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Instrumental Fracture in Endodontics: A Short Review

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Abstract

One of the most frequent accidents that take place during standard endodontic treatment is instrument fracture. The fractured instrument such as a metallic obstruction in the root canal system, hinders cleaning and shaping operations, and affects the effectiveness of endodontic therapy. The management of instrument fracture, factors that affect instrument fracture, and precautions for instrument fracture are the three headings used to elaborate on this topic in this review.

Keywords: Endodontics, Root canal treatment, Endodontic therapy, Separated instrument, Prevention

1. Introduction

Endodontics is an integral part of dentistry, which is concerned with the study of the form, function and health of the dental pulp and periapical region, as well as the pathologies associated with them, while ensuring prevention and therapeutic management [1]. Like all other disciplines, endodontics has benefited from numerous scientific and technological advances that have led to the introduction of nickel-titanium (NiTi) rotary instruments, which are responsible for an intriguing revolution in dental practice. Consequently, the abundant use of this technology in recent years can only be a logical and inevitable result. The idea behind these developments is the conviction that the efficiency of biomechanical shaping of the root canal system can be greatly increased, as well as it can give rise to modern methods, responsible for the elimination of certain transcendent practices of traditional endodontics [2].

When an instrument fractures, every endodontics practitioner goes through a range of emotions, including frustration, despair, and anxiety [3]. However, it is often said that the dentist who has never fractured the end of a reamer, file or broach has not treated many canals [4]. In the same context, and despite the increased flexibility of NiTi files, instrumental fracture remains an inherent problem with their use [2].

The main aim of this review is to offer a comprehensive overview of the current state of nickel-titanium (NiTi) rotary instruments in endodontics, focusing on the latest advancements. Furthermore, we aim to identify key areas for future research in this field. Our review will cover a variety of topics, including factors influencing instrument fractures, therapeutic options, decision-making processes, precautions for preventing instrument fractures, and management strategies for instrument fractures. By addressing these objectives, we hope to give clinicians and researchers with useful insights into the benefits and limitations of NiTi rotary devices in endodontic treatment.

2. Management of instrument fracture

2.1. Primary management stages

2.1.1. Inform the patient

Regardless of the cause of the instrumental fracture, the patient needs to be informed right away in a calm manner. In order to reduce any potential attempts at concealment, it was indicated that the occurrence would unavoidably be recorded in the

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patient's record. Given that negligence is never to blame for the outcomes, good communication and the patient's consent continue to be the best option at our disposal [5].

2.1.2. Locate the fragment

When determining whether endodontic retreatment is necessary, the exact position of the broken fragment is crucial. This is particularly true if the separated fragment is situated in the root's apical third, which has thin dentinal walls and a significant risk of perforation. Radiological diagnosis is more challenging for stainless steel instruments than for nickel/titanium instruments when the entire root canal system is filled and the fractured fragment is fixed in the root canal filling, regardless of the cement used or the periapical radiological modality (digital or conventional radiography) used [6].

2.1.3. Determine the nature of the fragment

The accuracy of the radiological image obtained can be affected by a number of factors. In fact, eccentric radiographs must be taken at various angulations in retroalveolar radiography due to the superimposition of structures in order to understand the instrument's three-dimensional position [7]. Regarding CBCT, the proximity of metallic objects or root canal filling material may produce artifacts that make it more difficult to study the fractured fragment [8]. Determining the type of the broken fragment also requires familiarity with the radiological appearance of the many instruments used in daily practice, particularly those constructed of NiTi and stainless steel [8].

2.2. Fractured instrument removal procedures in endodontics

2.2.1. Chemical means

There are many risks associated with treating instrument fractures with conventional methods, including an excess of dentine radicular loss that increases the risk of canal perforation [9]. In the same context, Madarati et al. reported a reduction in the mechanical radicular resistance that was significant regardless of whether the fracture occurred deeply in the radicular canal or in the rectiligne region of the canal [10].

In response to the results above, induced electrochemical dissolution emerged as a chemical technique to control the instrumental fracture while maintaining the tooth's structural integrity. This method depends on the fragment being in continual contact with an electrode that is used as an anode in an electrolyte solution. The electrode's electron migration is caused by the potential difference between the anode and the cathode, which releases metal ions into the solution (Fig. 1) [10]. Due to the electrical insulation provided by the dentin and cementum, and as a result of the passage of electrons in a single, external circuit, the system assures that electrical current does not reach the soft tissues [9].

As for the predictability of removing instruments using chemical methods Amaral et al. (2015) examined the dissolution of 6-mm-long portions of experimental 20 and 30 stainless steel hand K-files after exposing them to a chloride and fluoride-containing solution. The researchers discovered that the consumption of the files over time was more pronounced for larger diameter files, which also showed greater weight loss and longer dissolving times. Additionally, the electrical charge produced during the polarization process by these bigger files was higher [11].

Fig. 1. A possible configuration of the induced electrochemical dissolution of a fractured file. The microelectrode combines an anode and a cathode, both immersed in a solution which favors contact between the anode and the fractured file [10].
2.2.2. Mechanical means

2.2.2.1. Ultrasound technique. Richman RJ started the demonstration of ultrasonography in endodontics in 1957. Martin et al., however, have actually concretized the full potential of this technique in terms of preparation and shape. The term endosonics was coined by Martin and Cunningham and was defined as “the ultrasonic and synergistic system of root canal instrumentation and disinfection” [12].

The strategy for removing a root canal obstruction, such as a broken instrument, is a complex procedure that includes several deliberate and organized phases, as shown below (Fig. 2) [13].

✓ (a) Radiographic confirmation of the presence of a fragment and determination of its location, size and length.
✓ (b-d) Instrumentation of the root canal to the fragment and creation of a seating platform with 1 modified Gates Glidden drill.
✓ (e, f) Exposure of the coronal segment of the fragment using ultrasound. Dry trepanning around the fragment with the ultrasonic tip activated at the lowest power settings.
✓ (g) Ultrasonic vibration and removal of the fragment.
✓ (h) Once the fragment is removed, the canal is renegotiated with an ISO K 10 file to the apical foramen, and root canal instrumentation is continued.

Regarding the predictability of instrument retrieval using ultrasound technique, the article conducted by Tzanetakis et al. provides a summary of a five-year retrospective clinical study at the Dental School of Athens. The study aimed to investigate the occurrence and management of instrument fracture during root canal preparation by postgraduate students [14].

Between October 2001 and June 2006, dental records from 1367 patients, including 2180 endodontic cases, were evaluated. The total prevalence of instrument fracture during root canal preparation by postgraduate students was 1.83%. This included a fracture rate of 0.55% for stainless steel hand instruments and 1.33% for rotary nickel-titanium instruments [14].

The study focused on the management of fractured instruments, with varying success rates depending on the location of the fracture within the canal. Tzanetakis et al. reported that the coronal third of the body had a 100% success rate for retrieval or bypass of fractured instruments. The success rate ranged from 45.4% in the middle to 37.5% in the apical third [14].

2.2.2.2. The file bypass technique. The compromise established for the creation of this instrumental removal procedure stands out for the reasons listed below:

An affordable method requiring common dental practices' instrumentation [15,16]. Prudent preservation of tissue integrity with minimum tissue loss and the creation of an active region for the ultrasonic insert [15,16].

For the practitioner using this approach to mitigate the significant risk of perforation and the development of stops [15], or worse, the expulsion of the fragment periapically, perseverance and good hand dexterity prove to be crucial attributes [17].

Following an unsuccessful bypass effort, this technique encourages the employment of two or three small-caliber files rotated around a separate instrument [12]. The forthcoming illustration, exemplifies the protocol (Fig. 3) [13]:

![Fig. 2. (a–h) Schematic illustration of the removal of the fragment by ultrasound [13].](image-url)
In relation to the predictability of instrument retrieval using the File Bypass Technique, this article by Shiyakov et al. sheds light on the success rates of retrieving fractured endodontic instruments beyond the root canal curve. The study focuses on the effectiveness of the file bypass approach when used in conjunction with a dental microscope [18].

The investigation was conducted in vivo with a sample size of 19 patients. The total recovery of the broken instrument served as the main measure of success. The results showed that this method had a success rate of 36.84% for recovering broken instruments [18].

✓ (a) Radiographic confirmation of the presence of a fragment and recognition of its location, size and length.

✓ (b) Instrumentation of the root canal to the fragment.
✓ (c) Efforts to bypass it with a size 08 pre-bent file.
✓ (d) After bypassing, reaming continues with larger caliber instruments trying to “engage” the fragment in their coils and retrieve it.
✓ (e-g) Sometimes the engagement and retrieval of the fragment is facilitated by the simultaneous insertion (braiding technique) of two or more instruments into the root canal, preferably Hedstroem files.
✓ (h) Once the fragment is removed, the canal is renegotiated with a 10-gauge file to the apical foramen, and the shaping of the canal is resumed.

2.2.2.3. Apprehension techniques (The Instrument Removal System). The Instrument Removal System (Dentsply, Tulsa Dental, Tulsa, Oklahoma) consists of three different size extraction devices, which are tubes with a 45° bevel at the end to hook onto the coronal end of a broken instrument, and a window at the same level. The outside diameter of the black is 1 mm, that of the red 0.8 mm, and that of the yellow 0.6 mm. The two components that make up each finished instrument are a microtube and a color-coordinated screw wedge. Thus, each microtube has a tiny plastic grip to help the user see properly during placement (Fig. 4) [3].

The protocol for removing a root canal obstruction using this technique is as follows [3].

✓ It is essential to create a straight root access with ultrasonography in order to expose the broken fragment's coronal end along a length of 2–3 mm.
✓ The previously expanded channel is passively entered by the microtube. Be aware that the end of the fragment is always facing the external root wall when there is a curved canal present. As a result, the microtube is inserted along the same path.
✓ The equivalent color-coded wedge is engaged over its whole height after the microtube is in position, stopping when it comes into contact with the obstruction. A second option with a different color is chosen if necessary.
✓ The obstacle is engaged by gradually rotating the screw block’s wrist in a counterclockwise direction. If problems arise, the rotation is turned by 3–5° in the other direction. This will make it possible to remove the broken piece.

When considering the predictability of the Instrument Removal System (IRS), the article by Alomairy presents findings from an in vivo study that investigated the efficacy of the IRS in retrieving fractured rotary nickel-titanium instruments. The study used a microscope and a rather small sample size of 15 cases to define success as the complete removal of the fractured instrument [19].

The success rate for instrument retrieval utilizing the IRS was documented at 60%, according to the paper, meaning that 9 out of the 15 cases examined resulted in successful and complete removal. However, it is important to stress that additional research is required to evaluate and corroborate these findings because of the small sample size of this study [19].

2.2.2.4. The Terauchi File Retrieval kit. In comparison to traditional mechanical techniques of apprehension, the Terauchi File Retrieval Kit (TFRK, Dental Care, Santa Barbara, California, USA) has shown to be more effective at removing root canal blockages lodged in the apical third. This technology was developed in 2006. Additionally, appropriate preservation is accomplished in the shortest amount of time [20,21].

This kit in its autoclavable cassette form contains the following instrumentation (Fig. 5) [13].

✓ A modified Gates Glidden n°3 drill
✓ A micro-trench burr
✓ A micro-exploration instrument
✓ A loop device
✓ An instrument for removing gutta-percha
✓ Four custom ultrasonic tips that can be bent to fit the curvature of the canal
✓ A mock-up tooth with three broken files for practice

When considering the predictability of removing instruments using the Terauchi technique, the article by Terauchi et al. presents a novel file-removal system and technique specifically designed for the successful extraction of separated files from root canals. The study illustrates the use of recently developed devices and techniques in removing separated files located in the apical third of curved canals by including four case reports [21].

The entire removal of the separated file without any iatrogenic mishaps, such as perforation or canal destruction, is considered the success of the surgery in this context. Even while the article doesn’t give a particular success percentage, it emphasizes the improved predictability this new technique offers in comparison to earlier approaches. Additionally, it is stressed that using an operational microscope is a crucial tool for successfully retrieving fractured instruments [21].

2.2.3. Softened Gutta-Percha Technique

The method of instrumental removal with softened gutta-percha is a conservative therapeutic approach that allows for the optimum preservation of dental tissues while also being straightforward and quick to use. An operating microscope is not required [22].

The operative protocol is as follows [22]:

✓ Introduction of Hedstroem stainless steel files of small caliber smaller than file #15, in contact with the separated fragment. Attempts are made to bypass the file in order to free it.
✓ A gutta-percha tip is soaked in chloroform for about 30 s, then inserted into the canal and left to harden for about 3 min.
✓ The fragment frozen in the gutta-percha tip is then removed by applying a delicate and controlled rotation.

It is significant to note that the Softened Gutta-Percha Technique is only referenced in one case report that was published in the International Endodontic Journal in 2009 while evaluating the predictability of removing instruments using this technique. On the effectiveness of this device, there
are no research available. Therefore, more study may be required to determine whether this method is effective.

2.2.4. Multisonic ultracleaning

The GentleWave, Multisonic Ultracleaning System (Sonendo Inc., Laguna Hills, Orange County, CA, USA) is a therapeutic method of excellence in preserving the integrity of dental structures. The benefits of this system are as follows [23].

✓ No root canal shaping or instrumentation is necessary, and there is no risk of extrusion.
✓ Since the process is carried out with an irrigant present, no heat is produced.
✓ The GentleWave technology states that in canals with bend angles greater than 30°, it has a 42% success rate.

The following operational procedure was followed during the GentleWave therapy, which lasted a total of 7 min and 45 s [48]: 3% NaOCl for 5 min, followed by 30 s of distilled water, then 8% EDTA for 2 min, followed by 15 s of distilled water [23].

These three phases are organized in a cycle. Each cycle is followed by an X-ray inspection to ensure the presence of the suspect fragment. It usually takes three cycles totaling 23 min and 25 s to remove the separated fragment [23].

The ex vivo study by Wohlgemuth evaluated the effectiveness of the GentleWave System in removing separated stainless steel endodontic files from the midroot and apical regions of 36 extracted human molars. The Multisonic Ultracleaning System (Gentle Wave) was used, and no microscope was used during the procedure. The success rate for removal was 83.3% in the middle third (15/18) and 61.1% in the apical third (11/18) [23].

It is important to note that this study has some limitations, including its ex vivo design and small sample size. Further in vivo case studies are necessary to confirm these findings and determine if they have implications for improving patient outcomes in root canal treatment when an instrument has been separated in the root canal.

2.2.5. Laser irradiation

The thermal effect is dependent on these four aspects [13].

✓ In the treatment of instrumental fracture with laser irradiation: The dentin around the fragment is melted by the laser, and then it is contoured and recovered using H-files.
✓ The fragment is melted by the laser.
✓ Laser energy melts the solder, connecting the fractured instrument to the solder-laden brass tube placed at the exposed coronal end of the fragment.
✓ The file fragment that is inside the hollow metal tube is welded together by the laser.

In dentistry, the Nd:glass laser was first used as an instrument removal tool in 1970. Since the laser irradiation is carried out inside a contained compartment, the risks to the root canal walls are thought to be limited. Compared to what is seen during root canal therapy, the laser energy that travels through the spaces between the file and the extractor is quite low [24].

When considering the predictability of removing instruments using the Nd:YAG laser, Cvikl's article investigates its efficacy in managing fractured endodontic instruments. The study, which was done ex vivo with a sample size of 33 cases, produced remarkable results. When the instrument fragment had more than 1.5 mm of accessibility, it was found that the procedure's success rate was 77.3%. The success rate, however, was much lower when the palpable length of the fragment was less than 1.5 mm, falling to just 27.3% [25].

3. Factors influencing instrumental fracture

3.1. Operator related

The impact of the operator is considered as a key factor influencing the instrumental fracture, when the other factors (speed and sequence of the instrument, morphology of the canal) remain constant [26]. The operator's ability to perceive and resist the tendency to bend or “lock in” is a skill that can only be acquired with clinical experience [27].

In this regard, the dental literature presents the following evidence.

✓ According to several research, unskilled operators fracture NiTi rotary instruments more frequently than expert users. This suggests that preclinical training should be used as a key strategy to reduce the frequency of instrument fracture [28]. In the same context, Parashos and colleagues discovered that the operator had the greatest influence on the defect rates of nickel-titanium rotary endodontic instruments. The defect rates across endodontists varied greatly, according to the authors, which may be attributed to clinical expertise or a deliberate choice to use instruments until faults were visible or after a predetermined number of uses. Additionally, the mean usage of instruments with and
without flaws was noted, coming in at $3.3 \pm 1.8$ for instruments with flaws and $4.5 \pm 2.0$ for those without. The researchers evaluated 7159 used and discarded rotary nickel-titanium tools that were provided by 14 endodontists in four different nations. The authors also stated that in order to ensure that their findings were indicative of each operator’s overall clinical practice, they included all teeth that each operator had treated in their research. These data collectively imply that operator experience and protocols may be crucial in lowering the frequency of intraoperative defects in rotary nickel-titanium endodontic instruments [29].

When attempting to answer the scientific question at hand, it becomes evident that two opposing viewpoints exist in the literature. According to research done by Yared and al, Baumann and al, Mandel and al, operator experience is not a decisive factor in the propensity to instrument fracture [30–32].

3.2. Anatomy related

3.2.1. Access cavity

One of the most important and fundamental steps in endodontic therapy is the construction of an adequate access cavity. The goal of the coronal access is to achieve the most optimal root canal shape and disinfection while maintaining the tissue integrity of the tooth. However, a number of errors can happen and affect the effectiveness of the procedure, particularly the under or over-extension of the access cavity preparation [33].

Establishing a straight line of sight to the root canal orifices, as well as direct access to the first curvature of each root canal, are considered imperative to the successful completion of root canal treatment. Increased stress is placed on the instrument in question if these two requirements are not met [34].

3.2.2. Root canal anatomy

3.2.2.1. Angle and radius of the root canal curvature

The shape of any root canal curvature is accurately described using two parameters: the angle of curvature (α) and the radius of curvature. To determine these, a straight line is drawn along the long axis of the coronal part of the canal, a second line is drawn along the longitudinal axis of the apical part of the canal. A point is determined on each of these lines at which the canal deviates to begin (point a) or to end (point b) (Fig. 6) [35].

The curved portion of the channel is represented by a circle whose tangents are located at points a and b. The angle of curvature can also be defined by the angle formed (α1 and α2) by the perpendicular lines drawn from the deflection points (a and b) that intersect at the center of the circle. The length of these lines is the radius of the circle, which defines the radius of canal curvature (r1 and r2) measured in millimeters (Fig. 6) [35].

The radius of curvature represents the degree of steepness or severity of a specific angle of curvature when the canal deviates from a straight line. The smaller the radius of curvature, the sharper the deflection of the canal. The angle of curvature and radius of curvature are independent of each other. Canals can have the same angle of curvature while having different radius of curvature, resulting in sharper curves [35].

3.2.2.2. Position of the root canal curvature

The location of the root canal curvature in the apical situation is a determining factor in cyclic fatigue strength, when the arch lengths as well as the radius are kept unchanged [36].

The number of cycles an instrument can withstand before fracture (NCF) determines the resistance to fatigue failure. The instrument experiences compression and tension over time, which contributes to cyclic fatigue failure. From a mechanical standpoint, the root canal radius is the primary determinant of the mechanical behavior of the instrument, secondary to the location of the curvature along the root canal [36].

The most likely explanation is that when the curvature is localized in the middle 1/3 of the canal, the area of critical stress concentration is in contact with the part where the diameter of the instrument is the largest, in contrast to a possible more apical
localization where the contact area is in the thinnest part of the instrument [36].

3.2.2.3. The state of the pulpal retraction. In 2011, Wu et al. reported that the degree of pulpal retraction has an impact on the clinical fracture of previously utilized ProTaper Universal rotary instruments (Dentsply Maillefer, Ballaigues, Switzerland). The presence of an increasing taper along the entire length of the working part allows each instrument to prepare a specific area of the canal. The coronal region of the instrument receives more torque than its tip in the situation of significant root curvature and a constricted canal. Consequently, the smaller portion of the S1 exhibits plastic deformation or even microfractures. After frequent use, these microfractures could get worse and coalesce [37].

3.3. Related to the root canal shaping instrumentation

The NiTi alloy with the adopted ratio contains about 56 weight % nickel and 44 weight % titanium. This equiatomic NiTi alloy can exist in two different temperature-dependent crystal structures, named austenite (high-temperature phase or mother phase, with a cubic B2 crystal structure) and martensite (low-temperature phase, with a monoclinic B19’ crystal structure) and has typical characteristics that are superelasticity (SE) and shape memory effect (MFE). These properties are the result of the transition from austenite to martensite (martensitic transformation), which can be induced by mechanical stress or temperature” [38].

A deformed rhombohedral phase (R-phase) can appear before the transformation to martensite under the following conditions: temperatures around 400 °C or substitution of a third element (iron, aluminum) or heat treatment after cold deformation [38].

3.3.1. Conception

A significant element affecting resistance to cyclic or torsional fatigue fracture is instrument diameter [39]. The dental literature provides the following evidence: a high incidence of distortion and separation is frequently found with smaller NiTi devices. The drop in instrument size and center metal mass, which led to a reduction in torsional fracture resistance, explains this. Smaller instruments have a higher torsion failure rate than larger ones for the same torque. However, larger instruments, which are less susceptible to torsional failure, are more susceptible to bending fatigue, perhaps as a result of higher stress buildup [28]. In 1997, Wolcott and Himel showed that the instrument taper has a significant impact in resistance to torsional and cyclic fatigue fracture, and they opted for the use of a variant taper system, which has the advantage of lowering the areas of contact with the canal and reducing torsional and fatigue failure compared to single taper instruments. Mechanically speaking, instruments with a single taper but various tip sizes have a tendency to jam or screw into the canal, overloading the instrument tip torsionally [28].

3.3.2. Fabrication process

In order to maximize the mechanical characteristics of torsional and cyclic fatigue resistance of the employed instruments without damaging the superelasticity, electropolishing is a second production option that is accessible. The spirals are machined during the production of the NiTi rotary files, which results in a hardening of the surface. Similar to this, machining produces tool marks and microcracks that resemble crystalline dislocation centers and can start fracture propagation, degrading the mechanical characteristics of the NiTi alloy. The central concept behind electropolishing is to remove a very thin surface layer by submerging the material in a highly ionic solution while being subjected to an electric current [40].

The company SybronEndo recently released a new version of the twisted file technology on the market (Orange, CA, USA). After the grinding procedure is complete, nickel-titanium endodontic instruments are subjected to this development, called the thermomechanical therapy. The goal is to slightly modify the phase of the alloy’s crystalline structure.

According to Hayashi et al., this procedure entails increasing the amount of martensite in the material through heat treatment. Martensite is known to be more flexible than austenitic NiTi. Numerous benefits can be deduced, including increased mechanical strength and flexibility as well as the reduction of certain internal tension brought on by the grinding process [41].

3.4. Relative to the technique and method of use

3.4.1. Operating parameters of motors

The study conducted by Li et al., highlighted the effect of instrumental rotation speed in relation to cyclic fracture resistance. As the rotational speed of a NiTi file at an angle increases, the time to fracture occurrence decreases. These results are explained by the accumulation of bending stresses within the metal after a certain number of bending cycles. In
other words, the number of rotations determines the
time of fracture rather than the speed at which the
file is rotated. In conclusion, the clinician should be
aware that by increasing the speed of rotation of the
files, a shorter duration of use is the rule, since a
critical number of rotations will instead occur at a
higher speed [42].

The resistance to torsional fatigue is significantly
influenced by the torque produced during root
canal shaping. The root canal dentin’s engaged
contact area with the instrument determines the
frictional intensity. This is influenced by the in-
strument’s sequence and approach, including the
use of various diameters and the selection of the
crown-down approach rather than the step-back
approach in order to lower the risk of fracture and
avoid engaging a sizable portion of the instrument
in the root dentin’s “taper lock” [43].

3.4.2. Instrumentation techniques

It takes remarkable manual dexterity to complete
the glide path, a crucial phase in endodontic therapy
that prevents torsional failure from breaking the
NiTi tool. This procedure was previously defined as
a smooth root tunnel from the root canal orifice to its
physiological termination. The creation of a free
route during root canal therapy is essential for
avoiding the taper-lock phenomena. This disturbing
incident emphasizes the need for free play of the
instrument tip in rotation to reduce torsional stress
on rotary files when the canal cross-section is
smaller than the instrument tip [44].

3.4.3. Reuse and sterilization

The precise calculation of the potential number of
re-uses for endodontic instruments is a question
that has still not received a satisfactory resolution.
Since damage from cyclic fatigue stress accumula-
tion is not clinically contestable, NiTi instruments
in particular do not have any explicit or clear recom-
mendations on this topic in the dental literature.
Mechanically speaking, the operator’s effect and the
instrument’s method definitely outweigh other ele-
ments when it comes to the quantity of uses. The
majority of the investigations strongly support the
following conclusion. But regardless of how NiTi
rotary files are handled, it is evident that they have
far less mechanical resistance to torsional or cyclic
fatigue fracture than brand-new instruments [26].

The literature seems inconsistent when it comes to
the effects of sterilizing on NiTi instruments. Ac-
cording to a number of studies, NiTi instruments
show signs of crack initiation and propagation after
numerous sterilisation/autoclave cycles, as well as
an increase in the depth of surface imperfections. It
has also been shown that cutting effectiveness has
decreased [26].

However, other studies have found that heat
sterilization has no appreciable impact on the fre-
cquency of NiTi instrument fractures, refuting the
harmful effects of heat sterilization on the mechanical
properties of NiTi files. But in relation to
recently created files that are twisted rather than
machined, the evidence becomes more obvious. It’s
interesting to note that the sterilizing procedure is
said to reverse the stress-induced martensite state
back to the austenite phase, improving the fatigue
life of NiTi files. Although, the temperatures needed
to attain these advantageous qualities are typically
unlikely to be reached in everyday use [26].

3.4.4. Irrigant

The mechanical characteristics of NiTi in-
struments may be adversely affected by the corrosive
action of sodium hypochlorite (NaOCl) as root
canal irrigant. NaOCl use, however, has also been
refuted on the grounds that it is unlikely to occur in
pitting or crevice corrosion of NiTi instruments, and
as a result, it did not raise the incidence of fracture
or the number of revolutions necessary to generate
flexural fatigue of NiTi instruments [26].

4. Types and mechanisms of instrumental
fracture

4.1. Definition of instrumental fracture

Fracture is the separation, or fragmentation, of a
solid body into two or more parts under the action
of a stress.

The initiation and propagation of the crack are
two components that make up the fracture process.
Fracture can be classified into two general cate-
gories, ductile fracture and brittle fracture [45].

4.2. Types of instrumental fractures

Metal failure can be categorized as brittle or
ductile. The term “ductility” reflects a material’s
capacity for plastic deformation prior to fracture. In
ductile fractures, it is common to observe the for-
mation of microvoids in the metal, which then
develop and consolidate to weaken the material and
cause the fracture [39]. Due to its considerable
plastic deformation, ductile fracture differs from
brittle fracture both macroscopically and micro-
scopically [46].

Brittle fractures have the following characteristics
[39].
✓ Low plastic deformation.
✓ Abundant in metals with low ductility.
✓ Stress initiation at the metal surface and stress concentration at the crack base leading to propagation along grain boundaries (intergranular) or between specific crystallographic planes (cleavage fracture).
✓ Presence of a stress elevator, generating the concentration of forces in one point or area, instead of being distributed over a smooth surface.
✓ The applied unit stress will be much higher and may exceed the tensile strength at that point or area.

The fractographic study is the study of choice to determine the modes and mechanisms of failure. A brittle fracture is associated with the presence of cleavage facets [47]. In brittle fractures, the crack fronts produce ridges that extend along various planes in the alloy and typically radiate away from the crack origin, creating the infamous chevron pattern [39].

In conclusion, instruments largely undergo ductile fracture. This mode of failure is desirable due to its predictability, unlike brittle fracture where failure is abruptly produced without significant permanent deformation, consequently, no warning of impending device failure is provided [48].

4.3. Fracture mechanisms of stainless-steel files

Zinelis et al., elucidated the fracture pattern of the H-files used. During the test, the propagation of cracks mainly localized in the region of turns is noticed, resulting in the degradation of mechanical properties and the increase of the tendency to fracture. This result is explained by the development and propagation of cracks during instrumentation, leading to a reduction in the effective cross-section of the instrument and subsequent catastrophic failure. This is typical fatigue failure behavior [49].

According to SEM analysis, the origin of the fracture was located at the cut surface and propagated perpendicular to the axis of the long file, consuming a significant portion of the cross-sectional area (Fig. 7 A and C), while the final fracture occurred due to a combination of tensile and shear overload. Intense secondary cracking (cracks located near the fracture plane) is also typical indirect evidence of the fatigue mechanism, as it indicates that many cracks originate and propagate simultaneously, but only one led to the final fracture [50].

The endodontist is often faced with several challenging clinical situations, including the management of files that have little or no abnormality prior to fracture and a high potential for fracture (Figs. 8 and 9). Sotokawa found an abundance of this type of fracture with K-files and thicker square (four-sided) files, which occupied a relatively large proportion of the total number of discarded files. From a mechanical standpoint, metal fatigue wear is deeply involved in file breakage, and production generally follows the following processes [51].

First, a focal point develops on one or more edges of the file and propagates toward the axial center,
giving rise to the fracture under the effect of torsional stress. Secondly, the drilling action causes further progression of metal fatigue, through the strong drilling action, and will produce cracks or tears parallel to the file axis, especially in curved channels. This is in contrast to light reaming which results in relatively less fatigue progression within the metal [51].

4.4. Fracture mechanisms of NiTi rotary files

It is important to recognize that the cyclic fatigue life value is dependent on a number of pre-determined uses inherent in any instrument at our disposal. If separation does not occur due to static torsional overload or an integral defect, instruments will have an average number of cycles to failure that is determined by the specific parameters of channel radius, channel angle, and instrument diameter [52].

Manufacturing defects are another factor to consider, as the machining of NiTi instruments is complex and results in surfaces with a high concentration of defects such as debris and pitting. Machining marks and cracks on the surface of the instruments are a source of propagation to the entire metal structure, thus explaining the unexpected fractures in new NiTi rotary instruments [52].

The relative importance of torsional and/or bending fatigue in the fracture etiology of NiTi rotary instruments is presented by [26].

✓ Some studies have reported that the majority of instruments are fractured due to bending fatigue, thus implicating overuse as the most important failure mechanism.
✓ Conversely, other studies have classified torsional fracture as the dominant mode of fracture, implicating the use of excessive apical force during instrumentation or the presence of pronounced root canal curvature as the primary responsible for torsional failure.

Torsional fracture occurs in the most common case when the tip of the instrument or some other part is stuck in the canal while the stem continues to rotate. When the elastic limit of the metal is exceeded by the torque exerted by the reducing contra-angle, fracture of the tip is inevitable [53]. The fractured instrument, following a torsional failure process, shows signs of plastic deformation such as unwinding and straightening (Fig. 9) [26].

Torsional fatigue strength is the ability of a file to twist before fracturing. This property is most relevant when a canal is narrow and the canal lumen is restricted, leading to increased torsional loading during root canal shaping [54]. The torsional fracture strength of NiTi files depends on the following factors [53]:

✓ The cross-sectional design.
✓ The chemical composition of the alloy.
✓ The thermomechanical process applied during fabrication.
✓ The relative size of the instrument in the channel.

4.5. Influence of fatigue on torsional strength and inversely

During the chemo-mechanical shaping of the endodontic system, NiTi instruments are subjected
to simultaneous torsional and bending stresses. To date, no simple means of analyzing the different stresses acting on the instrument is available. The suggested approach, as for any study containing several variables, is the decomposition into constant individual components. In order to study the different forms of stresses acting on the instrument, it is acceptable to isolate the effect of shear stress or rotational bending to examine a single variable [55].

However, it is important to consider that fatigue and shear stresses can act in parallel to cause device fracture. From a mechanical standpoint, this is explained by the frequently identical location of bending and torsional stresses during implementation by these NiTi rotary instruments in channels with accentuated curvature. The ultimate shear strength (torsional at 3 mm from the tip) of NiTi instruments is significantly reduced, implying a decrease in cyclic fatigue strength [55].

5. Therapeutic choice and elements of decision making

5.1. Decision chart

Very recently, Solomonov proposed in 2022 a clinical algorithm based on the understanding of the biological processes responsible for periapical lesions. This algorithm was then elaborated into a flowchart by Deniz N and Orhan EO (Fig. 10) [56].

5.2. Therapeutic innovations to support decision making

Due to the complexity of clinical cases and the requirement to develop an appropriate diagnostic and treatment plan, the clinician is left on his own without practical tools to assist him in his therapeutic decision. The practitioner must therefore only rely on his clinical judgment. Finite element analysis (FEA) and virtual treatment planning (VTP), two numerical approaches, are all making their way into the area. Virtual treatment planning (VTP) improves maxillofacial reconstruction accuracy and outcome, and patient-specific finite element analysis (FEA) predicts bone fracture better than experienced orthopedic clinicians. The impact of instrument location and resection length on stress distribution in the root has been assessed in endodontics using FEA [57].

5.2.1. The virtual treatment planning technique (VTP)

The different anatomical structures can be segmented, semi-automatic segmentation is based on the assignment of pixel labels, "grains", within each anatomical structure. Labels are generated based on the structures “air,” “tooth,” “bone,” and “intra-dental canal material” to produce a multi-label 3D image. This initial 3D image is then modified to simulate the procedures of the different instrumental removal strategies [57].

The different virtual removal strategies can be analyzed on a modified 3D image. The latter offers the operator the possibility to add or remove bone, ultrasonic tip, or instrument masks to plan his procedure. For the nonsurgical strategies. The modified 3D image could also be used to simulate the practitioner’s clinical perspective [57].

5.2.2. Finite element modeling technique and mechanical analysis of results (FEA)

An explicit static analysis was performed to calculate principal deformations and Von Mises stresses [57]. The results of a finite element analysis are expressed as distributed stresses in the structures studied. These stresses are known as Von Mises stresses [58]. For all FE models, the mechanical behavior of the tooth is evaluated, and the stress with respect to each treatment option can be analyzed [57].

6. Precautions regarding instrumental fracture

For safe use of NiTi file instruments, it has been advised to adhere to the following guidelines.

- Ensure that the glide path is established at the working length with stainless steel files at least up to 15 gauge, prior to the rotary instruments [28].
- Ensure that the crown-down technique is preferred, when shaping the endodontic system [28].
- Avoid keeping the instrument in a fixed location, especially in curved canals and with tapered and large-caliber instruments [28].
- Limit the use of rotating instruments during root canal shaping to approximately 5–10 s [28].
- Ensure continuous and adequate cleaning of the file spires after each use to avoid accumulation of dentinal debris and application of more load on the instrument, which increases the risk of fracture [28].
- Advance slowly the file in progressive movements through the canal until resistance is felt. Never force but rather allow yourself to be guided [59].
- Ensure that the endodontic access cavity should allow a direct view of all root canal orifices and straight-line access to the first curvature of each root canal [34].
✓ Ensure complete removal of the pulp ceiling, to limit restrictions that are the main reasons for stress accumulation and fracture [34].

✓ Maintain an endodontic approach as close to a straight line as possible, avoiding excessive instrumental curvature [34].

✓ Be sure to maintain a glide path that allows torque to be maximally effective [34].

✓ Ensure that the preparation made, in case of a nonconforming access cavity, allows for adequate holding and that the fingers are well supported on the teeth to control the pecking distance and prevent the rotating instrument from jamming in the canal [28].

✓ Ensure that the use of an insertion-retraction (pecking) action is respected, with instruments of appropriate caliber, while respecting what the root canal anatomy offers and the design features of the instrument [28].
✓ Ensure The removal of the instrument at the first sign of mechanical resistance in the canal [28].
✓ Check that the files should not be forced apically, and the movement of introducing a rotating NiTi file into the canal should be gentle, in view of the fact that separation can occur instantaneously if the file is used forcefully [28].
✓ Note that the current trend recommendation is the use of reduced speeds to minimize the risk of fracture [34].
✓ Adhere Strictly to the speed and torque values specified by the manufacturer for each specific rotary instrument system [34].
✓ Use a low-torque endodontic motor, because if the torque is set just below the limit of elasticity of each instrument, the risk of fracture is significantly reduced [60].
✓ Use the recommend motors that set torque values to minimal levels (less than 1 Ncm), for less experienced operators and for students, as well as for canals with small radius of curvature [32].

7. Conclusion

The failure of the root canal procedure can be complicated and compromised by instrument fracture in endodontics, which results in inadequate cleaning, shaping, and obturation. Several methods for removing fractured instruments have been documented. Every method employed to remove broken instruments must also guarantee the preservation of the root structure. The competence and expertise of the operator are among the most essential of the numerous complex aspects that contribute to the fracture of rotating NiTi instruments. Prevention is a significant and important part of endodontic treatment since many of the conditions that contribute to instrument breakage can be avoided by adhering to preventive measures.

Conflict of interest

There is no conflict of interest.

References
