Review Article

International Journal of Dental and Health Sciences
Volume 05,Issue 02

ELECTROCHEMICAL DISSOLUTION OF NiTi FILES IN ENDODONTICS: A REVIEW

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ABSTRACT:

Instrument separation is one of the most difficult situation that encountered by almost all dental practitioners. Rotary system has evolved very much but the incidence of instrument separation is still dishonorable. Eventhough rotary instrument had overcome many of the disadvantages of stainless steel files, no one can predict the life of rotary files like, when it fractures and from where it fractures, since NiTi files doesn't shows any signs of fracture. The instrument retrieval system has also evolved very much with the evolution of NiTi files. The major disadvantage of all current instrument retrieval systems is that it requires removal of some amount of dentine, surrounding the fractured instrument and which in turn put the prognosis of tooth to a questionable prognosis. A method of electrochemical dissolution was suggested by Ormiga et al. (2010) and he dissolute NiTi files electrochemically. In this review, we are addressing in detail about the metallurgical properties of NiTi, various electrodes used for dissolution process, mechanism of dissolution process and its application in clinical dentistry. The present review also outline the principle, current perspective and the potential for further exploration of similar systems.

Key words: NiTi file; Electrochemical dissolution; Root canal treatment; Endodontic therapy.

INTRODUCTION:

The history of Endodontics begins since 17th century. Endodontic therapy is a treatment sequence of infected pulp of a tooth which results in elimination of infection and protection of decontaminated tooth from future microbial invasion. Root canals and their associated pulp chambers are physical hollows with in a tooth that contains blood vessels and nerve tissues collectively called Dental pulp.Endodontic therapy involves removal of this structures followed by subsequent cleaning and shaping and finally filling the canal with inert material.

Stainless steel (SS) files were used for root canal treatment. The main disadvantages of SS files are non-flexibility, straightening of curved canal followed by ledging and transportation. Later NiTi files were invented and that resolves many problems faced and errors during traetment have been eliminated.

The NiTi files were introduced and used in the field endodontics before two decades and it significantly improved the

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out come of root canal treatment. The advantages of NiTi are its super elasticity and shape memory and it exhists in two stable forms, Martensite and Austenite. These conformational changes are due to varying temperature and external tension.[1]

The main disadvantage with NiTi files is its unexpected failure and which renders the prognosis of the tooth a questionable one. Many factors other than separated instrument also affects the prognosis of tooth. If instrument separation resulted in a tooth with periapical pathology affects the prognosis.

The retrieval of separated instrument is a challenging process. The success instrument retrieval process depends upon the fragment size/length, position in the canal, anatomy of canals etc. The known methods and techniques for instrument fragment recovery require removal of surrounding dentine to access the segment. An electrochemical means of retrieval process was introduced by Ormiga *et al*. (2010)[2] in which the fractured segment is dissoluted either partially followed by effective removal of the same from the canal. The present review also outline the principle, current perspective and the potential for further exploration of similar systems.

The Perspective

Electrochemistry for Endodontics

Endodontics encompasses the study, practices and research pertaining to dental pulp, the etiology, diagnosis, prevention and treatment of diseases and injuries occurs in dental pulp and associated periradicular conditions. Endodontics study, research and its actual practices and applications have enormously improved the quality of dental treatment. The main endodontic procedures are endodontic therapy or root canal therapy, endodontic retreatment, surgery, treating cracked teeth, and treating dental trauma etc. If any disease or injuries effects on the dental pulp containing nerves, arterioles, venules, lymphatic tissue, and fibrous tissue, endodontic treatment is essential to resolve the problems and protect the affected area.[3]

Endodontic triad mainly comprises of cleaning shaping and filling of root canal. Success of root canal treatment release on accurate diagnosis and development of proper treatment plan followed by application of knowledge of shape and anatomy of the root canal, its disinfection and executing the debridement, and obturation of the entire root canal system[4]. Nonsurgical method of root canal treatment is probably retaining a tooth, that otherwise would require removal of tooth. Success of root canal treatment of a tooth with vital pulp is greater than necrotic with periradicular pathosis, the difference is being the persistent irritation of necrotic tissue remnants, and the inability to remove the microorganisms and the related by-

products. The major factors affecting this processes are the instruments used, anatomy and morphology of the tooth, and irritants available for treatment. Instruments must in good contact and plane the canal walls to debride the root canal.[5]Morphologic factors such as lateral and accessory canals, canal curvatures, canal wall irregularities, fins, cul-de-sacs, and isthmuses make complete debridement a questionable one. Therefore the goal of cleaning is not the total elimination of the irritants but to reduce their quantity significantly.

Stainless steel file or reamer are used for cleaning and shaping of infected tooth, for the last few decades. The canal was enlarged until clean white dentine shavings were seen on the apical few millimeters of the instrument. The filing was continued for further two or three sizes, to complete the preparation. This method was satisfactory for the case of straight canals, but was unsuitable for curved canals. If the instrument sizes is increased to solve the facing problem it become less flexible and results iatrogenic errors in curved root canals. Common problems encountered were ledging, zipping, elbow formation, perforation and loss of working length owing to compaction of dentine debris. Modern techniques for preparing the root canal involve a crown-down approach that efficiently removes infected debris and to improve access for irrigants and NiTi files replaced the role of stainless steel hand instruments.[6]

In recent years, the main invention in the field of dentistry is nickel-titanium alloy instruments with variety of features. The mechanical properties such as super elasticity and shape memory of the alloy encouraged its use in Endodontics. NiTi instruments have been demonstrated to preserve the original anatomy, the shape and position in space of the apical foramen.[7]

Twisting or machining is the method of making of NiTi files. It is manufactured by casting of the metal alloy or stamping wire blanks. Most of the instruments have a non-cutting tip that is designed in such a way that it follows canal anatomy rather than cutting and hence reduces the chance of ledging. The main problem faced by the use of NiTi files is that, it undergoes separation without any signs of fracture. The two main cause of breakage of NiTi files are cyclic fatigue and torsional stresses. If the material has repeated stress placed on it over a period of time is the cause of cyclic fatigue, it mainly occurs in areas of canal curvature and ultimately, this repetition breaks file during usage. Torsional stress generated if the file is twisted even if a portion is locked and the remaining portion of the file continues to rotate maximum and then occurs a breaking or snapping of the file.[8]

During treatment procedures, there exists potential for instrument breakage the instrument. Three possible outcomes that may be encountered while treating a case with seperated instrument. It includes:-Retrieval, Bypass and sealing

the fragment within the root canal space. Today, seperated instruments can usually be removed due to technological advancements like ultrasonic instrumentation and Microtube delivery methods. Specifically with dental operating microscope, a clinicians can visualize the broken instrument in the root canal and there by a nonsurgical removal is possible. But the instrument retrieval is influenced by diameter, length, position,and type of metallic object in the root canal. Instruments trapped in the straight portion of the canal can usually be removed. When a fractured instrument lies partially around the canal curvature, but the coronal aspect can still be visualized and accessed, then removal may or may not be possible. If the separated instrument is apical to the curvature of the canal and visualization is not possible, then nonsurgical removal usually cannot be practiced. Traditional instrument retrieval posed formidable challenges. Over time retrieval systems evolved but were often ineffective because of limited vision and/ restricted space . Leaving a fractured instrument inside the root canal coupled with incomplete obturation or ineffective coronal seal may lead micro-organisms to penetrate inside the canal and cause periapical lesion.[9] All advancements in instrument retrieval systems compromise some amount of dentine to gain access into fractured instrument and there by further weakening thef tooth structure.

A concept of electrochemical dissolution was described by Ormiga et al. utilizes the basic principle of electrochemistry. Electrochemistry is the study of chemical processes that cause electrons to move. This movement of electrons is called electricity, which can be generated by movements of electrons from one element to another in a reaction known as an oxidation-reduction ("redox") reaction. When the electrodes (metals and non-metals) in contact with their ions are arranged on the basis of the values of their standard reduction potentials or standard oxidation potentials, the resulting series is called the electrochemical or electromotive or activity series of the element. A primary set up for electrochemical dissolution of NiTi fragment shown in Figure 1.

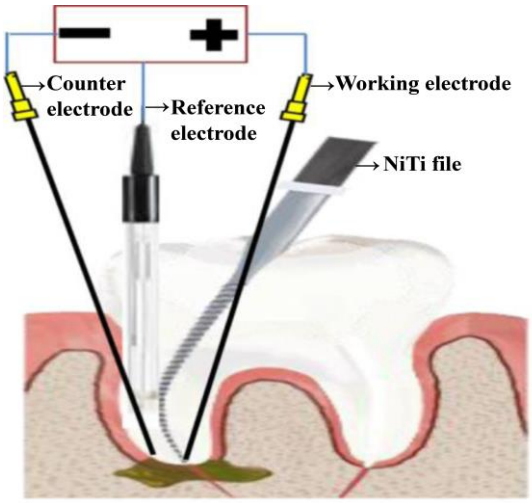

Figure 1. Requirements for a model electrochemical dissolution of NiTi fragment in rootcanal

Basic chemistry of electrochemical dissolution (ECD) of metals/alloys

Metals are electropositive elements that react with a corrosive contact to give their Oxides or corresponding salts.

Majority of the elements in the universe are metals. Elements in s, d, f -block in the periodic table are metals and some of the elements in p-block elements are also metals. Metal alloys are homogenous mixture of metal and metal or nonmetal. The metal dissolution in Chemistry started with the reaction of producing amalgam of metal decomposition in alkaline solutions.

Metals and their alloys show oxidation tendency in different environments and they corrode in different medium as follows.

$M \rightarrow M^{n+} + ne^-$

Their dissolution in acidic aggressive medium generates their salts as product. The reaction with halo acids is generally can denoted as

$M + yHX \rightarrow MXy + y/2\ H_2$

M - Metal

HX - Hydrogen Halides

MXy - Metal Halide Salt

H_2 - Hydrogen gas

The extent of dissolution of metal in different environment is different and the activity of them is also different. According to electrochemical activity, metals are arranged in a series called electrochemical series. Metal placed at the top of the series show high oxidation tendency while that at bottom, show low oxidation tendency. A part of the series [10] is shown in Figure 2.

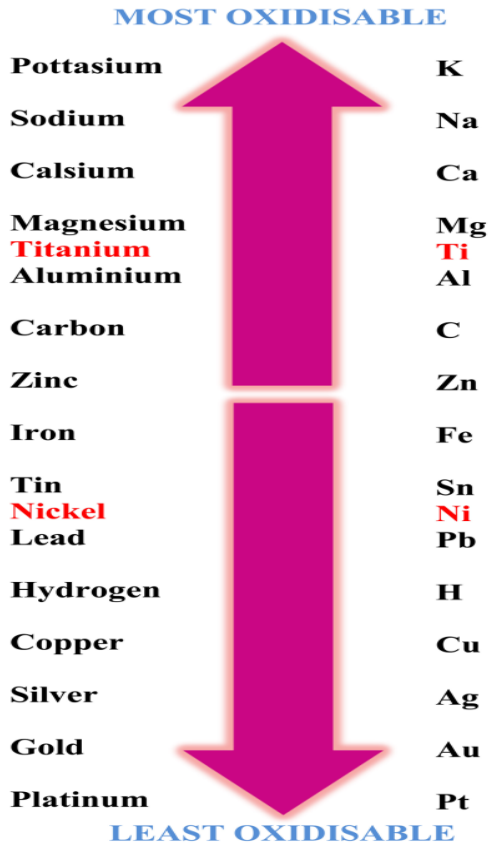

Figure 2. Electrochemical series of some metals

Metals itself can dissolve or dissociate in corrosive media through a redox process without any energy supply. With an electrical assistance, metal dissolve or oxidize easily when it is in contact with an electrolyte. For that, should supply an electrical potential greater than the oxidation potential of the metal.

Anodic polarization/ dissolution of NiTi fragment

Separated instrument retrieval by ECD adopts Anodic Polarization as its basic principle to dissolute NiTi file fragment. The electrochemical reaction consists of oxidation and a reduction halves in two regions. Oxidation occurs at anode (NiTi

fragment) and reduction at cathode. For an electrochemical reaction to carryout there should be an anode, a cathode, an electrolyte and DC supply/ potentiostat / electrochemical work station. Anode is connected to positive end of electrical source where the anodic dissolution is to be done. The reactions occurring in anode is represented as:-

$M \rightarrow M^{n+} + ne^-$

For an anodic polarization reaction to setup the working electrode must be connected to positive end of DC power supply. The connection diagram of anodic polarization is shown in Figure 3

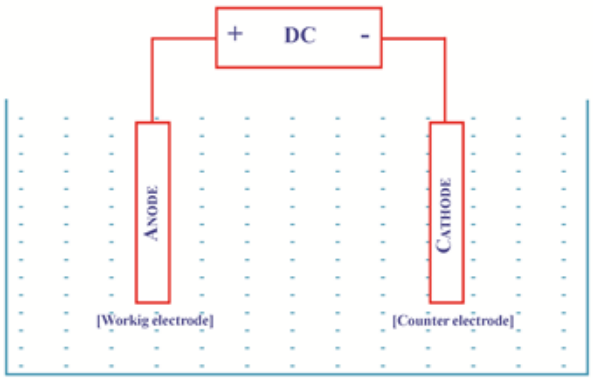

Figure 3. Connection for a basic anodic polarization/dissolution reaction

Inorder to dissolute NiTi fragment by means of electricity, the NiTi fragment should be positively polarized with DC supply.

An overview of electrodes used for electrochemical dissolution process

For an invitro study, anodic dissolution is normally carrying out by using a three component system. These components include a working electrode, a reference electrode and a counter electrode.

Working Electrode

The metallic/alloy fragment seperated in the root canal is needs to be dissociated. Separated NiTi file is the working electrode at which dissolution is carrying out. For contact, a Platinum wire of suitable diameter and length should be made to connect with separated file fragment in the root canal. The reaction taking place in the file may be summarized as follows:-

$Ti \rightarrow Ti^{4+} + 4e^-$

$Ni \rightarrow Ni^{2+} + 2e^-$

Oxidation of the file fragment taking place and it dissolves in the electrolyte medium and it wash out with that solution. For any metal based file, the same process and the contact material can be used for dissolution.

Counter electrode

Platinum metal can be used as a counter electrode due to its inertness in different aggressive medium and catalytic activity during electrochemical reaction. The counter electrode should be negatively polarized and reduction reaction occurs on the electrode surface during electrochemical reaction. The products produced or gases evolved in the electrode is according to the electrolyte in which these electrodes where dipped.

Reference electrode

For measuring the potential variation and easy reporting of the data, usually uses Standard Hydrogen Electrode, Standard Calomel Electrode and Ag/AgCl/KCl (sat) as reference electrode. The potential and current variations during dissolution can be only report with respect to these reference electrodes.

Method

For any electrochemical process to takes place, it requires atleast two electrodes namely an anode and a cathode. In electrochemical dissolution of NiTi files, the fractured NiTi file in contact with platinum wire acts as anode and the reduction reaction takes place at anode. That is responsible for the progressive consumption of file. Platinum wire is used as cathode mainly due to its inert nature. This entire assembly is immersed in an electrolyte. Electrolyte composition may vary according to the nature of the metal.

Combination of Ti, Zn, Ni, Cr and Al are considered as passivating alloys and literatures reported that fluoride ion is necessary to disrupt passivation and to increase dissolution/corrosion rate. All reported studies used fluoride containing chloride based electrolytes for dissolution.

Ormiga *et al.* (2010) [2] developed a new concept of retrieval of fractured NiTi files in root canal by means of electrochemical dissolution. He used K3 files for this study. The electrochemical cell used in this study consists of a reference electrode and platinum as a counter electrode. Electrolytes used were NaF 5 g/L+ NaCl 1 g/Lwith a pH of 5. Here anodic potential was applied to NiTi files and were subjected to dissolution process for 25, 17 and 8 minutes. Study results showed that the current attained initial value of 55 mA and then declined. Optical microscopic analysis was done to access progressive consumption of file with increasing polarization time. From this study result, it was concluded that the concept of fractured file retrieval with ECD process is feasible.

Further studies of Electrochemical dissolution by Ormiga *et al*. (2011)[11] was directed towards K3 file with same electrolyte and pH. Here he sectioned the file at three different diameters namely D3, D6 and D14 and inferred that greater dissolution was for D 14 and lesser dissolution for D3 that is due to lesser diameter of D3. By calculating the total electrical charge during dissolution he concluded that it takes nearly six hours to completely dissolute D3. This long duration of time was not clinically acceptable.

Dissolution has occurred throughout the entire length of the file even though the counter electrode is made to touch at the tip of the working electrode (NiTi fragment). This is mainly due to the conducting nature of working electrode and it acts as an excellent conductor of electric charge. Decrease in length was

first seen at the tip of the file and it was mainly attributed to its tapering nature of file. Even though the weight loss observed in different regions of file was uniform, a greater weight loss was seen at the tip of the file since the resistance is inversely proportional to cross sectional area.

Alcantra *et al*.[12] conducted the same study conducted by Ormiga *et al.* (2010)[2], only difference was with reference electrode ie AgCl/KCl was used and NiTi fragments were placed inside an artificial canal constructed inside endoblock. All the fore mentioned systems were subjected to Electrochemical dissolution. Here dissolution was achieved but only minimal.

Kowalczuck *et al*. (2017)[13] evaluated ECD of NiTi files in extracted human teeth. PTU files were fractured inside mandibular incisors and dissolution rates were accessed using two different electrolytes ie NaF 12 g/L + NaCl 1 g/L and NaF 12 g/L + NaCl 180 g/L respectively. More dissolution was associated with NaF 12 g/L + NaCl 180 g/L group. From his study it is concluded that fluoridated solution with NaCl lead to increase in electric current followed by microscopic reduction in length of fractured segment.

All the previous studies on Electrochemical dissolution was conducted by exposing entire NiTi file in a beaker containing electrolyte or by immersing an entire tooth block containing NiTi files in a beaker of electrolyte. For a single tooth the concentration of electrolyte in a beaker is infinity and hence actual dissolution process in rootcanal is still a questionable one. The corrosion that has occurred here was a pitting type of corrosion similar to a concentration cell created inside the mouth with dissimilar metals in the presence of saliva as electrolyte.

Applying Faraday's law of electrolysis current supplied or available on the reactive electrodes increases, the reaction on the electrode also increases i.e. current is directly proportional to rate of dissolution. By applying a constant potential and continuous circulation/ supply of active electrolytes containing chloride increased the conductivity of electrolyte and generated greater cathode reactions.

Mechanism of Electro dissolution

It was proposed that pitting type of corrosion has occurred through various stages. It includes:-

Pit initiation
↓
Pitting growth
↓
Transition from pitting to fatigue crack nucleation
↓
Formation of short crack growth
↓
Transition of short crack growth to long crack growth
↓
Finally crack coalescence.

CONCLUSION:

The electrochemical dissolution of NiTi files may be feasible but it is time consuming. The general perspective covering the available literature is reviewed. The feasibility of this process in posterior tooth especially mesiobuccal root of mandibular molars should be assessed since instrument separation is more common for it. In the light of numerous developments of electrochemical sensors, it is also required to develop smart electrochemical electrodes that may function along with sensors during actual application. Compared to available literature, further studies about the materials, methods are required to confirm the feasibility of this process clinically.

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