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Management of Fractured Endodontic Instruments

A Project Submitted to the Council of the College of Dentistry at the University of Baghdad Department of Restorative and Aesthetic Dentistry in Partial Fulfillment of the Requirements for the B.D.S. Degree

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Certification of the Supervisor

I certify that this project entitled “Management of Fractured Endodontic Instruments” was prepared by the fifth-year student Manar Salah Abdulkadir under my supervision at the College of Dentistry/University of Baghdad in partial fulfilment of the graduation requirements for the Bachelor Degree in Dentistry.

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Date:

Dedication

I dedicate this work to God. I would not be where I am today without his guidance and endless blessings throughout my entire life, for which I am truly grateful.

No matter how many times I say it, “Thank you” will never express my gratitude to my family for always helping me and supporting me to achieve my dreams and goals.

To my friends, who were always by my side through the hardships of life: you are a blessing to me.

Special thanks to my supervisor, and all my teachers for their scientific support and for all the experience and knowledge they helped me acquire.

Acknowledgement

First and foremost, I thank God, from the bottom of my heart, for His infinite blessings and for giving me the strength and the means to keep moving forward and progress in my life.

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Abbreviation	Whole Words
EDTA	Ethylenediaminetetraacetic acid
GG	Gates-Glidden
NiTi	Nickel-titanium
SS	Stainless steel

Introduction

Instrument fracture is a serious complication during endodontic treatment of teeth, having an adverse effect on the outcome of the nickel-titanium (NiTi) treatment, especially if the fracture prevents apical access to the infected root canal **(Soares et al., 2008)**.

Despite the advent of NiTi files, the risk of fracture during the endodontic preparation of root canals, especially in severely curved canals, remains a serious concern. The fracture of NiTi files during preparation may result in a compromised prognosis for the tooth. In the presence of periapical lesions, instrument fracture may reduce the chances of successful healing **(Spili et al., 2005)**.

It is noticed clinically that when an instrument fractures in a root canal system, it is often associated with incomplete root canal obturation, ineffective coronal seal or poor definitive restorations. This further leads to micro-organisms penetrating the root canal system, indicating the development of a periapical lesion and treatment failure **(Oztan, 2002)**.

In a majority of cases instrument fracture results from incorrect use or overuse, occurring most frequently in the apical third of the root canal **(Parashos and Messer, 2004)**.

Rotary NiTi files are known to fracture without any visible signs of deformation and potential fracture, compared to the evident warning signs seen in traditional stainless steel (SS) files **(Zuolo and Walton, 1997)**. Fractures can be avoided mostly by discarding instruments that show signs of metal fatigue. However, NiTi instrument separation can happen without any sign of fatigue. The reported frequency rate for fractured instruments varies from 0.7% to 6% of cases **(Spili et al, 2005)**.

The common approach for dealing with a broken instrument is its removal. The use of an operative microscope to facilitate canal widening to the level of the broken fragment and its removal by ultrasonic tips and/or some type of grasping equipment is accepted worldwide **(Ruddle, 1997)**.

Aim of the Review

To explore the causes of instrument fracture, the different fragment removal techniques, how to minimize injury to the root and the preventive measures to avoid fracture.

Chapter One: Review of Literature

1. Factors Affecting Intracanal Instrument Fracture

1.1 Operator-Related Factors

Root canal treatment requiring adequate training and skills, like many other dental procedures **(Parashos et al., 2004)**.

The dentist need to choose from variety of instruments, each one having its own design, mechanical properties and its own guidelines for use; this process can already create some confusion.

The handling of instruments is characteristic for each clinician so it could be modified through training **(Regan et al., 2000).** Avoiding aggressive penetration in the root canal by applying too much apically-directed force on the instrument and sensing when a rotary instrument is about to bind inside a root canal so that it is withdrawn before torsional overload occurs are skills that can be developed through practicing on extracted teeth and clinical experience **(Saber, 2008)**.

1.2 Anatomy-Related Factors

1.2.1 Access Cavity

A completed and adequate access cavity should allow unobstructed visual access to all root canals and act as a funnel to guide the instruments into the canal, straight to the apex, or to the point of first curvature (Figure 1) **(Peters, 2008)**. Interference by the cavity walls or by unremoved dentin shoulders in the coronal third of the root canal can increase the stress on the instruments during preparation by increasing the number and severity of curvatures (iatrogenic S curve) **(Roda and Gettleman, 2016)**.

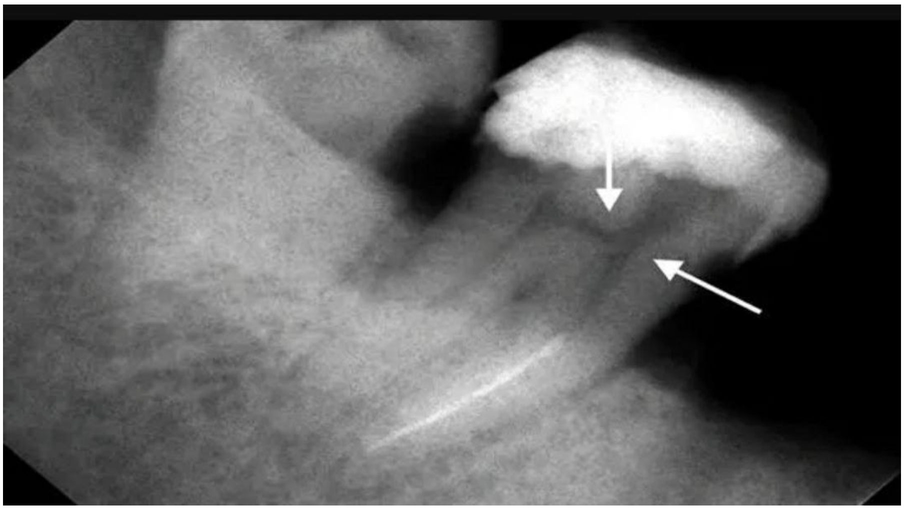

Figure 1. Fractured instrument in the mesial root of a mandibular molar due to inadequate access cavity preparation **(Lambrianidis, 2018)**.

SS instruments possess several advantages regarding their placement in the root canal as compared to NiTi files that require considerably more attention to gaining straight-line access. SS files can be pre-bent enabling their introduction into difficult-to-access canals, NiTi instruments are very difficult to pre-bent accurately **(Coltene Endo, 2014)**.

1.2.2 Root Canal Anatomy

The risk of instrument failure seems to increase in cases with complex root canal anatomy **(Peters et al., 2003)**. Fractures appear more often in molars than premolars or anterior teeth and also in the mesiobuccal root canal of maxillary and mandibular molars than in other root canals. These findings could be explained by the overall morphological complexity of the molar root canal system and the existence of multiple canals within each tooth, but the primary reason is most likely the curvature of these root canals **(Iqbal et al., 2006)**.

The curvature of a root canal is described by its angle and radius; the wider the angle and the smaller the radius, the more sever the curvature. These two parameters can vary independently of each other (Figure 2) **(Pruett et al., 1997)**.

As the file rotates, it undergoes repeated cycles of tension and compression, with tension occurring near the outer curved surface and compression near the inner. This repeated cyclic loading may result in crack initiation and eventually in fracture **(Pruett et al., 1997)**.

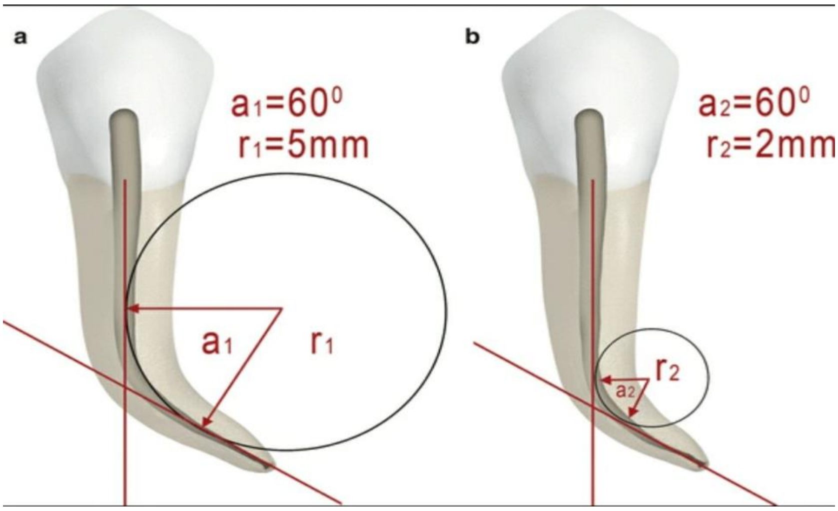

Figure 2. Angle and radius. The two root canals have the same angle but different radii of curvature **(Lambrianidis, 2018)**.

Ex vivo studies have suggested that root canal curvature may increase the failure rate of rotary NiTi instruments due to both torsional overload and cyclic fatigue **(Pruett et al., 1997)**.

1.3 Instrument-Related Factors

Raw materials, design, and manufacturing process can have a significant impact on instrument fracture **(McSpadden, 2007)**.

-Early studies have provided some support to the widespread concept that rotary NiTi instruments seem to fracture more often than hand SS instruments during clinical use **(Iqbal et al., 2006)**.

-Most instruments are milled rather than twisted, a process that allows creation of complex shapes through computer-aided design and manufacturing (CAD-CAM) technology but that can also result in surface imperfections such as milling grooves, cracks and pits (Figure 3), these irregularities act as stress concentration points and enable the initiation of cracks **(McSpadden, 2007)**. Several methods, such as thermal nitridation and electropolishing, have been applied to reduce these surface imperfections to improve the resistance of instruments to failure **(Praisarnti et al., 2010).**

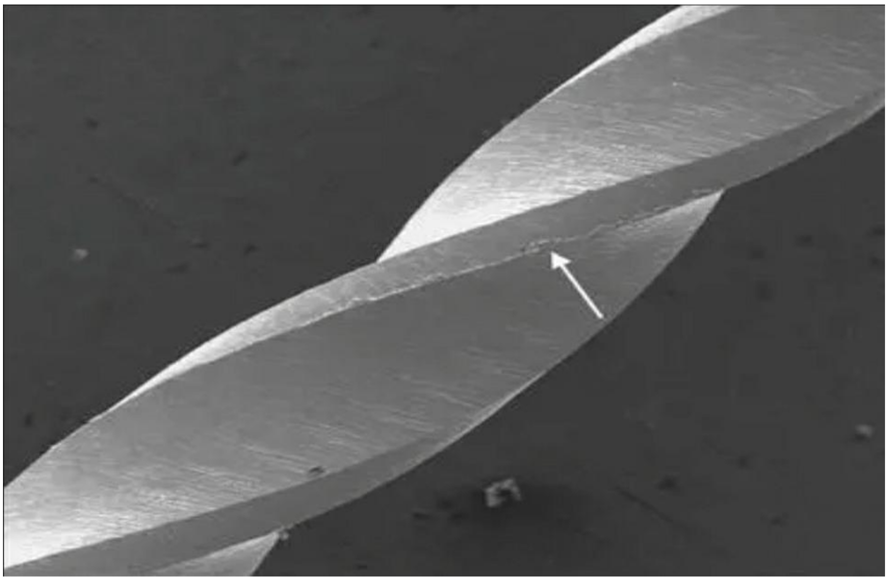

Figure 3. Irregularities on instrument surface. (Magnification ×100) **(Lambrianidis, 2018)**.

-The cross-sectional area of an instrument could also affect instrument fracture **(McSpadden, 2007)**. Increasing the cross-sectional area by either increasing the size or the taper will increase the resistance to torsional failure, but it will concurrently decrease the resistance to cyclic fatigue **(Peters and Paque, 2010)**.

1.4 Technique/Use-Related Factors

1.4.1 Motors-Operating Parameters

Electric motors are almost unanimously recommended over air-driven motors for rotary instrumentation nowadays, mainly because they can maintain a constant rotational speed and also limit the maximum torque applied to the instruments; both parameters can be easily adjusted by the operator. Air-driven motors lack such precise controls and may be also affected by air-pressure differences. Nevertheless, the instrument fracture rate may be similar for both types of motors **(Bortnick et al., 2001).**

The widespread adoption of electric motors has occurred in parallel with the prevalence of the low-speed low-torque instrumentation concept **(Gambarini, 2001)**. Manufacturers of rotary NiTi files recommend a specific rotational speed, usually in the range from 250 to 600 revolutions per minute (RPM) **(Kitchens et al., 2007)**. In addition, fatigue failure seems to occur more often with motor-driven NiTi files compared with the same files used by hand, possibly because handheld files rotate at a much lower speed **(Cheung et al., 2007)**.

1.4.2 Instrumentation Technique

The instrumentation technique has an influence on instrument failure **(Roland et al., 2002)**. For instance, hand-operated NiTi files used clinically in a modified balanced force movement seem to fail mainly due to torsional overload, while motor-driven files of the same type appear to fracture mostly because of cyclic fatigue **(Cheung et al., 2007)**. The crown-down approach has been recommended for the vast majority of rotary NiTi instruments in order to reduce friction and minimize the fracture risk **(Peters, 2004).** Regarding the technique, light apical pressure, continuous axial movement (pecking motion), and brief use inside the root canal are almost unanimously recommended in order to prevent torsional overload and prolong the fatigue life **(Gambarra-Soares et al., 2013).** In general it is advisable for inexperienced users of a particular system to adhere to the recommended instrument sequence.

It is important to create a continuous smooth pathway to the apical of the root canal (glide path) before using the main series of rotary NiTi instruments to avoid locking and eventual torsional failure **(Peters, 2004)**. A glide path can be prepared by small-size hand SS instruments or by specially designed rotary NiTi instruments **(Alovisi et al., 2017).**

1.4.3 Reuse and Sterilization

The number of times that a file can be safely used is still unknown. Manufacturers claim that the only predictable way to prevent failure is by discarding rotary instruments on a regular basis. It is recommended to use small hand SS instruments no more than twice. More recently, single use of all rotary NiTi instruments has been suggested as a precaution **(Arens et al., 2003)**, while others advocate this strict rule only concerning the smaller files **(Haapasalo and Shen, 2013)**, possibly because any defects may be more difficult to detect. The type of alloy, the design and size of the instrument, and the case difficulty are parameters frequently taken into account in order to decide when to discard an instrument.

Prolonged clinical use of NiTi rotary files seems to reduce their resistance to cyclic fatigue **(Bahia and Buono, 2005)**.

Instruments need to be cleaned and sterilized before and after their use; the effect of this process on instrument failure is still controversial. Multiple sterilization may induce surface alterations on NiTi files, including corrosion and defects, and may also increase their surface roughness. and reduction in the torsional strength will happen **(Thierry et al., 2000)**.

1.4.4 Irrigant

During instrumentation, root canals and the pulp chamber should be flooded with irrigant, like sodium hypochlorite, to help in killing bacteria, dissolving tissue remnants and for lubrication **(Zehnder, 2006)**.

The possible corrosive effect of sodium hypochlorite and of other irrigants on root canal instruments is an additional concern **(Sonntag and Peters, 2007)**. Total immersion of the instruments in sodium hypochlorite, seems to have a more pronounced effect than partial immersion **(Darabara et al., 2004)**.

2. Treatment Options for Management of Fractured Instruments

2.1 No Intervention

This option is applicable in two cases, when there is no point in intervening because the fragment is located to a non-restorable and/or severely compromised periodontal tooth, or when no clinical or radiographic signs of pathosis are present. Such characteristic examples might be the presence of a long-lasting fragment in the apical third in a symptomless tooth with no radiographic lesion or a long-lasting fragment beyond the foramen with no clinical symptoms or radiographic sign of pathosis **(Lambrianidis, 2018)**.

2.2 Non-Surgical Management

This approach can be divided into two phases. In the first phase as a general rule, efforts are made to retrieve the fragment and, if this is not possible, to bypass it. The second phase includes the instrumentation and obturation phase **(Lambrianidis, 2018)**.

2.2.1 Coronal and Radicular Access

After diagnosis, coronal access is the first step in the removal of broken instruments to create straight-line access to all canal orifices and radicular access is the second step (Figure 4).

A number of different techniques may be employed to flare the canal coronal to an intracanal obstruction. However, experience suggests a predictable way to create safe radicular access is to initially use hand files, small to large, coronal to the obstruction. Hand files create sufficient space to safely accommodate Gates-Glidden (GG) drills that used to create radicular access and a uniform tapering funnel to the obstruction. Generally, a GG-1 or GG-2 can be carried to the depth of the head of a separated instrument. The GG's are used cautiously in approximation to the obstruction with attention to brush-cutting out of the canal **(Ruddle, 2004)**.

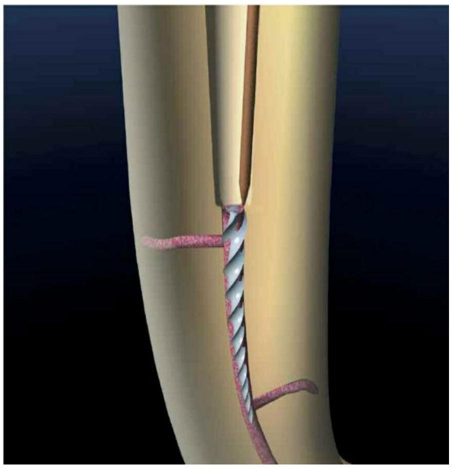

Figure 4. A graphic demonstrates the coronal and radicular access **(Ruddle, 2004)**.

2.2.2 Creating a Staging Platform

When the canal has been optimally shaped, then microsonic techniques are usually the first option selected to remove a broken file segment. At times, when an ultrasonic instrument is introduced into a pre-enlarged canal, its activated tip does not have enough space, lateral to the broken file segment. As such, if more lateral space is required, then a “modified” gate glidden used to create a “staging platform” **(Carr, 1998)**.

The bud of the GG drill is altered by cutting it perpendicular to its long axis at its maximum cross-sectional diameter. This modified GG is carried into the canal, rotated, and directed apically until it lightly contacts the most coronal aspect of the obstruction at a reduced speed of approximately 300 RPM . This step creates a small staging platform which facilitates the introduction of an ultrasonic instrument and facilitate excellent vision to the intra-radicular obstruction. **(Friedman et al., 1990)**

2.2.3 Bypass Technique

Bypassing technique is considered more conservative regarding the amount of dentine removal when compared to removal techniques especially if the fragment is located in the apical one third or beyond the canal curvature. It has been reported that if the file is bypassed, the obturation quality is not compromised **(Saunders et al., 2004)**.

This technique depends on locating or catching a tiny space behind the broken instrument with precurved small k-file in a watch-winding motion, with ethylenediaminetetraacetic acid (EDTA) gel to facilitate the task. When the operator catches that space and the k-file is engaged there, some pecking motion should be started along with watch-winding motion until reaching the apex, bypassing should be done till size 20 or 25 k-file **(Hülsmann and Schinkel, 1999)**.

The shaping can be completed either with manual files and step-back technique or with rotary files, but its slightly risky (small taper is preferable here, usually 4% is enough to manage a good obturation for the root canal system). Possible risks of this techniques create a false root canal parallel to the original one, ledge formation, perforations, secondary separation of instrument, fragment extrusion through the apical foramen **(**figures 5 and 6) **(Terauchi et al., 2006)**.

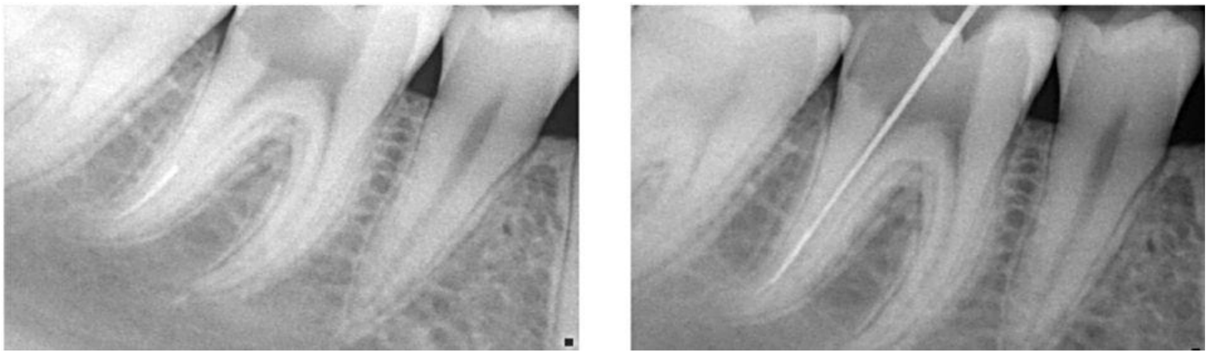

Figure 5. File separated and bypass done (mesial view).

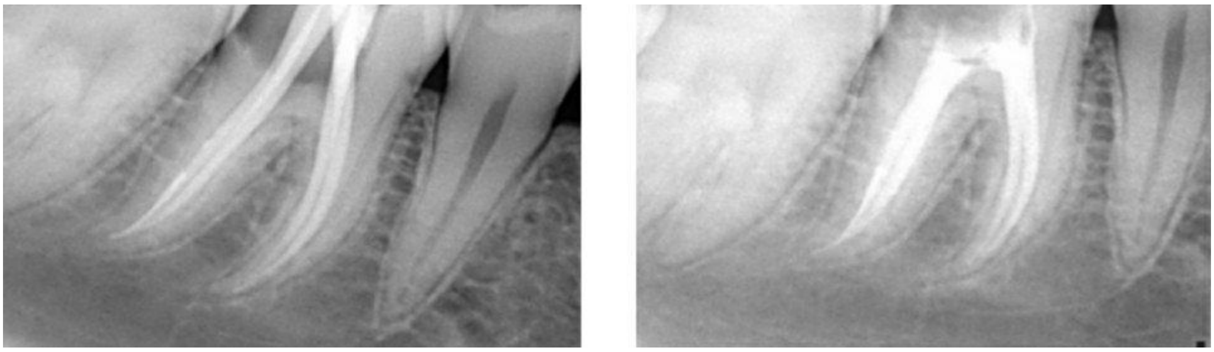

Figure 6. Master cone and obturation (mesial view).

2.2.4 Techniques for Removing Broken Instruments

A number of devices, technologies and techniques have been reported to remove an intracanal obstruction such as a broken instrument **(Nehme, 2001)**.

Today, all broken instruments can be eliminated if straight line access can be safely made to the coronal-most extent of a broken instrument **(Ward et al., 2003)**.

2.2.4.1 Ultrasonic Technique

The first option to remove a broken instrument is to utilize ultrasonic instruments.

An appropriate sized ultrasonic instrument is selected, that its length will reach the broken obstruction and its diameter will fit into the previously shaped canal.

The tip of this ultrasonic instrument is placed in intimate contact against the obstruction and typically activated within the lower power settings in a counter clockwise direction, around the obstruction (figure 7) **(D'Arcangelo et al., 2000)**.

Typically, during ultrasonic use, the obstruction begins to loosen, unwind and then spin. Gently wedging the tip between the file and canal wall oftentimes causes the broken instrument to "jump out" of the canal **(Madarati et al., 2008)**.

Sometimes excellent coronal and radicular access, expose the separated instrument, perform ultrasonic procedures, and still be unable to loosen the instrument out of the canal. It is unsafe to continue around a broken instrument due to lack of vision, so a small hand files may be used to bypass and remove a broken instrument **(Shiyakov and Vasileva, 2014)**.

To maximize efficiency and success, the handle from a SS hand file can be intentionally removed and the shaft of the instrument inserted into a device called the File Adapter. Small, SS hand files can be precurved and inserted into available space and used at low power in an ultrasonic effort to remove a broken instrument. This technique is useful when the root is thin or a portion of the file lies apical to a canal curvature **(D'Arcangelo et al, 2000)**.

Figure 7. A graphic demonstrates ultrasonic device **(Ruddle, 2004)**.

2.2.4.2 Holding technique

The concept of these techniques is to expose the coronal portion of the fragment using a range of trephine drills or ultrasonic tips prior to the use of a second instrument that will engage the coronal aspect and withdraw the fragment from the canal.

The Masserann Technique

The Masserann technique **(Masserann, 1966, 1971)**, is one of the holding technique, it is being used for the removal of fractured instruments and the kit consists of:

• End-cutting, tubular trepan burs of increasing size.

• Two sizes of tubular extractors (1.2 and 1.5 mm).

The trepan burs are hollow tubes with edges designed to cut dentin peripherally to the fragment. They are meant to be used with an anticlockwise rotation. During the apical movement of the drill, the coronal end of the fragment is engulfed in the tubular portion. The extractor (Figure 8) is tube-like with a plunger rod which, when screwed inside the extractor, locks the exposed coronal end of the fragment.

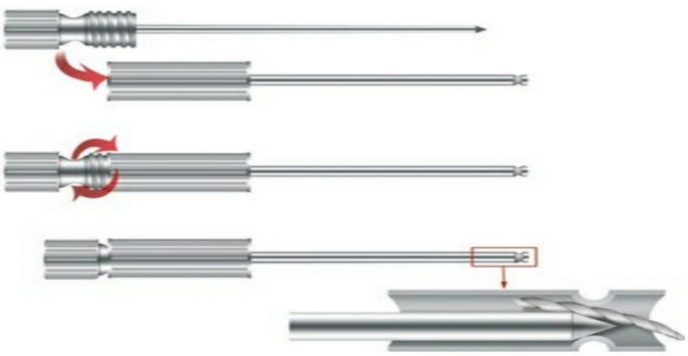

Figure 8. Masserann extractor **(Lambrianidis, 2018)**.

2.2.4.3 Microtube Removal Technique

With this technique, the coronal segment of the fragment is exposed and positioned in the center of the root canal, and then a hollow tube device with an adhesive is slid into it. In most of the proposed tube techniques, cyanoacrylate is used as an adhesive. The alternative to cyanoacrylate is resin (**Andrabi et al., 2013)**.

The most characteristic and well-known systems for this technique are:

1. The Endo Extractor
2. The Cancellier Extractor Kit
3. Hypodermic surgical needles
4. The separated instrument removal system
5. The Micro-Retrieve & Repair System

A. The Endo Extractor

The Endo Extractor kit consists of:

• Four extractors of different sizes and colors

• Four trephine burs corresponding to each extractor

• A cyanoacrylate adhesive

• A debonding agent

The appropriate pre-selected micro-tube extractor with the adhesive is slid into place over the exposed coronal segment of the fragment. The adhesive is used to bond the hollow tube to the exposed end of the file. Care must be exercised to use only a few drops of adhesive to avoid blocking the canal. The time required for the adhesive to set is 5 min for a snug fit and 10 min for a loose fit **(Gettleman et al., 1991)**.

B. Hypodermic Surgical Needle

This is a simple cost-effective method in which no special equipment is needed, which can still result in predictable success **(Andrabi et al., 2013)**. Cut hypodermic surgical needles, transformed into micro-tubes, are used in this technique either as:

1. Hypodermic Surgical Needle with an Adhesive:

This technique consists of:

• Hypodermic surgical needles of various sizes cut as micro-tubes 5–10 mm long.

• Adhesive.

The steps of this technique are:

– Exposure of approximately 1.5–2 mm of the coronal segment of the fragment by troughing around it with a trephine bur, by ultrasonic means, or even with a shortened hypodermic needle rotated under light pressure to groove around the coronal part of the fragment.

– Selection of the appropriate needle and cut it with a disk and converted into a micro-tube.

– A few drops of cyanoacrylate glue or strong dental cement (i.e., polycarboxylate) are dropped into the cut hypodermic needle, and inserted over the exposed coronal segment of the fragment.

– When set, the whole assembly as a single unit is pulled out of the canal through gentle slight counterclockwise rotation and a simultaneous pullout motion.

2- Hypodermic Surgical Needle with Hedstrom File

An alternative to the use of adhesive in connection has also been proposed **(Suter, 1998)**. This consists of:

• Hypodermic surgical needles of various sizes cut as micro-tubes 5–10 mm long.

• Hedstrom files because of their unique ability to engage. The size of the file to be used is related to the size of the needle micro-tube selected.

The steps to be followed are **(Monteiro et al., 2014)** :

-Insertion of the needle micro-tube over the exposed fragment.

-A correctly pre-selected Hedstrom file is pushed in a clockwise motion through the needle to wedge the upper part of the fragment and the needle's inner wall tightly together.

-The three connected objects can then be gently pulled out of the root canal.

2.2.4.4 Canal Finder System

The Canal Finder System consists of:

A special handpiece. The system produces an up-and-down pecking motion and a quarter of a turn rotation that guides the instrument into the path of the root canal, exclusively designed for the system engine-driven instruments **(Hülsmann 1990a; b).**

In this technique, starting with a size #8 and size #10 path-finding file, an attempt is made to work along the obstruction and to loosen the fragment. The flutes of the files are mechanically engaged with the fragment, and through the vertical vibration of the file, the fragment is loosened and eventually retrieved in the majority of cases **(Hülsmann and Schinkel, 1999)**.

2.2.4.5 File Retrieval System

This system, has been found effective in remove instruments fractured at the apical third of the canal in a short retrieval time with the removal of a minimal amount of root dentin **(Terauchi, 2012)**. This kit consists of:

• A modified GG #3 bur and microtrephine bur

• A loop device

• Four customized ultrasonic tips that can be bent to accommodate canal curvature

creation of an unobstructed straight-line access to the coronal portion of the fragment by the use of low-speed cutting burs (28 mm long) flexible enough in the shanks to be able to go around a curved canal. They were used in a counterclockwise motion, and they loosened or even removed the fragment (**Terauchi et al., 2006),** if it is not retrieved, loop device with a NiTi wire (0.08 mm) is used to engage the peripherally exposed fragment and retrieve it.

2.2.4.6 Wire Loop Technique

In this removal method, an appropriately-sized microtube is selected and a wire passed through the tube then looped at one end and passed back through the tube. This loop will engage the coronally exposed obstruction and remove it by pushing the tube apically while simultaneously pulling the wire ends coronally **(Roig-Greene, 1983)**.

2.2.4.7 Forceps/Pliers Technique

Steiglitz forceps, plier-type or modified needle holder instruments are suitable only in cases where the fragment extends into the pulp chamber and the instrument can engage and grab the coronal aspect of the instrument then with gentle movements retrieve the fragment **(Fors and Berg, 1983).**

2.2.4.8 Softened Gutta-Percha Technique

Softened gutta-percha has been reported **(Rahimi and Parashos, 2009)** to remove loosely bound fragments located in hard-to-reach areas inhibiting straight-line access and thus not allowing direct vision. With this technique:

– With small-sized SS Hedstrom files (#8, #10, and #15), the fragment was partially bypassed and loosened.

– A gutta-percha point was dipped, for about 30 seconds, in chloroform and then inserted into the canal and allowed to harden for roughly 3 min.

– The gutta-percha point and fragment were then successfully removed using careful and delicate clockwise and counterclockwise pulling actions.

2.2.4.9 Laser Irradiation

The neodymium-doped yttrium aluminum garnet lasers (Nd:YAG lasers) **(Hagiwara et al., 2013; Cvikl et al., 2014)** are successfully used to manage instrument fragments in less than 5 min in laboratory studies. This is done in many ways, all correlated to temperature effects:

1. The laser melts the dentin around the fragment, and then H-files are used to bypass and retrieve it.
2. The laser melts the fragment.
3. The laser welds the file fragment positioned within the metal hollow tube (Figure 9)

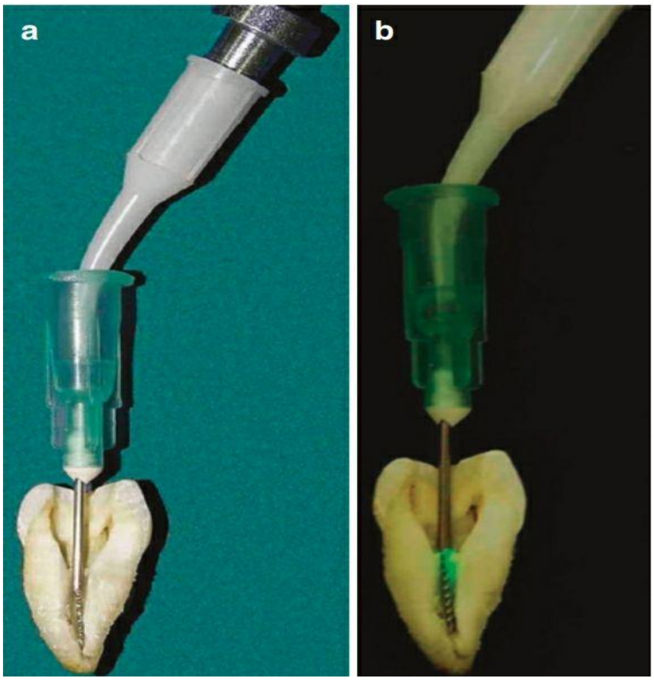

Figure 9. Laser irradiation. Procedure of welding of a fractured K-file using Nd:YAG laser irradiation **(Lambrianidis, 2018)**.

2.2.4.10 Electrolytic Technique

The removal of fractured instruments by mechanical means requires the removal of dentin, which may weaken the root and increase the risk of perforation particularly when the fragment is beyond the root curvature. The electrolytic technique aims to partially or even totally dissolve the fragment through electrolysis **(Okawauchi, 1993)**. For this purpose, a system of electrodes is inserted into the root canal so that the anode comes into contact with the fragment. Electrolytes used with the technique include normal saline, sodium hypochlorite in various concentrations, and saline with hydrochloric acid.

Okawauchi (1993) have demonstrated that this technique:

• Is more effective on carbon steel than on SS instruments.

• Is less effective when the fragment is lodged in the apical third.

• Is safe, as histologic examination did not reveal inflammation in periapical tissues.

• Easily shows its degree of effectiveness.

Effectiveness visible when the color of the electrolyte changes brown because of the ions of the metal.

The major disadvantages of this technique are the need for special equipment, the use of acid in the electrolyte, and its limited effectiveness on SS instruments **(Ormiga et al., 2010; 2011)**.

2.3 Surgical Management

As a rule, surgical management with apicoectomy, hemisection, root amputation, or intentional reimplantation is performed when the conservative approach fails or is considered from the outset to lead to failure. It is the only reasonable alternative to extraction **(Lambrianidis, 2018)**.

2.4 Tooth Extraction

This is performed when all other therapeutical options (non-surgical and surgical) have proved unsuccessful or are considered to be a failure **(Lambrianidis, 2018)**.

3. Parameters Influencing the Removal of Fractured Instruments

The successful management of fractured instruments ranges greatly. The longer the time needed to manage a fractured instrument, the greater the chance/possibility for complications and the lower the success rate **(Ward et al., 2003; Suter et al., 2005)**. The variation can be attributed to the variety of factors influencing the retrieval.

These factors can be grouped into:

3.1 Tooth Factors

The type of tooth, the root canal morphology and particularly its cross-sectional shape and diameter, the thickness of the dentin, the presence of root canal curvature, and the radius and degree of the root canal curvature are among the decision-making and influencing factors in the management of fractured instruments **(Shen et al., 2004)**.

As a generalized finding, the success rate of retrieving instrument fragments is higher in straight and wide canals than in curved and narrow canals **(McGuigan et al., 2013)**.

3.2 Localization of the Fragment

The location of the fragment in relation to the curvature of the root canal is the main determinant, rather than the method used to retrieve it. Fragments in the coronal third managed more easily and with a higher success rate compared to the fragments in the middle or apical third **(Madarati et al., 2008)**. When a fractured instrument lies partially around the canal curvature, and particularly when it lies totally beyond the curvature, safe nonsurgical management usually cannot be accomplished unless a straight-line access can be established to their most coronal portion **(Ruddle, 2002)**.

3.3 Fractured Instrument Factors

The material fragment made of fragments of rotary NiTi are more difficult to remove compared to SS instruments. NiTi endodontic instruments fracture at a smaller length, due to their rotational motion and have also a greater tendency to fracture repeatedly becoming smaller and smaller when ultrasonic energy is applied to them **(Ward et al., 2003)**.

The type of the instrument. Lentulo spirals, for example, have been found to be easier to remove than reamers or Hedstroem files, this could be attributed to their ability to be bypassed via their empty centers **(Suter et al., 2005)**.

The length of the fragment. Anecdotal findings, suggest that long fragments are easier to remove than short ones. Probably because only the tip of the fragment is engaged into the root dentin, leaving at the coronal segment enough space for its loosening and removal. Another cause is the coronal part of long fragments lies in the visible and thus easier to be handled portion of the root canal **(Suter et al., 2005)**.

3.4 Operator Factors

The knowledge, skill, experience, creativity, and patience of the operator are crucial in the management of fractured instruments. All retrieval/bypassing techniques depending solely on the tactile sensitivity and sheer perseverance of the clinician. Thus, for instrument fragment management, an experienced operator knows the most appropriate techniques and applies the particular one with which he/she is most familiar with and has most experience **(Hülsmann and Schinkel, 1999; Lambrianidis, 2001).**

3.5 The Technique Chosen

The technique chosen can be a key factor in the successful removal. It has been suggested, that it may not be as important as anatomical factors. Obviously, the application of any technique is closely related to the operator factors **(Madarati et al., 2013).**

3.6 Patient Factors

The extent of mouth opening and difficulties in accessing the canal with the fragment are the two main anatomical factors to be carefully evaluated as they greatly influence management efficiency and eventually decision-making. **(Madarati et al., 2013**).

4. Prevention

Several nonsurgical and surgical techniques have been proposed and clinically applied for the management of instrument fragments. These management attempts can be considered as unpredictable and may include the possibility of further iatrogenic complications. Thus, clinicians must consistently take all necessary precautions during root canal treatment or retreatment procedures to prevent instrument fracture **(Parashos et al., 2004)**.

Recommended guidelines to be carefully considered:

-preoperative clinical and radiographic examination of the anatomy of the tooth to be treated must be performed before treatment **(McGuigan et al., 2013)**.

-Assessment of the "difficulty level" in endodontic instrumentation to enable the selection and use of the most appropriate instruments and root canal preparation technique(s), for example S-shaped curves, calcifications, and dilacerations canals. **(McSpadden, 2007)**

-Adequate/appropriate access cavity should be prepared to ensure unhindered straight-line access of the endodontic instruments to the apex **(Kosti et al., 2011)**.

-Endodontic instruments should be carefully inspected prior to, during, and after use, preferably under magnification, for any signs of fracture or plastic deformation **(Booth et al., 2003)**.

-Rotary endodontic instruments have non-cutting tips; thus, they should be advanced only into an explored and patent canal section. This is particularly recommended for the apical third of narrow and/or calcified canals **(Sattapan et al., 2000)**.

-NiTi systems should be used within safe torque and speed limits for optimal performance, provided by the manufacturer **(McGibney, 2016)**.

-Pre-curved instruments should be used in curved root canal. The level of precurvature depends on the radiographic appearance of the degree of curvature of the root **(Berutti et al., 2004)**.

-Instruments should always be used in sequence of sizes without skipping sizes **(Hatch et al., 2008)**.

-Instruments should not be overused. This is mostly recommended for small sized SS and NiTi instruments **(Kim et al., 2014)**.

5. Comparative Evaluation of Non-Surgical Removal Techniques

5.1 Bypass Technique

It should be seriously considered that not only the removal but also the bypassing of a fractured instrument can and should be regarded as a success as it may allow proper cleaning and disinfection of the space apical to the retained fragment and eventually complete and tight obturation of the most apical part of the root canal.

5.2 Ultrasonic Technique

This is the most popular technique among general dentist and endodontic specialists **(Madarati et al., 2008).** This is due to the high overall success rate reported with this technique. Despite the effect of ultrasonic vibration during removal efforts on the external root temperature, the loss of tooth structure, and the creation of ledges this technique considered superior to the Masserann technique **(Gencoglu and Helvacioglu, 2009).**

5.3 Holding Technique

After nearly more than half a century since its introduction, the Masserann system, the first holding technique, is still in use and is considered effective in selected cases, especially in those where the instrument fragment is located in a readily accessible position. The Masserann system has limited application in posterior teeth, particularly in patients with limited mouth opening and in teeth with thin and curved roots due to their bulk external diameter that may cause perforation. **(Terauchi et al., 2007)**

5.4 File Removal System

It has been reported that the File Removal System could successfully retrieve instrument fragments from the root canal in a relatively short time with minimal removal of root dentin. The extremely elongated ultrasonic tips made of ductile SS are mostly helpful (**Terauchi et al., 2006; 2007)**.

5.5. Loop Techniques

Although the wire loop technique has been essentially replaced by more practical or successful techniques, it remains a technique which utilizes equipment available in almost all dental offices and it is still in use **(Terauchi, 2012)**.

5.6 Softened Gutta-Percha

It is a simple technique that does not require any special equipment nor any additional removal of hard dental tissue, and thus it can be tried in selected cases when the fragment is partly bypassed and loosened.

However, care should be exercised to avoid the extrusion of softened gutta-percha to the periapical tissues **(Rahimi and Parashos, 2009).**

No studies are available on the efficacy of this device.

5.7 Laser Technique

There are no clinical studies on management of instrument fragments with laser irradiation. The harmful effects of temperature on root dentin and on periodontal tissues as a result of temperature rise on the internal and external root surface and the probability of root perforation in curved root canal or thin roots, remain ongoing concerns when this energy is used within the root canal **(Hagiwara et al., 2013)**.

5.8 Electrolytic Technique

This technique has not been clinically attempted yet, as it could be dangerous if the electrical current is conducted by the soft tissues. Additionally, the cytotoxic effect onto the periapical tissues isn't evident yet.

Studies on the effects of the dissolution products on periodontal ligament fibroblasts have revealed that they are cytotoxic **(Mitchell et al., 2013)**.

Chapter Two: Conclusions and Suggestions

Every dentist, even specialists, are prone to fracture endodontic instruments due to the many factors that contribute to this complication, and experience alone is not enough to avoid it.

Still, we can decrease the likelihood of fractures by checking the instruments before use, taking care of them or disposing of them after a set number of uses, and various other preventive measures.

There are various techniques and treatment options for management. Choosing the most appropriate one depends on the case condition and it can help to reduce the chances of complications noticeably.

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