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Review Article

# Causes of Endodontic Instrument Separation

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## Abstract

One of the most common mishaps in endodontics is instrument separation, which has an important impact on the treatment outcome, preventing complete shaping, cleaning and filling of the root canals and leading to adverse effects on the prognosis of the involved teeth. Any endodontic instrument can fracture during its use, due to the intervention of some favorable and determining factors. As it is easier and more important to prevent instrument fractures than performing instrument retrieval, the understanding of the mechanisms through which they occur is of utmost importance for diminishing and ultimately avoiding the risks for such an undesirable event to take place.

**Keywords:** Instrument Separation; Nickel-Titanium (NiTi),

## Introduction

Scientific and technological progress has over time made possible the conservative approach to an increasingly important number of difficult clinical cases. The continuous evolution of the instruments and shaping and obturation techniques had as its main goal the achievement of an endodontic treatment as safe, predictable and error-free as possible.

Endodontic treatment success is dependent on the completion of a series of sequential stages. Starting with the diagnosis and ending with the post-endodontic restoration, each stage of treatment is influenced by the great degrees of complexity and variability of the root canal anatomy, which leave their mark on the difficulty of the therapeutic approach.

The anatomy of the root canal system is intricate and differs in configuration, complicating the process of eliminating organic material and lowering the microbial load, particularly in the apical third. Proper root canal preparation techniques are necessary for instrumentation, notably in this region of the root canal which is irregularly shaped, has various ramifications and an important number of remaining microorganisms [1].

During root canal treatment errors such as ledging, zipping, perforation, and apical transportation may occur, with instrument separation being one of the most problematic. Performing root canal treatment involves the use of many different instruments for shaping, irrigating and obturating, all of which are susceptible to fracture in the canal, especially in the apical third, posing great challenges for the successful completion of the treatment [2].

The reasons that favor and determine the fracture of endodontic instruments will be further referred to.

Successful cleaning and shaping of the endodontic system are mandatory to achieve the primary goals of endodontic treatment: prevention and/or elimination of apical periodontitis by eradication of the involved microbiome, its derivatives and virulence characteristics from the root canal system [3]. Clinical root canal instrumentation procedures have two basic goals: the preservation of natural teeth throughout the patient's life - "retention" - and treat or prevent apical periodontitis - "healing" [4].

Each step performed during the root canal treatment involves all sorts of instruments which unfortunately may break during their use: shaping stainless steel manual files, nickel-titanium rotary files, irrigation needles, ultrasonic tips, spreaders, pluggers, Lentulo spiral fillers, etc. Left unresolved, this is a situation that has adverse effects on the prognosis of the orthograde endodontic treatment of the affected tooth, leading to both clinical and medico-legal implications.

Understanding the causes of the fracture of an endodontic instrument is essential to prevent the occurrence of such an unwanted event.

Despite the constant significant advances in instrument design, alloy composition and manufacturing processes, endodontic file separation during instrumentation remains a major concern [5].

The incidence of endodontic instruments separation reported in the literature is variable according to:

- The studies carried out - in vitro or in vivo;
- Report on number of teeth or number of root canals;
- Experience of the clinician - endodontist, endodontic resident, general dentist;
- The type of teeth considered - predominantly molars;
- The instruments used - stainless steel manual or nickel titanium rotary instruments;
- Type of the rotary system;
- The kind of imaging investigation being used - Xray, CBCT.

The separation rates for endodontic instruments vary largely in the literature: from 0.25% to 6% for stainless steel instruments and from 1.3% to 10.0% for NiTi rotary instruments [6-8].

Today, shaping root canals is in most cases performed using NiTi rotary instruments. John McSpadden and William Johnson are the promoters of nickel titanium rotary endodontics. When first introduced in endodontic practice in the early 1990's it was firmly believed that these new instruments were practically unbreakable due to the specific flexibility and superelasticity of the nickel titanium alloy. Belonging to the class of shape memory alloys (SMAs), nickel titanium shows unique functional properties. Depending on the initial phase states before deformation, their properties are divided into superelasticity and shape memory effect (SME) [9].

Unfortunately, cyclic fatigue and torsional loads occurring during shaping root canals are important factors leading to unpredictable separation of rotary nickel titanium instruments. The low yield and tensile strength of NiTi compared to stainless steel resulted in an increased susceptibility to fracture at lower loads. These factors are especially important when shaping difficult root canals, with challenging anatomy, sharp curvatures, calcifications, and when endodontic retreatment is performed. Rotary nickel titanium instruments proved to be in fact at least as prone to separation as manual stainless-steel ones were in the past.

On the other hand, it should be mentioned that since the introduction of nickel-titanium alloy as the material of choice for the manufacture of rotary endodontic instruments, the success rate of root canal treatment has increased significantly. This is due to anatomically predictable root canal preparation, consistent and uniform preparation of the root canal space, overall efficiency, decreased preparation time, and less operator fatigue.

With the emergence of reciprocating rotary motion, it could be noticed that the considerable resistance to cyclic fatigue of reciprocating instruments lead to a much lower separation incidence compared to continuous rotating ones: numerous studies showed a separation incidence of only 0% to 1.71% [10-14].

Rotary files can separate in different places along their length, depending on the cause of the separation:

- In proximity of the tip, mainly due to excessive torque;
- In their middle third or in the proximity of the shank, usually caused by cyclic fatigue.

The root canal system's anatomical diversity and complexity is one of the most common reasons for instrument fracture [6] obviously leading to a rate of more than 90% of the cases located in molars, of which more than 50% are the mesial roots of lower molars [2]. The highest frequency of instrument separation is recorded in the mesiobuccal canal [7].

There are multiple factors involved in the etiology of endodontic instrument fracture:

- Frequently severely restricted access and visibility
- Root canal geometry: angle and radius of root canal curvature
- Instrumentation technique
- Instrument design and cross-section
- The metallurgical specifics of the alloy
- Dynamics of the instrument in the root canal
- The number of uses
- The number of sterilization cycles
- The experience of the clinician.

It is important to note that separation of stainless-steel instruments are often preceded by clinically visible distortions, NiTi rotary files may separate within their elastic limit and without any warning signs, as a distortion rarely occurs before fracture [2].

Etiological factors of endodontic instrument separation fall into four categories, though some of them may overlap in multiple categories [5].

The complexity of the endodontic system

- Acces cavity
- The number and orientation of root canals
- Anatomical elements (bifurcations, anastomoses, isthmuses, etc.)

The endodontic instruments used

- Type of alloy
- Instrument design
- Manufacturing process

The instrumentation technique used, involving

- Endomotor operating parameters
- The number of cycles of reuse and sterilization
- Irrigants and irrigation methods

Operator-related factors

- Proficiency
- Skills
- Experience

### The complexity of the endodontic system

The first step to achieve correct endodontic treatment procedures consists in preparation of an access cavity that is going to allow the removal of obstructions in the pulp chamber, the location of all canal orifices and the shaping and cleaning the entire root canal system.

Although in accordance with the principles of minimally invasive endodontics, creating conservative, ultra conservative (ninja), truss, guided access, caries-driven or restorative-driven access cavities endangers the possibility of unrestricted access to the entire endodontic system, increases the curvature of the endodontic instrument and raises the risks of instrument separation.

The greater the complexity of the endodontic system the more substantial the risk of instrument separation. Fractures are more prevalent in molars, with the mesiobuccal canal of upper and lower molars exhibiting the highest incidence. The reason for this is a combination of factors, including the accessibility, diameter, and curvature of the root canals.

Greater canal curvature increasingly exposes NiTi instruments to higher levels of cyclic fatigue, with steep curves further exacerbating the exposure. Increasing the degree of calcification exposes the instruments to greater levels of torsional stress.

The increase in canal curvature in the apical third increases the likelihood of file separation in this area, especially beyond 30°.

The greater the root canal curvature, the greater repetitive cycles of loading and unloading occur and thus more important the cyclic fatigue. The degree of curvature is dependent both on the angle and on the length of the radius [15]. The canal deviates abruptly when the radius of curvature is smaller, hence at the same angle of the root canal curvature a smaller radius implies a greater bending of the endodontic instrument [16]. Rotary NiTi instruments are prone to fracture more easily when the tip binds in an acutely curved root canal compared to a straight one.

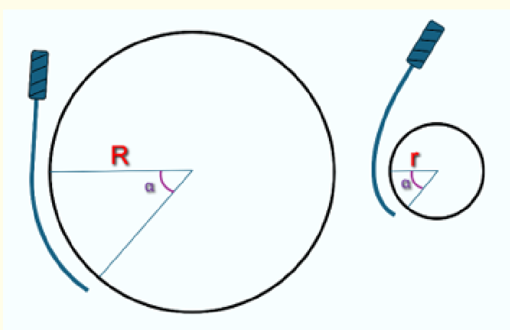


**Figure 1:** Importance of the relationship between angle and radius of curvature. Root canals with the same angle but different radii (R > r).

The rotary instrument's efficacy in the buccolingual plane is hindered by the combination of oval and curved canals. Insisting increases the risk of instrument separation.

On the other hand, the gradual formation of hard tissue along the walls of the root canal is a natural process associated with aging, which usually progresses slowly over time. In some cases, such as dental trauma, auto transplantation, or orthodontic treatment, this deposition of hard tissue can be unexpectedly accelerated, resulting in rapid narrowing or complete closure of the root canals. Called calcific metamorphosis, root canal calcification, or pulp canal obliteration, such a situation leads to important challenges and increases the risk of procedural failures, among which instrument separation [17].

In the case of root canals having calcifications as well as significant curvature, torsional stress and cyclic fatigue work together to decrease instrument resistance to both.

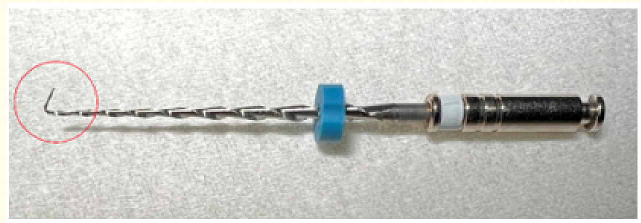

**Figure 2:** Nickel titanium rotary instrument bended when trying to negotiate a calcified root canal [Prof. Dr. Bogdan Dimitriu].

### The endodontic instruments used

Factors influencing fracture resistance of the endodontic instruments are both related to the NiTI alloy and to their design and cross-section.

Latest advancements in NiTi metallurgy aim to better clinical behavior, increasing flexibility, elasticity, resistance to cyclic and torsional fatigue, efficacy and durability.

The superelasticity and shape memory of NiTi alloys is due to the reversible transformation of their phases: martensite, R-phase, and austenite. The phase composition and, consequently, the physical properties of NiTi alloys are determined by temperature-dependent phase change [18].

NiTi alloys become superelastic at temperatures above the austenite (reverse transformation) fnishing temperature ($A_f$) and are rich in martensite and R-phase, which are less rigid and more ductile than austenite, below this temperature level [19]. The flexibility of NiTi rotary instruments at clinical temperatures is improved by heat treatment, which is frequently used to boost Af and increase the proportions of martensite and R-phase [18].

At room and body temperature traditional NiTi alloy instruments conventionally exist in the austenite phase. This implies stiffness and low resistance to fatigue which raises risks of separation in severely curved canals.

The fatigue resistance of the instrument may be altered by heat treatment, which relieves the internal strain of NiTi and accelerates phase transformation, producing a more martensitic phase at clinically relevant temperatures.

Techniques such as heat treatment, electropolishing, and file cross-sectional modifications have been devised to prevent NiTi rotary file instruments from breaking.

The fracture of endodontic rotary instruments can be broadly classified into two types: fractures due to cyclic fatigue and fractures due to torsional fatigue [19].

Cyclic fatigue occurs due to tension-compression cycles through repeated extension and compression of an instrument in a curved canal at the point of maximum bending, measured either by the number of cycles or the time until fracture occurs [20-24].

For a rotary endodontic instrument, the tension-compression cycles become notably dangerous when the root canal presents a smaller radius of curvature, and the bending is thus more severe.

To prevent the concentration of the flexural strain on a single area of the instrument, it is generally advised that instruments be moved continually in an axial direction rather than being kept in a static position inside a curved root canal. It is also recommended to discard instruments after a single when used in very calcified or sharply curved canals [5].

NiTi rotary instruments' reciprocating motion considerably lessens cycle fatigue, presenting a significantly longer cyclic fatigue life [25].

Several variables, including instrument design, taper, cross-sectional geometry, core mass, surface, and heat treatment, affect the complex phenomenon of cyclic fatigue in NiTi instruments [21].

Advances in instrument manufacturing processes, designs and protocols can improve resistance to cyclic stress. Instrument fracture can be significantly impacted by the design, manufacturing process, and raw materials used [5].

As file diameter increases, rotary NiTi files' resistance to cyclic fatigue diminishes [26].

Torsional fracture occurs when part of the instrument binds to the canal while the shank continues to rotate, with fracture happening once the elastic limit of the alloy is exceeded. In such a situation, the instrument may exhibit signs of deformation such as twisting, unwinding and straightening and, if breaking, it usually occurs in the apical third of the root canal.

Increased torsional loads happen when large tapered endodontic instruments are used in constricted root canals. In a root canal that is low-tapered and unprepared, a large tapered endodontic instrument can rapidly increase torsional stresses. NiTi instruments that have a lower metal mass and small cross-sectional area are generally characterized by lower torsional strengths [19].

**Figure 3:** Tooth 36 - separated rotary nickel titanium instrument in mesiobuccal root canal [Prof. Dr. Bogdan Dimitriu].

### The instrumentation technique

The recommended rotational speed for endodontic instruments is usually comprised between 250-500 rpm, with higher speed increasing risks of fracture due to [27]:

- Increased stress and strain rate and decreased time for stress relaxation
- Increased risk of taper lock

- More heat generation during conversion of austenite to martensite, leading to precocious fatigue of the alloy.

Torque is one of the factors that influence the frequency of instrument failure. It is related to the apically directed force and preoperative canal volume, the values being lower for smaller and less tapered instruments and higher for bigger and more tapered ones.

Torque is generated by the engine-driven rotary NiTi instrument when the file starts rotating [28].

The root canal treatment is carried out under highly complex conditions, and the torque produced is influenced by various factors. The NiTi file system's geometric characteristics and heat treatment have a consequence on the torque it generates.

The torque generated is affected by the kinetics of the NiTi file system: the generation of torque can be observed to have different patterns when switching between continuous rotation and reciprocation movements.

The newer adaptive motion is comprised of both continuous and reciprocating rotation which switch their motion depending on the workload [28]. Compared to continuous motion, this alternative movement for the NiTi file system generates a lower torque [29].

The total torque generated by the NiTi file can be directly tied to the time it rotates within the root canal. Using a pecking motion at a low speed may decrease the momentary maximum torque, but the slow pecking motion's longer preparation time may result in an increased total torque generated and the possibility of instrument cyclic fatigue and higher separation risk [28].

The number of cycles of reuse and sterilization is also an important parameter concerning the risk of future instrument separation, due to lowering cutting efficiency and the corrosive effects on the surface of instruments. An endodontist who feels a decrease in cutting efficiency may apply more pressure to the instrument to maintain a constant cutting capacity, thus increasing torsional stress and risk of separation [30].

After five cycles of sterilization a decrease in cutting efficiency of NiTi rotary instruments can be noted [30].

Reusing endodontic files may result in changes in their physical properties and fractures, especially after shaping curved and calcified root canals. Autoclave sterilization leads to a reduced cyclic fatigue resistance and alters the superficial structure of NiTi endodontic instruments [31].

Repeated sterilization cycles can produce negative effects on endodontic files, such as changing the chemical composition of their surface due to oxidation and micro pitting, causing changes in the morphological characteristics and reducing the cutting efficiency by 50% [32].

It is important to note that all endodontic instruments should be carefully examined under magnification before reuse for signs of deformation or wear.

An additional concern is the potential corrosive effect of sodium hypochlorite and other irrigants on root canal instruments. Corrosion begins to appear after immersing NiTi instruments for five minutes in 5% sodium hypochlorite [5].

An important difference between partial and total immersion of the instrument in sodium hypochlorite solution is whether the instrument shank is also immersed or not. If the shank is made of a different metal than the cutting part the simultaneous presence of two metals in a solution of sodium hypochlorite can lead to release of ions and generate galvanic reactions that can accelerate the corrosion processes [33].

Repeated irrigation results in a decrease in cutting efficiency of Ni-Ti rotary endodontic instruments and an increase in surface roughness. There is a strong relationship between the fracture mechanism and the surface characteristics of Ni-Ti rotary instruments: an increase of the surface roughness leads to a decrease in cutting efficiency and a higher risk of fracture [34,35].

### Operator-related factors

Factors related to operator skill and control were ranked as the most important among those contributing to instrument separation [5].

With a constantly expanding variety of instruments, the clinician must be familiar with the instruments, their specific method of use, and the manufacturer's recommendations. It is obvious that extensive ex vivo practice is of main importance. In most cases, instrument separation determined by procedural errors are due to torsional stress, which is frequently an effect of incorrect use.

The operator must use judgment to exclude an instrument that has a suspected defect or that has been used in a root canal that is difficult to prepare.

Lack of careful inspection of eccentric x-rays and even CBCT before starting the root canal treatment can lead to lack of assessment of possible root canals hidden curvatures.

There are significant differences in the use of NiTi instruments among types of practice and years since graduation, as experience, proficiency and skills are important factors involved in achieving a correct endodontic treatment. Endodontist or postgraduate endodontic specialists in a higher grade are the ones to whom more difficult cases should be referred.

## Conclusion

The complexity of the endodontic separation phenomena is due to the involvement of an important number of factors.

There are multiple precautions to take to prevent instrument separation:

- Understanding of root canal anatomy, keeping in mind that locations of root canal curvatures are often as important as the severity of the curvature
- Selection and use of the most appropriate instruments
- Using hand files before rotary files
- Creating a straight line of access into the root canal
- Performing coronal preflaring
- Pre-curving and watch winding stainless steel hand files for managing calcified root canals and create a glide path
- Keeping the instrument always moving
- Never instrumenting in dry canals
- Lubricating the instruments - a file without lubrication requires a significantly higher torque
- Avoiding forced instrumentation
- Cleaning instrument flutes during instrumentation of the root canal
- Single use of hand files and rotary instruments in difficult cases
- Carefully inspection of the endodontic instruments before, during and after use
- Complying with manufacturer's instructions.

It should also be noted that the results obtained with one type of instrument cannot be directly extrapolated to other types due to significant differences concerning the alloy, design and modality of use.

Though retrieving a separated endodontic instrument is possible using different methods and armamentarium, instrument removal techniques lead to significant loss of tooth hard tissues, which increases the risk of tooth fracture, and unfortunately not all instruments can be removed. Furthermore, complications can occur during the process, such as separation of another instruments and perforations, thus making prevention of instrument fracture obviously crucial.

Clinical decision-making preventive strategies include case selection, operator expertise, and limited reuse of endodontic instruments.

The separation of endodontic instruments remains a significant concern in the field of endodontics, impacting both the procedural outcomes and patient confidence. Recognizing the factors contributing to instrument separation, such as cyclic fatigue, torsional stress, and improper technique, is crucial for clinicians aiming to minimize the risk. Adopting best practices, including the use of high-quality instruments, adhering to manufacturer's guidelines, and thorough training in advanced techniques, can greatly reduce incidents of separation.

Additionally, technological advancements, such as enhanced metallurgical properties in modern endodontic files and the application of adaptive motion systems, provide promising solutions to this challenge. Regular maintenance of equipment, diligent pre-procedural assessments, and the use of magnification tools can further aid in preventing instrument breakage.

While it is not always possible to completely remove the risk of separation, early recognition and appropriate management of a separated instrument can prevent further complications and preserve the overall success of the treatment. Education and training in retrieval techniques, as well as improved patient communication, are essential in handling such occurrences effectively.

It cannot be emphasized enough the importance of a comprehensive approach that includes preventive measures, advanced technology, and effective management strategies meant to mitigate the risk of instrument separation and ensure the highest standards of endodontic care.

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