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Research Article

Variety of Surface Engineering Techniques of NiTi Instruments- A Narrative Review

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Abstract

Aim: The aim and objective of this review is to present and discuss the characteristics of NiTi alloys and to present an overview on the variety of surface engineering techniques which may improve cyclic fatigue resistance, hardness and wear resistance while maintaining the torsional resistance and mechanical properties.

Methodology: A literature search for this narrative review was conducted in Google Scholar, PubMed and Web of Science using the keywords NiTi rotary instruments, cyclic fatigue, surface engineering techniques, surface treatment. Over 98 articles were found.

Result: Identification of over 98 studies for preliminary analysis. Articles unrelated to the surface treatment of NiTi instruments were excluded. The included articles were checked to identify further relevant literature. Overall, 25 articles were included up to 2021.

Conclusion: This review summarizes that there appears to be a risk of corrosion for NiTi instruments without surface treatments and also the cyclic fatigue resistance of NiTi files is influenced by the surface treatment. Thus by performing various surface engineering techniques, a smooth surface, from which machining defects were removed can be achieved. Hence, improved cyclic fatigue resistance, hardness and wear resistance while maintaining the life of the instruments can be achieved.

Keywords: NiTi Rotary Instruments; Cyclic Fatigue; Surface Engineering Techniques; Torsional Resistance; and Mechanical properties

Introduction

Over the past two decades, nickel-titanium (NiTi) instruments have become an important part of the armamentarium for root canal treatment. It has proven to be faster, easier, and more efficient than hand instrumentation especially in the curved canals [1].

However, rotary NiTi files might present structural changes resulting from the manufacturing process or from usage. These changes propagate fracture lines, and very often they cannot be detected visually. These structural defects present in NiTi files can be minimized by Surface Modification Techniques [2].

Aim and Objective

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Methodology

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Discussion

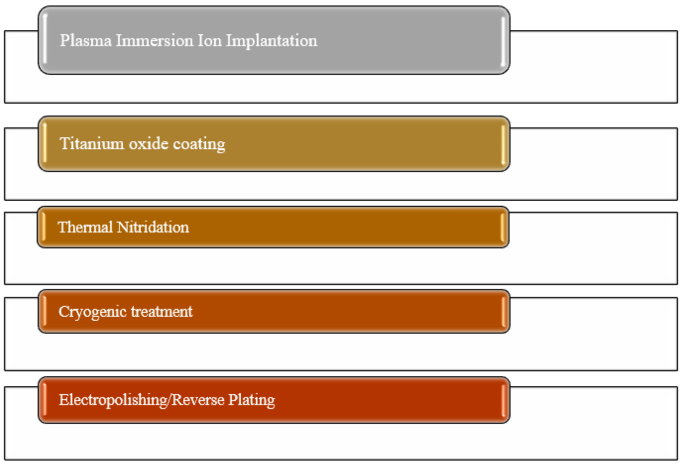
What makes NiTi alloy so special?

It is an alloy that exists in two crystal structures, austenite and martensite; transitions from one crystal lattice to the other make NiTi superelastic (SE) and give it a shape memory (SM). Its high flexibility is critical for rotary endodontic files because with highly elastic instruments, forces between the file and the canal wall during instrumentation are reduced. This results in the file remaining centered in the root canal space, and in a lower propensity towards canal straightening or other preparation errors.

Why Surface treatment of NiTi?

- To enhance cleaning surface of NiTi instrument
- Minimize defect , increase surface hardness and flexibility
- Enhance cutting efficiency
- Increase resistance to cyclic fatigue.

Strategies of Surface Treatments Include



Plasma Immersion Ion Implantation (PIII)

- Plasma immersion ion implantation (PIII) done to reduce the release of Ni from NiTi, without deteriorating the mechanical properties of the bulk by forming a continuous interface between the surface and the bulk [3].
- The plasma can be generated by a number of methods as shown in figure 1.
- During PIII, the specimen is placed in a chamber and immersed in the plasma; then a highly negative pulsating voltage is applied to the sample figure 2 [4].
- Briefly, ion implantation is a line-of-sight process in which ions are extracted from plasma, accelerated, and bombarded into a device.

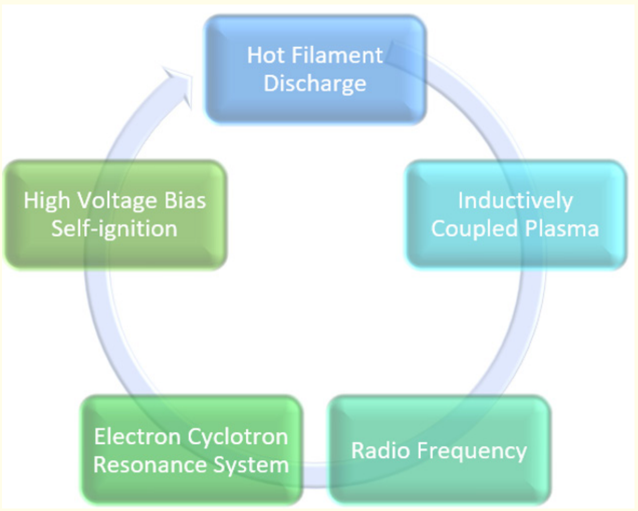


Figure 1: Flow chart showing plasma generation.

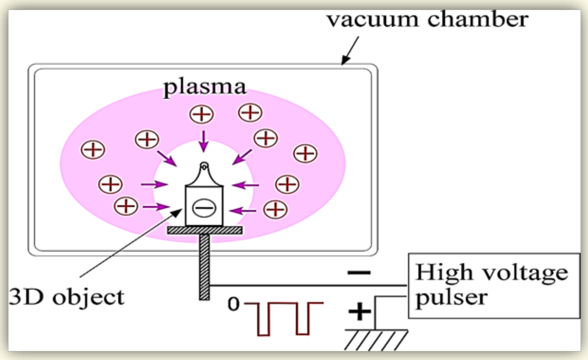


Figure 2: Specimen placed in a vacuum chamber and immersed in the plasma; then a highly negative pulsating voltage is applied to the sample.

Oxide formation on NiTi/Titanium oxide coating

- It is known that Ti has a higher affinity with oxygen, when compared to Ni. Therefore, with increased exposure time at moderate temperatures, the oxide formed is composed mainly of $TiO2$ with a slow formation and growth [5].
- Since the $TiO2$ layer can support relatively large deformations. Hence, a route to coat endodontic instruments with a flexible $TiO2$ protective layer via dip-coating sol-gel technique has been shown to improve the cutting efficiency, corrosion behavior and fatigue resistance.

Thermal Nitridation

- The nitriding method known as Powder Immersion Reaction Assisted Coating (PIRAC) produces TiN on NiTi.
- The clinical application of this method is not recommended at temperature of 300°C as the superelastic character of the instrument may be lost. Therefore, the instruments nitrided at 250°C are preferred for clinical Application [5].

Cryogenic Treatment

- As a newer cooling approach, cryogenic treatment (CT) involves submersing metal in a super-cooled bath containing liquid N (-196°C/-320°F) and then allowing the metal to slowly warm at room temperature (Deep dry cryogenic method) [5,6] figure 3.

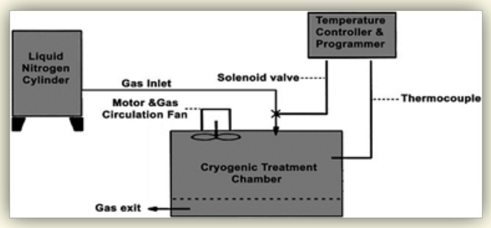


Figure 3: Cryogenic chamber setup [7].

Electropolishing/Reverse Plating

- EP removes the native oxide layer and sinters a more homogeneous and stable passive TiO2 layer. In this process, the amount of Ni on the surface decreases. It is employed as a final finish during manufacturing of NiTi instruments [8].
- Method used - instrument connect to anode immersed with other electrode in temperature bath of electrolyte followed by passing current in the solution - this process alter the surface texture and composition and make it more homogeneous. Electrolytes used are most often concentrated acid solutions such as mixtures of sulfuric/phosphoric acid [5,9] figure 4.

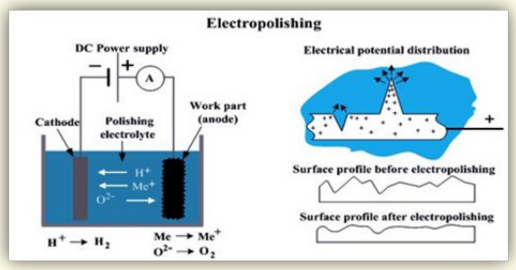


Figure 4: Electropolishing-an electrochemical process that removes material from metallic work piece.

Nano-polishing treatment

- Nano-polishing technique, is a method of surface treatment to remove surface defects that may remain after machining procedure [10].
- It is a controlled chemomechanical process that involves submerging the machined files into an acidic solution which contains nano-particles for surface polishing [11].
- Under the controlled conditions, the nano-polished instruments may have better cyclic fatigue resistance while maintaining similar torsional properties.

EDM- electrically discharge machine.

- Is the process of machining electrically conductive material by using precisely controlled sparks that occur between electrode and work piece in the presence of fluid, the electrode may be considered the cutting tool [12] figure 5.

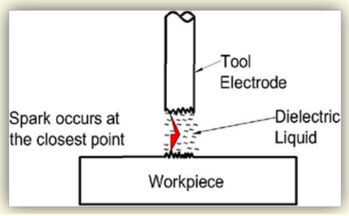


Figure 5: EDM process. Note: EDM, electrical discharge machining [13].

The Physical Vapour Deposition (PVD) Technique

- It is common method to deposit wear-resistant thin film coatings on instruments. With this technique, it is possible to deposit fine-grained, thin TiN films (1-7 m) on instruments at low temperatures, resulting in a surface hardness of about 2200 Vickers units [14] figure 6.
- PVD treatment is used to increase cutting ability, wear resistance, and resistance to corrosion and autoclave sterilization processes of NiTi files [15].

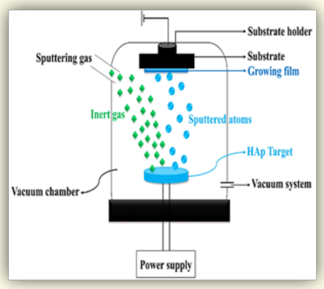


Figure 6: Schematic illustration of physical vapour deposition (PVD) process.

Hydrofluoric acid surface treatment

- Hydrofluoric acid (HF), which is the ingredients of Kroll's reagent, is used for chemical polishing of ground NiTi alloy.
- Chemical polishing with higher concentrations of HF reduced the rough surface and stress concentrating microdefect, which might improve the cyclic fatigue resistance.
- HF surface treatment might anodize and passivate the titanium oxide layer which was produced during manufacturing, which might also improve cyclic fatigue resistance [16,17].

Techniques	Advantages	Disadvantages
Plasma Immersion Ion Implantation (PIII)	Improved wear resistance. Increased cutting efficiency.	Less surface depth penetration of the metal. Less economical.
Cryogenic Treatment	Affects the entire cross section of the metal rather than just the surface. Increase cutting efficiency as well as overall strength of metal. Inexpensive.	Not effective on the wear resistance.
Electropolishing	Enhanced corrosion resistance. Improved surface characteristics.	Evidence available is controversial. Deeper the grooves of the instruments lower will be the fracture resistance.
EDM- Electrically Discharge Machine	Increasing cyclic fatigue resistance by more than 700% at room or body temperature. Better structural preservation.	The slow rate of material removal. The additional time and cost used for creating electrodes for EDM.
The Physical Vapour Deposition (PVD) Technique	Improved cutting efficiency and corrosion resistance.	Not much data and studies on PVD-coated endodontic instruments is available.
Hydrofluoric Acid Surface Treatment	Smoothening of rough surfaces. Reduce stress concentrating microdefects.	Changes are limited to a few nanometers to a few micrometers from the very surface.

Table 1: Various surface engineering techniques of NiTi instruments with advantages and disadvantages are listed down below.

Conclusion

This review summarizes that there appears to be a risk of corrosion for NiTi instruments without surface treatments and also the cyclic fatigue resistance of NiTi files is influenced by the surface treatment. Thus by performing various surface engineering techniques, a smooth surface, from which machining defects were removed can be achieved. Hence, improved cyclic fatigue resistance, hardness and wear resistance while maintaining the life of the instruments can be achieved

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