks, which result in local melting and partial evaporation of small metal pieces, leaving a surface finish that is typically crater - like. The instrument is then heated for 10 minutes to 5 hours at a temperature between 300 and 600 °C, either before or after the cleaning procedure. The non - contact nature of the EDM process is intended to prevent early material failure that could result from traditional grinding methods. (17)

MAX wire (Martensite - Austenite Electropolishing - Flex), FKG
Recently, a unique NiTi alloy called MaxWire (Martensite - Austenite Electropolishing - Flex, FKG) made of **NiTi CM - 500 Alloy** was developed specially for manufacture of the XP - endo Finisher (XP - F), XP - endo Finisher Retreatment (XP - R), and XP - endo Shaper (XP - S) instruments in the FKG file system.

The alloy treatment causesitto transitions from the martensitic to the austenitic phase at temperatures equal to or higher than 35°C. This gives the instrument a semi - circular shape that enables it to project against the walls of the root. canal when rotating, performing eccentric rotary motion. The main purpose of this instrument is it can expand or contract to accommodate the morphology of the root canal system

C Wire
One Curve (MicroMega) a single - file NiTi rotary system, was introduced in 2017. The production of the One Curve file system uses the C - wire heat treatment technology. According to the manufacturer, this instrument has a controlled memory and can pre - bend, which improves root canal shaping. The variable cross section of the One Curve file improves cutting efficiency and centering. One Curve file is said to have 2.4 times greater cyclic fatigue resistance then its predecessor (20)

T Wire
In comparison to One Shape, the 2Shape File System (MicroMega) aims to increase both flexibility and cyclic fatigue resistance by 40%. It is produced using a proprietary heat treatment (T - wire). With its triple helix cross section, two primary cutting edges, and one secondary cutting edge, this system offers the best possible balance between cutting efficiency and debris removal. The two files in the 2Shape rotary file system are TS1 (25/.04) and TS2 (25/.06). (20)

Fire Wire
EdgeEndo (Albuquerque, NM, US) recently unveiled a number of file systems that resemble other file systems currently on the market in terms of their shape, manufacturing process, and preparation methods.

In particular, the EdgeTaper Platinum (ETP) system (EdgeEndo, Albuquerque, NM, US) has been introduced to the market with the claim that it proposes an endodontic system similar to the ProTaper Gold (PTG; DentsplySirona, Ballaigues, Switzerland) one, with an improvement in the flexibility and cyclic fatigue resistance resulting from a new heat treatment: the FireWireTM.

Latest advances
Newer files systems are coming to the market containing many metallurgical files together in one package eg: ProtaperUltimate (DentsplySirona) and Genius Proflex (Ultradent). Multi coloured heat treated alloy have also beenlauncedeg: - RCS Rainbow One File (Ramo Medical). All these newer files taking advantage of different NiTi alloys in one file system.

2. Conclusions

New generations of files are offered in the market to improve and enhance the properties of the conventional NiTi alloy. The current trend of instruments is to manufacture them with new alloys and heat treatments, reducing the ability of the alloy to have super elasticity. The alloy in this state has been shown to better follow the trajectory of curved root canals.

So far it was thought that there is no file or mechanized system considered the best, that is no single file system can achieve all expectations. But with the technological advancement in the field of Metallurgy, it has become possible to control the phase transformations temperatures and thus be in charge of its movements. With the latest packaging where different types of NiTi alloys are given together in single rotary system, it becomes more convenient for the clinicians.

Currently, the clinician has a wide variety of systems to decide which one use to achieve a much more predictable outcome in every specific case. Thus the clinician should not be limited to the older classifications alone, but it is important to get a better understanding of the newer NiTi rotary file systems having the cutting edge metallurgical properties.

Conflicts of Interest: None

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