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Endodontic Treatment of Tooth Canals With A Fracture Instrument

A Project Submitted to
The College of Dentistry, Ashur University in Partial Fulfillment for
the Bachelor of Dental Surgery

BY

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Certification of the Supervisor

I certify that this project entitled " Endodontic Treatment of Tooth Canals With A Fracture Instrument " was prepared by the fifth-year student (Eman Adel Ismaeel/Fatima Shihab Kaittan/ Fatima Radi Rahim),under my supervision at the College of Dentistry/Ashur University in partial fulfilment of the graduation requirements for the Bachelor Degree in Dentistry

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Pg.no.

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.

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We would like to express our sincere gratitude to everyone who contributed to the completion of this research.

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Last but not least, we truly appreciate our families and friends for their constant encouragement, patience, and emotional support during our academic journey.

Introduction

The fracture of endodontic instruments presents a dilemma that every clinician deals with during root canal treatment (Hulsmann et al., 1999). The prevalence of instrument fracture has been reported between 1% and 5.1% (Iqbal et al., 2006; Tzanetakis et al., 2008). Significantly more instrument fracture was observed in molars compared with premolars and incisors or canines. Moreover, it has been found to occur most frequently in the mesiobuccal roots of molars, due to the curvature and anatomy of the canal (Iqbal et al., 2006; Ungerechts et al., 2014). The probability of instrument fracture has been shown to be almost seven times higher for rotary instruments than for hand files (Iqbal et al., 2006). NiTi rotary file fractures are caused by excessive cyclic flexural fatigue, torsional fatigue, or a combination of both. More recent evidence highlights that both characteristics interact with each other, and considered as a union, they are measured with the polar moment of inertia (Zanza et al., 2021; Seracchiani et al., 2021). stainless steel instrument fracture is caused by excessive torque (Parashos et al., 2006). There are three orthograde treatment choices for the management of fractured instruments. The first two strategies maintain the fragment within the root canal, either by obturation up to the accessible part of the canal or by bypassing the fragment. The third treatment option is the retrieval of the broken instrument from the root canal (Shahabinejad et al., 2013). Although removal of the broken instrument is the most favorable management option in cases with periapical involvement, a complete bypass might also provide a good prognosis by allowing the thorough debridement of the entire working length of the root canal in cases where retrieval is impossible (Madarati et al., 2013) . The anatomy of the canal and the location of the broken instrument can make instrument removal stressful and time-consuming. Moreover, removal techniques may result in excessive loss of dentine, decreased root fracture resistance, and other complications, such as root perforation, extrusion of the fragment beyond the root apex, and an increase in the temperature of the external root surface (Lertchirakarn et al., 2003; Souter et al., 2005). The successful removal of broken instruments does not guarantee the success of the root canal treatment. Therefore, a clinician should find a balance between the successful removal of the broken instrument and the maintenance of the maximum amount of tooth tissue in terms of quality and quantity

The Aim Of The Review

To evaluate different methods of fracture file management, It's complication, the factor that affect it and it's prognosis in different type of canal curvature and different fracture position.

Factors Conteributing To Fracture

1. Instrument Design

It has been shown that when instruments are subjected to flexural and torsional load their cross-sectional area and design may affect their resistance to fracture. (Berutti et al., 2003; Xu et al., 2006).

2. Instrumentation Technique

A crown-down instrumentation technique enlarging the coronal aspect of the canal before apical preparation and creation of a manual glide path preparing the canals manually with a SS file to working length before rotary NiTi instrumentation has (Roland et al., 2002 been proposed to reduce the frequency of instru ment fracture ;Patiño et al., 2005). These techniques aid in reducing instrument 'taper lock' or 'instrument jamming' which is associated with torsional fracture. Crown-down instrumentation reduces torsional stresses generated particularly in the smaller instruments (Schrader and Peters et al., 2005). and a glide path limits the level of torque on the instrument thereby protecting against shear fracture. (Patiño et al., 2005).

3. Instrument Size

A higher incidence of fracture and distortion in smaller NiTi instruments has been recorded in a number of in vitro studies. (Yared et al., 2002). Certain investigators, (Yared et al., 2002; Berutti et al., 2003). have coccluded that smaller instruments are more susceptible to torsional failure than larger instruments and have recommended that small files (eg 0.04 taper ProFile size 20) should be considered as a single use instrument, such is the likelihood of distortion. Conversely, a large clinical cohort study (Wolcott S et al.,2006). reported the greatest number of instrument failures occurred when using the larger diameter files, suggesting that larger stiffer files experienced greater stress during use. (Haikel et al in 1999 suggest that logic would). that smaller files are more susceptible to distortion as they are the principal files involved in negotiation and initial instrumentation of the root canal system

4. Dynamics of Instrument use

Torqeu

Torque-controlled electric motors are generally recommended for use with rotary NiTi systems. An in vitro study has demonstrated that torque controlled motors, which perform below the elastic limit of the file, reduce instrument fracture due to torsional overload (Gambarini et al., 2001). However, clinical studies did not demonstrate any significant difference in failure of Profile NiTi instruments used with high or low torque motors. (Yared et al., 2001; Iqbal et al., 2006). Another clinical study investigated three torque control levels (high, moderate and low) during NiTi canal preparation and reported that if the operator was inexperienced fracture rates decreased with a low torque-controlled motor. (Yared and Kulkarni **et** al., 2002). Nevertheless, this study observed no difference when experienced operators used a high or moderate torque-controlled motor

Rotational Speed

The effect of rotational speed on fracture remains to be elucidated, with some studies reporting rotational speed to have no influence on fracture incidence (Yared et al., 2002). while others reported the opposite (Martín et al., 2003; Herold et al., 2007). Difficulties arise when comparing these studies as different methods of testing, instrument types and operator experience were employed in each study. However, manufacturers generally recommend a specific number of rotations per minute (rpm) for the safe use of rotary NiTi instruments, which is usually in the region of 250-600 rpm

5. Canal Geometry and Tooth Type

Cyclic fatigue testing of rotary NiTi files has demonstrated that fracture occurs at the poin t of maximum flexure, which cor responds to the point of greatest curvature within simulated root canals. Specifically these tests have shown that as the angle of curvature increases and the radius of curvature decreases there is a reduced number of cycles to file fracture (Zelada et al., 2002; Peters, 2004; Grande et al., 2006). This is supported by clinical research which identified that the majority of instruments fractured in the apical third of the canal, as this is the area of maximum curvature and smallest diameter. (Iqbal et al., 2006). Iqbal and co-worker (Iqbal et al., 2006). srationalised this by concluding that the probability of separating a file in the apical regions was thirty-three times greater than in the coronal-third and six times greater than the middle-third of the root. The observed increase in file fracture in the apical third of root canals was corroborated in other studies, (Yared et al., 2000; Wu et al., 2011). this is clinically relevant as, the greater the degree of flexing that a rotary NiTi instrument is subjected to when used in curved canals, the shorter the instruments life expectancy Furthermore, the more complex the root canal anatomy, the greater the torsional failure. (Peters et al., 2002). The radius of canal curvature is generally decreased in molar teeth, which also decreases the instrument's ability to resist torsional forces. (Booth et al., 2003). This has been observed clinically where instrument fracture was significantly greater (up to 3 ×) in molars than in (Iqbal et al.,2006). The relative increase in fracture of files in molar teeth premolars has been reported elsewhere. (Yared et al., 2000; Shen et al., 2009). Additionally, the probability of fracturing an instrument in the mesiobuccal canal of a maxillary molar was three times greater than the disto- buccal canal; similarly the probability of fracturing a file in the mesiobuccal canal of a mandibular molar (known for their greater curvature) was greater than the mesiolingual canal. (Iqbal et al., 2006).

6. Number of Uses

Since 2007, 'The Department of Health' in the United Kingdom has dictated that for reasons relating to cross infection and theoretical prion transmission, all Department of Health- endodontic files are single use (Letters et al., 2005; Commissioning and System Management et al., 2007). File manufacturers have recently advocated that files should be single use only and have introduced features into new files which distort when autoclaving, hence preventing reuse (WaveOne™, Dentsply Maillefer, Ballaigues, Switzerland). The literature is unclear in providing guidance on the issue of the number of uses, particularly in relation to NiTi instruments where damage to the files is often not evident clinically before fracture (Yared et al., 2000). Several studies state that NiTi instrument failure is influenced more by the manner in which they are used rather than how many times they are used. (Parashos et al., 2004; Shen et al., 2009). However, regardless of the manner in which files are used, NiTi rotary files undergo a reduced flexural fatigue resistance with repeated usage and the torque necessary to induce failure of a previously used instrument is significantly lower when compared with new instruments (Gambarini et al., 2001; Plotino et al., 2006). Surprisingly, no correlation has been established clinically between the number of uses and the frequency of file fracture. (Schrader and Peters et al., 2005). Advocates of single use files suggest that even brand-new instruments fracture (0.9%) and as files become progressively fatigued with repeated use, recurrent use cannot be justified. (Arens F C et al., 2003). It has been postulated that the reason for fracture of new files may be due to a combination of manufacturing defects, operator error and/or complex canal anatomy (Shen et al., 2009). Others have recommended discarding instruments, SS or NiTi, after a predetermined number of clinical uses. (Sattapan et al., 2000). A large cohort study demonstrated that reusing ProTaper rotary NiTi files up to four times did not significantly increase the incidence of fracture, but no details were provided as to the prevalence of severely curved canals included in the study (Wolcott et al., 2006). Another study concluded similarly, that rotary instruments could be used clinically to complete endodontic treatment in up to four molars, (Yared et al., 2000). However this study excluded teeth with complex root canal anatomy that is, sclerosed canals and/ or canals with severe curvatures. Most deformations and fractures appeared to occur after multiple use in complex anotomical configurations with almost 75% of NiTi deformations occurring after use in molar teeth (Shen et al., 2009). Signs of deterioration in rotary NiTi instruments have been reported to be visible under SEM even after one use, but this may not be clinically relevant. (Gambarini et al.,2001). Since visible inspection is not a reliable method for evaluating used NiTi instruments, (Wolcott et al.,2006). employing a pru- dent approach of instrument disposal is sensible. At present it is not possible to provide a definitive guideline as to a safe number of uses of rotary NiTi files as use varies depending on the tooth, operator and root canal anatomy. What is clear, however, is that there is a trend towards the single use of rotary NiTi files during root canal treatment

7. Manufacturing Process

Traditionally, NiTi endodontic files are 'machined' from a blank NiTi alloy wire during manufacture. The process has been shown to create an irregular surface characterised by grooves, pits, multiple cracks and metal rollover (Kuhn et al., 2001; Alapati et al., 2003). with the frequency of such irregularities increasing proportionally with the taper of the instrument. (Valois et al., 2005). The manufacturing process itself leads to work hardening of rotary NiTi instruments, creating brittle areas. (Kuhn et al., 2001). These surface imperfections may act as a centre of stress concentration, initiating crack formation during clinical use. (Kuhn et al., 2001). In general, surface defects affect the ultimate strength of the material and have a major bearing on the fatigue resistance of the instrument. As a result manufacturers have endeavoured to improve the mechanical properties of the files by modifying the surface or alloy microstructure during the manufacturing process.

Treatment Option

When a file fractures during root canal treatment there are several treatment options available to the clinician. The definitive management should be based on a thorough knowledge of the success rates of each treatment option, balanced against potential risks of removal or file retention

8. Operator Skill/Experience

Operator experience is a consistently reported factor in relation to the incidence of clinical instrument fracture (Yared et al., 2002; Mesgouez et al., 2003). When other factors (instrument speed and sequence, canal morphology) remained constant, the ability of the operator was the key factor in instrument failure. However, no significant difference in fracture rate was also reported between experienced and inexperienced operators, a finding that was attributed to the allocation of complex cases to the more proficient operator (Iqbal et al., 2006) .Each rotary NiTi system has a 'learning curve', highlighting the importance of proper training and initial supervision in the use of NiTi endodontic systems as these instruments will fracture if used incorrectly or excessively (Sattapan et al.,2000;Gambarini, 2001).

9. Patient Factors

Fractured instrument removal generally involves a prolonged period in the dental chair, therefore, general dental issues such as patient apprehension and time constraints become more pertinent. Health issues may also alter the balance in favour of instrument removal if extraction is best avoided. Conditions such as severe bleeding disorders or patients receiving intravenous bisphosphonate medication are at increased risk of postoperative complications subsequent to dental extractions (McLeod et al., 2007). Finally, cost to the patient may be an influencing factor as removal of fractured files is a technically challenging procedure, often requiring the assistance of a specialist. Patients may decide that removal of the fragment is not worth the additional financial outlay compared to extraction or observation

Instrument Retrieval Protocols

Instrument retrieval protocols can be divided into three categories: mechanical, chemical and surgical methods. Surgical methods should be performed as a last resort since they are invasive and require a significant amount of dentin sacrifice involving rootend resection when the fractured instrument is in the apical or middle third of the canal. However, surgery should be considered first when the fractured instrument is mostly extruded beyond the apical foramen or completely outside the root since it does not require an invasive amount of dentin sacrifice. Chemical methods using solvents, including iodine trichloride, nitric acid, hydrochloric acid, sulphuric acid, iodine crystals and iron chloride solution, to corrode the fractured metallic instrument, as well as electrolysed sodium fluoride and sodium chloride solutions for instrument dissolution as an electrochemical process (Ormiga.,2010), are inefficient for instrument retrieval given the considerably long time required to dissolve the whole metallic instrument. Moreover, they are considered unpredictable since these chemical solvents can only touch the fractured instrument surface in the canal, which may cause damage to the surrounding soft and hard tissues. Therefore, compared with nonmechanical methods, mechanical methods, especially those using ultrasonics, allow higher success rates, minimally invasive preparation and faster instrument retrieval (Cujéet al., 2010; Fu et al., 2011; Nevares et al., 2012; Terauchi et al., 2021). However, the success rates of instrument retrieval using ultrasonics widely vary from 33% to 100%, with the average retrieval time ranging from 3 to >60 min (Terauchi et al., 2007; Alomairy, 2009; 2021) due to differences in the instrument retrieval protocols according to the location and visibility of the fractured instrument (Al-Fouzan,2003; Ward et al.,2003; Cujé et al., 2010; Ramirez;Terauchi et al., 2021;). Nonetheless, compared with nonmechanicalb methods, mechanical retrieval methods are more reliable and practical; accordingly, they are frequently used in clinical settings

Mechanical Protocols For Instrument Retrieval

All mechanical protocols for instrument retrieval comprise two steps. The first step is preparing the root canal using rotary or ultrasonic instruments to loosen the fractured instrument. The next step is making retrieval attempts using special devices Generally, mechanical methods .or ultrasonics to remove the fractured instrument. for instrument retrieval can be classified into two groups, namely those involving trephine burs to trough the fractured instrument periphery in the preparation step followed by removal attempts using devices and those involving ultrasonics or special files to create a tiny space only on the side of the fractured instrument in the preparation step followed by removal attempts using devices or ultrasonics. These devices include special files and loops to remove the fractured instruments. Mechanical devices involving trephine burs include the Masserann Kit (Micro-mega), Cancellier Extractor Kit (SybronEndo), Endo Extractor (Brasseler Inc.), Endo Rescue (Komet/Brasseler), Micro-Retrieve & Repair System (Superline NIC Dental) and iRS (Dentsply Tulsa Dental). These systems use a hollow cutting-end tube with a diameter of 0.7–2.4 mm to expose the coronal portion of the fractured instrument in the preparation step. However, they require considerable dentin sacrifice to place the extractor for grabbing the fractured instrument given the large diameter tube used with respect to the canal size. Therefore, the use of trephine burs of any size is restricted to anterior teeth or straight portions in posterior teeth (Okiji, 2003; Ruddle, 2004) since both the trephine burs and large-diameter extractors are used in a straight line to the fractured instrument. The use of such instruments around a curve to the fractured instrument may cause additional complications, including excessive dentin removal and root perforation, which may predispose the tooth to root fracture over time (Saunders et al., 2004; Souter & Messer, 2005; Spili et al., 2005; Hashem, 2007). Taken together, systems involving trephine burs can be used to remove fractured instruments only in the coronal third of the canal mainly in Systems involving ultrasonics or special files include the Canal Finder .anterior teeth System (FaSociete Endo Technique); EndoPuls system (EndoTechnic); and small-diameter ultrasonic tips, including a CPR-7 titanium alloy ultrasonic tip (Obtura-Spartan Corp.), ET25 (Satelec Corp) and TFRK-S (DELabs). The systems comprise a special handpiece and special files, which generate a vertical movement to bypass the fractured instrument. However, great caution is required when bypassing the fractured instrument around a curve given the risk of perforating the root canal, pushing the fractured instrument in a further apical direction, or even extruding the fractured instrument beyond the apical foramen. Moreover, instrument retrieval using the Canal Finder System has an overall success rate of only 68% Compared with the aforementioned systems, ultrasonics are safer, more conservative in dentin sacrifice and more successful even in posterior teeth in both the preparation and retrieval steps (Terauchi et al., 2007; Cujé et al.; 2010, 2021). Nonetheless, all the aforementioned protocols are not standardized for predictable instrument retrieval, which is attributed to their differences in the success rates of instrument retrieval. However, a recent study suggested that fractured instruments visible under a DOM (Digital oral microscope) can be predictably removed using ultrasonic instruments alone through a single standardized retrieval protocol that minimizes potential variables (Terauchi et al., 2021). Compared with the aforementioned nonstandardized protocols

Instrument Retrieval Standardized Preparation Protocol For Visible Fracture Instrument

First, cone-beam computed tomography (CBCT) imaging is preoperatively used to measure the fractured instrument length and canal curvature as well as to locate the inner wall of the fractured instrument. The canal curvature is calculated by measuring the angle generated by a straight line drawn from the orifice to the coronal end of the fractured instrument and a line parallel to its long axis (Lin et al., 2005; Suter et al., 2005 ; Estrela et al., 2008; Cujé et al., 2010). Subsequently, the treatment protocol for instrument retrieval is developed based on the CBCT findings The preparation step begins with canal enlargement to the fractured instrument using a no. 2 or 3 Gates Glidden (GG) drill when the canal curvature is <15° or a large-diameter martensite-phase NiTi file size, including the #60/.02 taper HyFlex EDM finishing file (Coltene/Whaledent AG), when the canal curvature is >15°. If the initially encountered canal size is larger than the no. 3 GG drill, the canal is not enlarged. However, GG drills can still be used to just enlarge the straight canal portion before the curve using a brushing motion against the outer wall to reduce the curvature Subsequently, a microtrephine (DELabs) bur is used to expose the coronal 1-mm portion of the fractured instrument when the canal curvature is <15° (Figure 1), but not when the canal curvature is >15° since it may cause ledge formation around the curve. Small-diameter ultrasonic tips such as TFRK-12/6/S ultrasonic tips (DELabs) or tips modified into a sword shape are used to cut a 90° semicircular space on the inner wall of the fractured instrument, which is extended to 180° using a straight spear-shaped ultrasonic tip to loosen the fractured instrument. When the fractured instrument is in a straightline canal, the semicircular space is created on the thickest canal wall side observed on the axial view of the CBCT image. The space depth to be cut is generally one-third of the fractured instrument length (Figures 2 and 3); furthermore, the space bottom is required to be even in the semicircular space (Figure 3). However, in case the fractured instrument is not loosened even after cutting beyond one-third of the instrument length, the space should be extended more apically loosening is observed or the fractured instrument is relocated from its original position. An apical extension of the space may be required, especially for austenite-phase fractured instruments or canal curvatures >30° (Figure 4). Ultrasonic preparations should be performed at 10%–20% of the maximum power setting (Lin et al., 2005; Tzanetakis et al., 2008; Cujé et al., 2010) using clear silicon oil as the lubricant with reasonable visibility or under dry conditions. The preparation phase is considered complete upon observation of loosening of the fractured instrument under the DOM even before the semicircular space reaches 180°, which is followed by the retrieval attempt phase. In case loosening of the fractured instrument is not observed with ultrasonics after the aforementioned preparation procedures, it is important to reconsider three main factors that affect successful loosening of the fractured instrument, which are described in Figure 5.

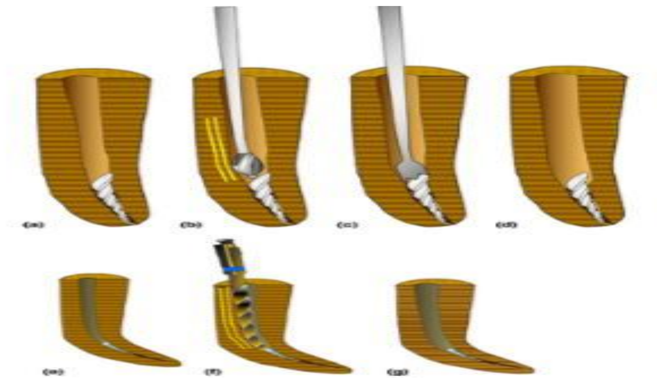

Figure ***1*** *Canal enlargement. (a) Preoperative root with a fractured instrument when the curvature is less than 15°. (b) #2/3 GG drill is used to enlarge the canal to the fractured instrument with a brushing motion against the outer wall. (c) Micro-trephine bur is used to expose the coronal 1 mm portion of the fractured instrument by rotating it counterclockwise at 600 rpm. (d) Coronal 1 mm portion is exposed. (e) Preoperative root with a fractured instrument when the curvature is greater than 15°. (f) Large diameter martensitic-phase NiTi rotary file is used to enlarge the canal to the fractured instrument with a brushing motion against the outer wall. (g) Widened root canal to the fractured instrument*

(*Yoshi Terauchi 2022*)

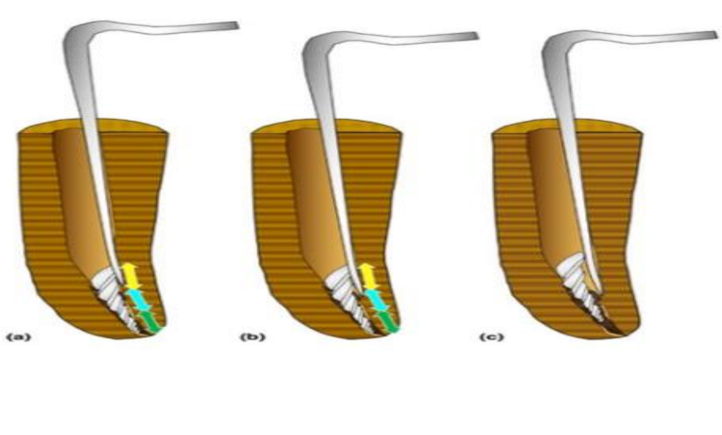

Figure *2 Standard ultrasonic preparation. (a) Thin ultrasonic tip is placed in the space between the fractured instrument and the inner wall. (b) Space on the inner wall is extended to one-third of the instrument length with ultrasonics. (c) Fractured instrument is observed loosening*

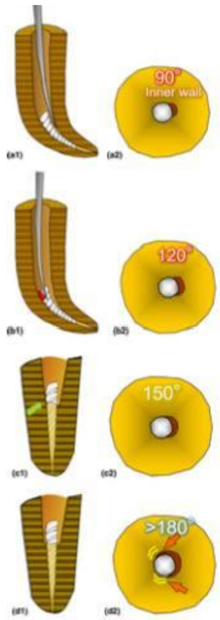

Figure 3 *180-degree semicircular preparation. (a1) Small-diameter ultrasonic sword-shaped tip or a tip modified into a sword shape is used to create a space extending to one-third of the fractured instrument length on the inner wall. (a2) Space on the inner wall is extended to a 90° semicircular space on the inner wall of the fractured instrument. (b1) Space is extended with a straight tip to 120° at the same depth (arrow pointing to the lateral space). (b2) Space extends laterally with s straight tip. (c1) Space on the bottom needs to be even with the surrounding space (arrow pointing to the uneven space on the bottom). (c2) Space is extended to 150°. (d1) Bottom of the semicircular space is flattened out. (d2) Space is extended to 180° making the fractured instrument 'dance' (arrows pointing to the space created to free the fractured instrument from the canal walls)*

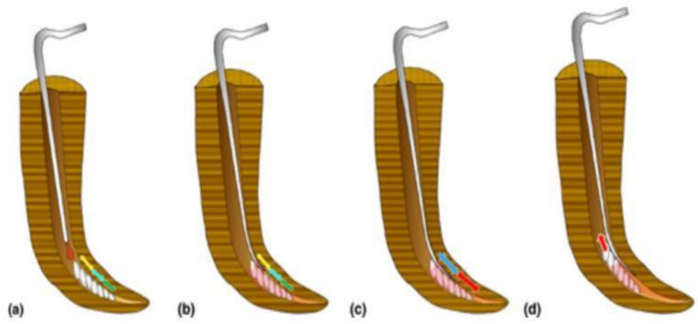

Figure 4 *Preparation procedure when the canal curvature is 30° or the fractured instrument is in the austenite phase. (a) Fractured instrument around the curve greater than 30°. Silicone oil drops to the fractured instrument to facilitate lubrication of it. (b) Space extended to one-third of the instrument length without loosening it. (c) Space extended to half of the instrument length. (d) Fractured instrument is loosened after the space extended to more than half the length of the fractured instrument*

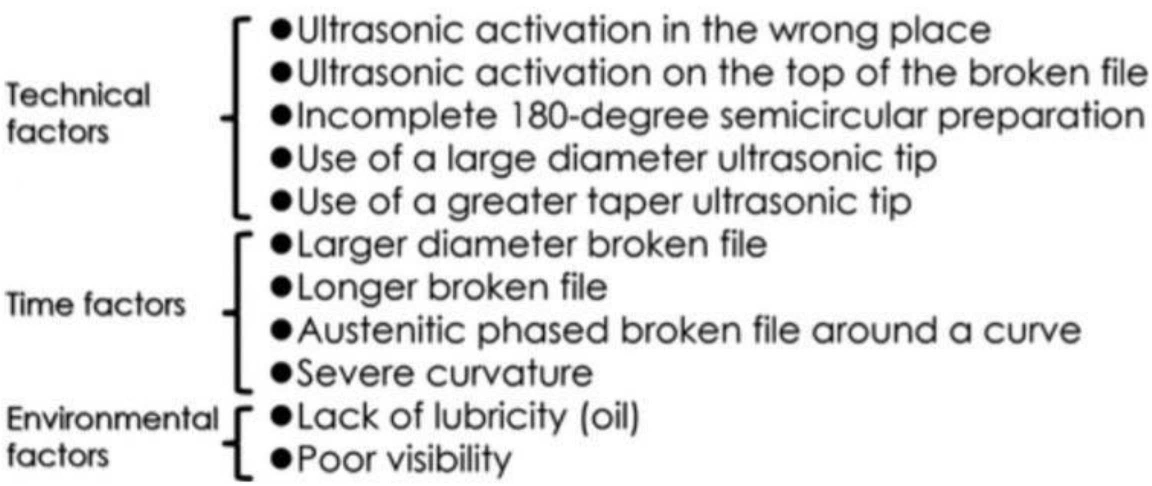

Figure 5 *Three main factors affecting the success in loosening the fractured instrument in preparation*

Standardized Preparation Protocol For NonVisible Instrument Retrieval

Similar to visible instrument retrieval, the treatment plan for nonvisible instrument retrieval is made based on the CBCT findings. Subsequently, the canal is enlarged to the nonvisible fractured instrument as described above Visible and nonvisible instrument retrieval have almost similar preparation protocols. The only difference is that the preparation phase for nonvisible instrument retrieval is limited to a 90-degree semicircular space on the inner wall performed without visualization, which makes it unpredictable. Large flexible martensite-phase NiTi rotary files, including the #60/.02 taper HyFlex EDM finishing file (Coltene/Whaledent), are used to enlarge the curved canal portion to the fractured instrument in the presence of EDTA. The canal size should be approximately 0.15 mm larger than the fractured instrument size, which should be wider than the ultrasonic tip used to create space on the inner wall to allow the removal of the fractured instrument through the space. No canal enlargement is required if the canal size is thrice larger than the coronal diameter of the fractured instrument. Since the fractured instrument cannot be initially visualized and the semicircular space created in the preparation phase cannot be predictably extended from 90° to 180°, wet conditions are required throughout the procedure. First, the canal should be filled with oil (biocompatible silicone oil) to facilitate loosening the fractured instrument in the preparation phase since this step is performed without visualization and the tactile sensation obtained from the ultrasonic tip is the only predictor of determining whether the fractured instrument is loosened. For successful loosening of the fractured instrument in nonvisible conditions, it is important to first obtain a sticky (resistance) feeling when withdrawing the ultrasonic tip from the space between the canal wall and fractured instrument, which indicates engagement to the canal wall. Second, it is important to be aware of any sudden transition from a sticky feeling to a loose feeling upon withdrawal whilst deepening the space by moving the ultrasonic tip in an up/down motion, which suggests that the fractured instrument is loosened. Moreover, the canal should be periodically irrigated with EDTA to remove debris.In nonvisible conditions, the ultrasonic tip should be thin and sharp enough to feel the tiny gap between the inner canal wall and the fractured instrument. First, a thin spoon-shaped tip (TFRK-6/12, DELabs) or a customized sword-shaped tip is precurved to fit the canal curvature and used to grope for a sticky feeling obtained with the fingers holding the handpiece (Figure 6a). In case a large-sized tip, including a greater tapered or progressive-tapered tip, is used, the ultrasonic tip placed in the space will push the fractured instrument in an apical direction due to the large diameter before the creation of a thin space in the gap between the fractured instrument and inner wall. Moreover, it is quite common to hear or feel a click and obtain a sticky feeling when the sharp ultrasonic tip slides over the fractured instrument into the gap in the inner wall. If a sticky feeling is obtained when the ultrasonic tip is withdrawn from the gap, it is important to obtain a radiograph with the ultrasonic tip placed in the gap to confirm its position on the inner wall. In case the radiograph reveals that the ultrasonic tip in the gap on the inner wall, the tip is ultrasonically activated to initiate a 90° semicircular preparation (Figure 6). Specifically, the ultrasonic tip is directly activated on the fractured instrument from the inner curve in both pecking and pulsing motions throughout the preparation phase to prevent secondary fracture and tip breakage. It is almost infeasible to create a 180° semicircular space or laterally extend the space in nonvisible conditions. For similar reasons, the ultrasonic activation intensity should be as low as practically possible, that is, it should not exceed 30% of the maximum power in the preparation phase. Since this conservative preparation step continues with ultrasonic activation directed to the fractured instrument on the inner wall, any dentine walls in contact with the fractured instrument are eliminated through indirect ultrasonic vibration transferred from the ultrasonically vibrating tip via the fractured instrument, which eventually results in fragment loosening (Figure 6b–e). The preparation phase is considered complete when the sticky feeling with the ultrasonic tip is lost or when the fractured instrument emerges from the nonvisible curve, with the retrieval phase being conducted next. The advantage of this preparation technique is its minimal invasiveness; contrastingly, its disadvantage is the unpredictability of complete loosening of the fractured instrument as well as the risk of secondary fracture or tip breakage if aggressively performed. Additionally, successful loosening of the fractured instrument is always time-consuming.

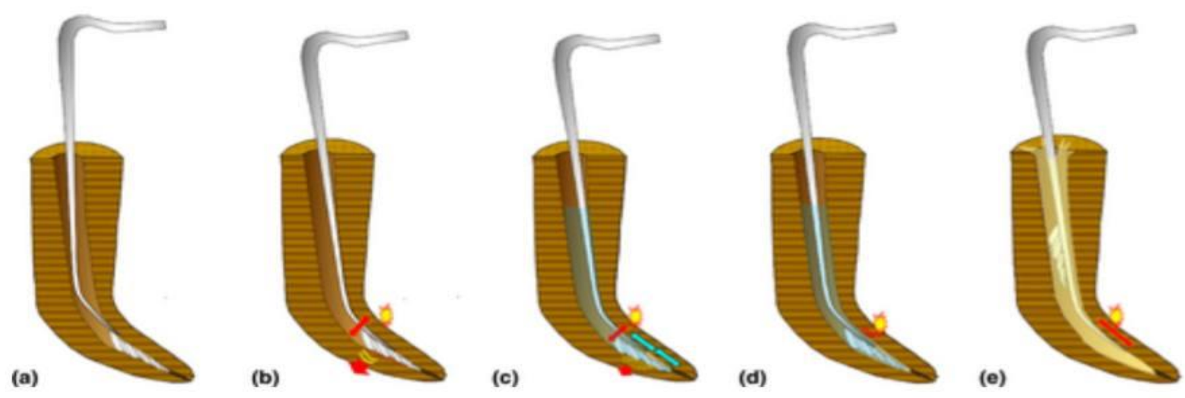

Figure 6

semicircular preparation on a lateral view. (a) Spoon/Sword-shaped tip is placed in the space °90 on the inner wall. (b) Ultrasonic tip is activated on the inner wall and ultrasonic vibration is transferred to the outer wall through the fractured instrument. (c) Ultrasonic activation stays in the same place with up/down and pulsing motions and surrounding dentin walls in contact with the fractured instrument are eliminated with ultrasonics. (d) Sticky feeling is lost on withdrawal of the ultrasonic tip and the fractured instrument is freed from the canal walls. (e) Ultrasonic *removal attempts are made in the presence of EDTA/soybean oil and the fractured instrument exits from the root canal*

Instrument retrieval protocol using ultrasonics

After completion of the preparation phase, it is important to confirm that the outer canal wall is smooth until the coronal extent with no overhangs blocking the fractured instrument from retrieval. In case there is an overhang on the outer wall, it should be removed using either a flexible NiTi rotary file or an ultrasonic tip. Before attempting to retrieve the fractured instrument with ultrasonics, the canal is dried using air from the Stropko irrigator (DCI International), which can lead to ejection of the fractured instrument. This is because the fractured instrument is already disengaged from the canal walls during the preparation phase and the blown air that bounces back from the bottom can cause the loosened fractured instrument to float from the canal walls and exit from the root canal. First, the canal is filled with soybean oil or EDTA when the canal curvature is >30° or <30°, respectively, to facilitate instrument retrieval with ultrasonics. Most fractured instruments (94%) <4.6 mm can be removed solely with ultrasonics within 10 s in the retrieval phase (Terauchi et al., 2021). Subsequently, instrument retrieval attempts are performed in wet conditions by filling the canal with an appropriate fluid, including EDTA and soybean oil, until the cavosurface (at least to half the pulp chamber level and 'not just in the root canal') in order to take advantage of cavitation and acoustic streaming in facilitating instrument removal using ultrasonics. If only the root canal is filled with fluid, the fractured instrument may not exit from the canal; instead, it may float within the root canal space during ultrasonic activation. Next, the ultrasonic tip is placed in the space and is continuously activated at a power setting 10%–20% higher than that used in the preparation phase, with short up-and-down strokes being performed on the inner curve until the fractured instrument is removed, which is usually achieved in 10 s (Terauchi et al., 2021; Figure 7). For ultrasonic removal attempts, the power setting can be safely increased since the ultrasonic tip is more resistant to fracture in wet conditions than in dry conditions. Moreover, the depth of ultrasonic-activated fluid increases proportionally to the applied power setting for removing debris apical to the ultrasonic tip in the canal (Malki et al., 2012). Moreover, the ultrasonic tip should be placed and activated on the inner wall as far away as possible from the fractured instrument, which provides space for ejection through the canal opening. Four reasons could contribute to unsuccessful instrument retrieval using ultrasonics within >10 s. The most typical reason is that the dancing fractured instrument might be stuck between the outer canal wall and the vibrating ultrasonic tip with a progressive taper or a large diameter (Figure 8). The second reason could be the space between the outer wall and ultrasonic tip being smaller than the fractured instrument diameter, which leads to no open space for the fractured instrument to escape (Figure 9)**.** The third reason could be that the fractured instrument might relocate into a more radicular direction after being pushed by the vibrating ultrasonic tip from the top or outer wall (Figure 10). Finally, the fourth possible reason is the amount of fluid filled in the canal space being insufficient to create acoustic streaming and cavitation for removing the fractured instrument from the canal.

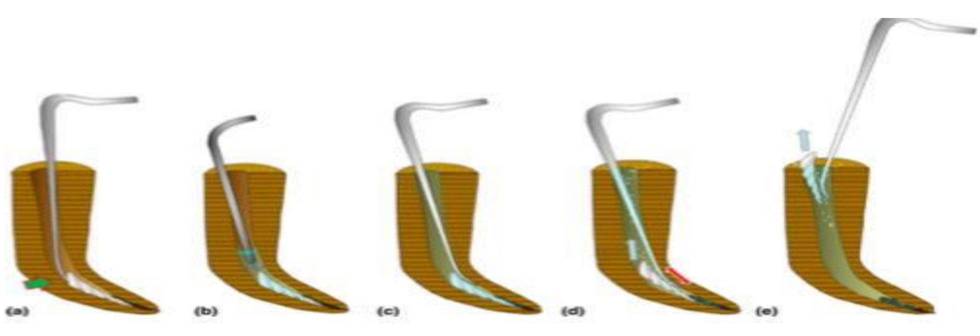

Figure 7 *Ultrasonic removal attempts. (a) Overhang on the outer wall can be in the way of the fractured instrument exiting out and need to be removed before the removal attempts are initiated.*

(b) Canal is filled with a fluid to facilitate ultrasonic removal of the fractured instrument. (c) Ultrasonic tip is placed in the space created on the inner wall. (d) Ultrasonic tip is ultrasonically activated in an up/down motion within the space. (e) Fractured instrument exits out of the root canal with ultrasonics

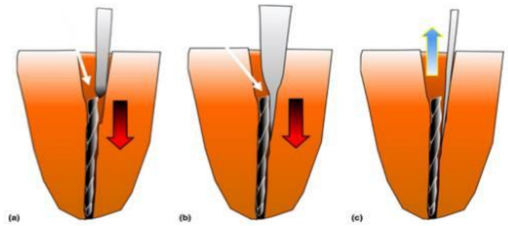

Figure8 *Size and taper of ultrasonic tips affecting instrument retrieval. (a) Large diameter/greater taper tip pushes the fractured instrument in an apical direction before being placed in the space. (b) Progressive taper pushes the fractured instrument in an apical direction as it is placed deeper in the space. (c) Small diameter/smaller taper tip placed in the space extrudes the fractured instrument in a coronal direction*

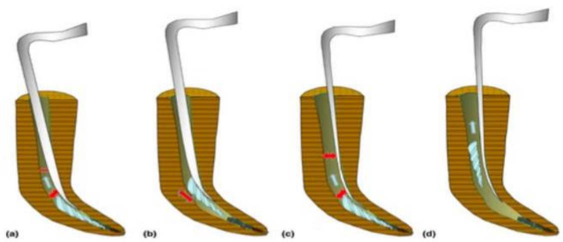

Figure 9 *Space between the ultrasonic tip and the outer canal wall affecting instrument retrieval. (a) Space smaller than the diameter of the fractured file. (b) Fractured instrument fluctuates in the space between the outer canal wall and the vibrating ultrasonic tip. (c) Space larger than the diameter of the fractured file. (d) Fractured instrument exits out through the space*

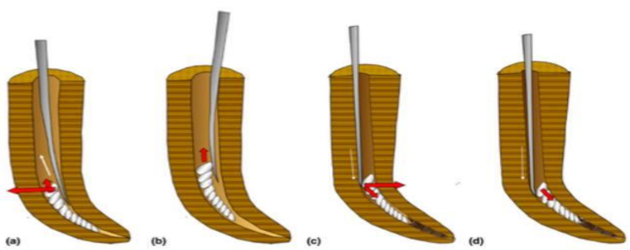

Figure 10 *Placement of ultrasonic tips affecting instrument retrieval. (a) Ultrasonic activation from the inner curvature. (b) Fractured instrument is kicked in a coronal direction by ultrasonic activation from the inner wall. (c) Ultrasonic activation from the outer curvature. (d) Fractured*

instrument is kicked in an apical direction by ultrasonic activation from the outer wall In case the fractured instrument is not retrieved within 10 s using the aforementioned protocols or it is initially longer than 5.7 mm, other retrieval techniques using the loop device or XP Shaper (XPS) rotary instrument (FKG Dentaire SA) should be attempted since it is difficult or time-consuming to keep using ultrasonics (Terauchi et al., 2021).

Fluid types used for ultrasonic instrument retrieval

The ability of a fluid to lubricate the fractured instrument in the root canal space and flush it away with the aid of ultrasonic-generated acoustic streaming and cavitation generated is mainly dependent on the fluid characteristics, including lubricity, viscosity and surface tension. Viscosity is defined as a fluid's resistance to flow and shear. The hydrodynamic force in high-viscosity fluids necessitates a high ultrasonic power setting to generate high pressure for dynamic impact on the fractured instrument since high-viscosity fluids absorb weak oscillatory shockwaves. In addition, aggressive oscillatory shockwaves generated by the high ultrasonic activation with high-viscosity fluids can create more powerful hydrodynamic pressure for pushing the fractured instrument compared with those with low-viscosity fluids. However, ultrasonic activation at a high power setting can cause ultrasonic tip breakage. Generally, fluids with high viscosity and surface tension reduce both acoustic streaming and cavitation, but increase lubricity, and vice versa. Water is a low-viscosity fluid with high surface tension (72 mN/m at 20°C), vegetable oil (e.g., soybean or olive oil) is a medium-viscosity fluid with low surface tension (23–32 mN/m at 20°C), syrup is a high-viscosity fluid with high surface tension, and ethanol is a low-viscosity fluid with low surface tension. Corn or soybean oil has a lower viscosity than olive oil (Sahasrabudhe et al., 2017) Generally, the fluid temperature is negatively correlated with the surface tension. Taking these factors into consideration, fluid with medium viscosity and low surface tension, including soybean/corn oil, may be ideal for use with a high ultrasonic power setting for fractured instrument retrieval, especially for canal curvature >30°; contrastingly, EDTA can be used with a medium power setting for canal curvature <30°. Additionally, the size of ultrasonic tips is negatively correlated with the generated acoustic streaming, with the resulting velocity being positively correlated with the power setting (Ahmad et al., 1987). Fluids with low surface tension result in more ultrasonic-generated oscillatory shockwaves on the fractured instrument, which make it more vulnerable to dislodgement and ejection by the continuous pressure waves of acoustic streaming and cavitation from the trapped space. Accordingly, EDTA, which has a low surface tension, is expected to facilitate immediate instrument removal from a straight canal given that it also removes hard-tissue debris produced during ultrasonic activation to clear out the way. Contrastingly, the loosened fractured instrument may not be ejected from a severe curve (>30°) in the presence of low-viscous EDTA, which may insufficiently lubricate the fractured instrument. The use of soybean oil, which has medium viscosity and low surface tension, for instrument removal from a severe curve using ultrasonics could enhance lubrication. However, compared with EDTA, soybean oil results in slower instrument removal from a curve <30° given its medium viscosity. Nonetheless, both fluid types can allow cavitation and acoustic streaming as well as decrease friction generated between the fractured instrument and the canal wall to facilitate instrument retrieval. Therefore, using a mixture of EDTA and soybean oil may be an alternative for instrument removal from a moderate curve (30°–20°).

Instrument retrieval protocol using the loop system

The XPS should be used to retrieve fractured instruments leaning against the outer wall with no space for loop placement over the fractured instrument. Otherwise, the loop is used to remove fractured instruments >4.5 mm or in case of unsuccessful instrument retrieval using ultrasonics within >10 s. Unlike ultrasonics and the XP-Endo Shaper, which are used in wet conditions, the loop is used in dry conditions since it should be visualized throughout the retrieval procedure. Additionally, loop systems, including EndoCowboy (Köhrer Medical Engineering), BTR Pen (CERKAMED) and Yoshi Loop (DELabs), can be used to engage and remove long loosened fractured instruments through forces directed more coronally. Loop placement in the canal requires a space with a diameter ≥0.4 mm; moreover, the coronal portion of the fractured instrument should be peripherally exposed by a depth ≥0.7 mm deep for grasping by the loop system. A #40 plugger is placed into the same space to measure the area created adjacent to the fractured instrument. This allows the introduction of the loop, which has a slightly smaller diameter than the #40 plugger, into the canal for engagement. Next, the loop size should be adjusted to fit the coronal diameter of the fractured instrument using an endodontic explorer, including a DG16 endodontic explorer (Hu-Friedy). Specifically, the tip of the DG16 endodontic explorer is placed in the loop, followed by tightening the loop around it. The apical portion of the DG16 is used to decrease and increase the loop size and coronal portion, respectively. Next, the loop is bent to 45° instead of 90° to facilitate loop placement over the fractured instrument since it occupies more room. Subsequently, the loop is inserted into the canal and pushed back to 90° upon the fractured instrument. The loop is then tightened around the loosened fractured instrument and pulled to smoothly retrieve it from the canal. In case any resistance is felt, the loop is slowly and gently pulled in different directions with a swaying motion until it is lifted from the canal. It should never be forced in a vertical direction to prevent breakage since the instrument retrieval is solely dependent on the pulling direction.

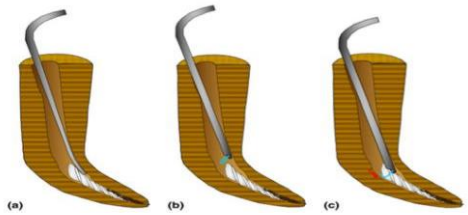

Figure 11 *Instrument retrieval with a loop. (a) #40 plugger is placed in the space created in the preparation phase to measure it. (b) Loop bent to 45° is introduced into the canal. (c) Loop is placed over the fractured instrument and tightened around it. (d) Loop holding the fractured instrument is pulled out of the canal in several directions*

Instrument retrieval protocol using the XP-endo Finisher

The XP-endo Finisher (FKG Dentaire) is a size #25 nontapered instrument that does not damage or alter the original root canal anatomy. It is mainly used to clean the root canal by scraping irregularities on the canal walls given its high flexibility as well as its ability to expand up to a 6-mm diameter and adapt to the root canal three-dimensionally (Azim et al., 2016; Leoni et al., 2017). This is facilitated by its change to a spoon shape after exposure to intracanal temperature following transformation to the austenitic phase, as previously described for the XP-endo Shaper. The XP-endo Finisher can effectively remove accumulated hard tissue debris and the smear layer from the root canal system (Elnaghy et al., 2017; Leoni et al., 2017). Moreover, a recent study demonstrated the efficacy of the XP file in removing calcium hydroxide paste from artificial grooves within the apical third of a root canal system (Wigler et al., 2017). Therefore, the XP-endo Finisher can be used at a high-speed clockwise rotation speed to remove a loosened fractured instrument from a wider canal, especially when the instrument is extruded beyond the large apical foramen into the apical tissues, by braiding it and creating a swirling fluid flow in the coronal direction (Figures 12 and 13). Additionally, the braiding technique can be performed using a Hedström or K-type file to retrieve fractured instruments located deep in the canal that cannot be observed on a DOM. However, successful retrieval using these files is solely dependent on tactile sensation, which makes them unpredictable for instrument retrieval (Shen et al., 2004; Suter et al., 2005). Moreover, braided Hedström files or K-files often detach during removal attempts

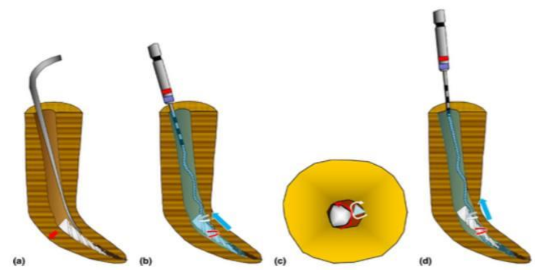

Figure 12 *Instrument retrieval with the XP-endo Shaper (XPS). (a) Loosened fractured instrument longer than 4.5 mm leans against the outer wall, making it difficult to place a loop over the fractured instrument. (b) XPS rotating at a higher speed in the space next to the fractured instrument in the presence of oil. (c) XPS rotating clockwise next to the fractured instrument makes it rotate counterclockwise to unscrew it in acoronal direction. (d) Fractured instrument rotating counterclockwise climbing up the canal walls in a coronal direction. (e) Fractured instrument ejects from the root canal*

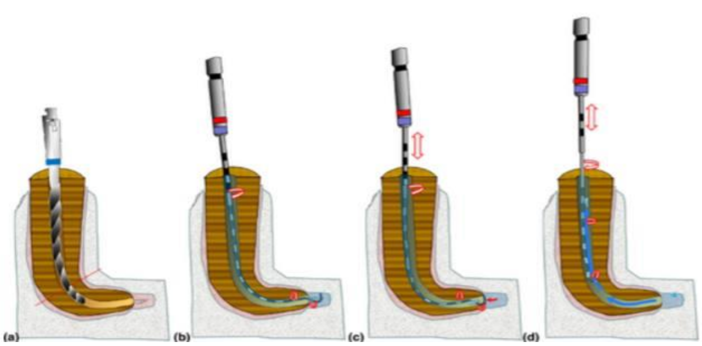

Figure 13 *Removal of a fractured instrument extruded beyond the apical foramen with the XP-endo Finisher (XPF). (a) Canal is enlarged to the apex with a large diameter NiTi file. The fractured instrument outside the root is always loose with no canal walls holding it. (b) XPF rotating at a higher speed creates turbulence and braids the fractured instrument in the presence of saline. (c) Fractured instrument starts moving back in the canal with a swirling flow in a coronal*

direction whilst rotating the XPF with short up/down strokes. (d) Fractured instrument exiting out of the canal with the XPF rotating clockwise at a higher speed

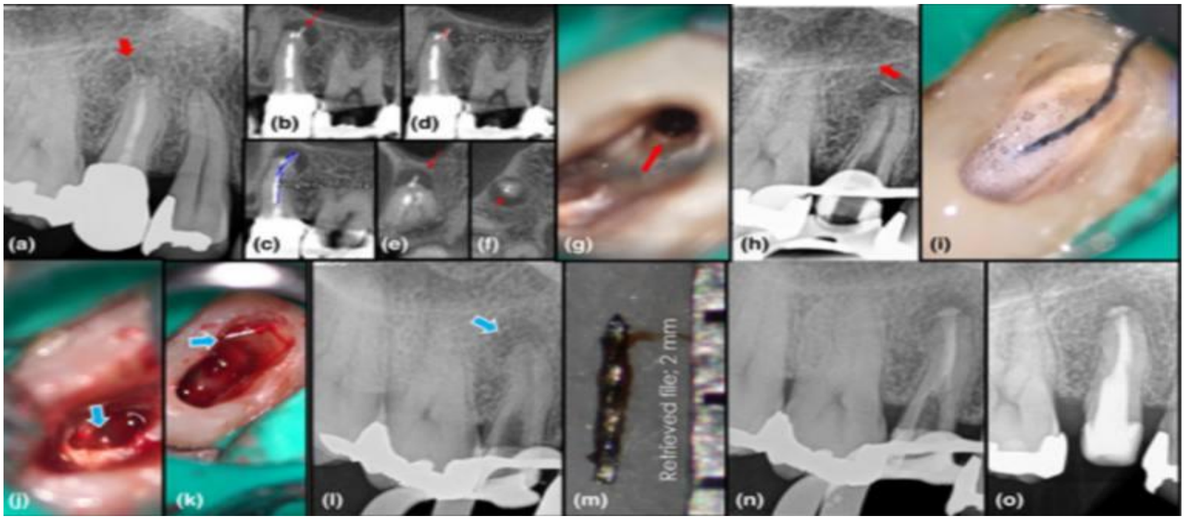

Figure 14 *Removal of a fractured instrument extruded into periapical tissues with the XP-endo Finisher (XPF). (a) Preoperative radiograph showing a fractured instrument beyond the apical foramen (arrow pointing to it). (b) Sagittal view of CBCT imaging showing the fractured instrument in the periapical tissues (arrow pointing to it). (c) Sagittal view of CBCT imaging showing that the canal curvature is 31.65°. (d) Sagittal view of CBCT imaging showing that the length of the fractured instrument is 2.03 mm. (e) Coronal view of CBCT imaging showing the fractured instrument in the periapical tissues (arrow pointing to it). (f) Axial view of CBCT imaging showing the fractured instrument adjacent to the root filling (arrow pointing to it). (g) Microscopic view showing that the fractured instrument is nonvisible beyond the curve (arrow pointing to it). (h) Intraoperative radiograph showing the fractured instrument pushed deeper into periapical tissues during removal of root filling materials (arrow pointing to it). (i) Microscopic view showing the XPF rotating at 2000 rpm beyond the apical foramen. (j) Microscopic view showing the fractured instrument emerging from the root canal during rotating the XPF (arrow pointing to it). (k) Microscopic view showing the removal of the fractured instrument (arrow pointing to it). (l) Intraoperative radiograph taken to confirm the instrument removal from the periapical tissues (arrow pointing). (m) Retrieved instrument measuring 2 mm. (n) Postoperative radiograph showing that the root canal was obturated with MTA. (o) Three-month postoperative radiograph showing advancing remineralization of the bony defect compared to the postoperative radiograph*

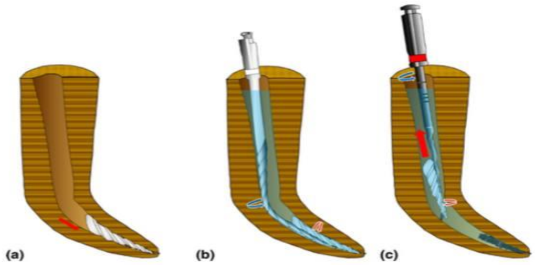

Figure15 *Nonultrasonic instrument retrieval in future. (a) Nonvisible fractured instrument longer than 4.5 mm beyond the severe curve. (b) Small diameter rotary file designed to bypass the fractured instrument to facilitate the introduction of the instrument retrieval file into the bypassed space. (c) Instrument retrieval file rotating in the bypassed space filled with oil unscrewing the nonvisible fractured instrument and removing it from the root canal. (c) Fractured instrument unscrewed by the instrument retrieval file rotating clockwise ejects from beyond the curve*

microscope

Positioning the microscope

The introduction of the operating microscope in a dental office requires significant forethought, planning, and an understanding of the required ergonomic skills necessary to use the microscope efficiently. Proper positioning, for the clinician, patient, and assistant is absolutely necessary. Most problems in using a microscope in a clinical setting are related either to positioning errors or lack of ergonomic skills on the part of the clinician.

It is possible to work at the microscope in complete comfort with little or no muscle tension if proper ergonomic guidelines are followed. In chronological order, the preparation of the microscope involves the following maneuvers:

1 Operator positioning

2 Rough positioning of the patient

3 Positioning of the microscope and focusing

4 Adjustment of the interpupillary distance

5 Fine positioning of the patient

6 Parfocal adjustment

7 Fine focus adjustment

8 Assistant scope adjustment

Retreatment

The biggest advantage in using the microscope is during retreatment. To perform a retreatment can be as simple as the removal of gutta-percha from a poorly obturated canal to more complex, delicate and time consuming procedures, like removing screw posts, separated instruments, silver points, amalgam pins, carbon fiber posts, or repairing a perforation or obturating an immature open apex. Before the introduction of the operating microscope, everything in endodontics was performed using tactile sensitivity, so that the clinician could "feel" the presence of a problem, like a ledge, a blockage, a broken instrument, a perforation, and the solution to that problem was never predictable. Until recently, instruments separated within the canal were treated by attempting to bypass the fragments (Fig. 16). This method was not only time consuming, but in many instances could increase the risk of separating a second instrument or perforating the root.With the use of the operating microscope every challenge existing in the straight portion of the root canal system, even if located in the most apical part, can be easily seen and then resolved, thanks to magnification and coaxial illumination. In a case of a broken instrument, for instance, the fragment can be visualized and then with ultrasonic vibrations can be removed, without damaging the root (Fig. 16) (Carr, Gary B. 2010)

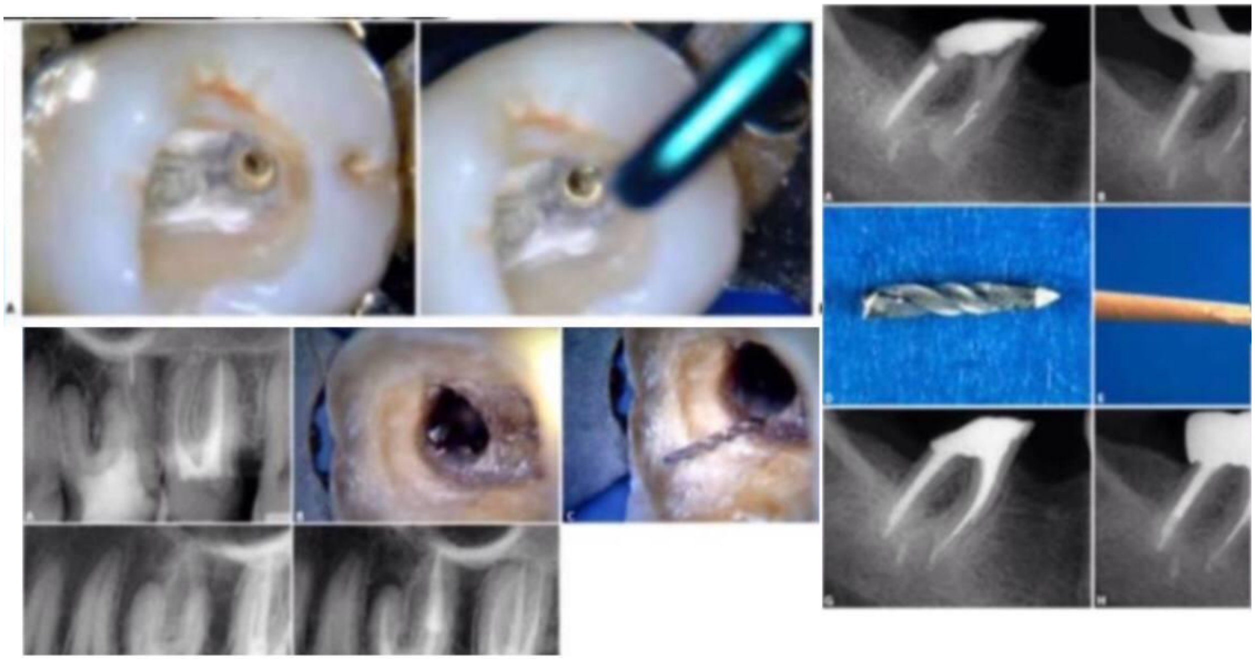

Figure 16 *Two broken instruments are present in the mesial root of this lower second molar. B. A #10 K File is bypassing the broken instrument in the mesio-lingual canal. C. Just enlarging the canal around, the fragment has been removed from the mesio-lingual canal. D. A #10 K File is now bypassing the broken instrument in the mesio- buccal canal. E. A gutta-percha point has been inserted in the mesio- lingual and then the K File has been introduced in the mesio-buccal, to detect if the canals are joining together: the impression left on the gutta- percha from the file is confirming that the two canals have a common foramen, therefore it is useless trying to remove the second fragment from the mesio-buccal canal. F. The gutta-percha is condensed in the mesio-lingual canal and now is in contact with the broken instrument*

Separation of an instrument inside the confines of the canal is one of the most vexing problems in endodontics. Iatrogenic accidents of this sort subject the patient and treating doctor to harmful stress levels, provide the legal profession with cases and frequently lead to further damage in attempting to remove or bypass the obstruction. Traditionally, fractured instrument cases are handled by attempting to bypass the instrument with other instruments, thereby running the risk of perforation or the separation of additional instruments. Other methods rely on trephine burs or extractors using cyanoacrylic glue (Fig. 16) or pinch-pressure devices (Fig. 16) to remove the offending instrument. These methods are ingenious, but unfortunately the scale of these devices is often too large for the task and frequently results in perforations or gross destruction of root structure.Using the operating microscope and a specially designed ultrasonic unit and tips, most instruments can now be easily removed. The instrument is visualized using high magnification. Then a specialized ultrasonic tip is energized, creating a trough around the coronal 2mm of the instrument. The doctor has commanding visual control at all times during this procedure, resulting in minimal loss of root dentin. After the troughing procedure, the instrument is vibrated with the side of the tip. It will begin to spin and move coronally because of its tapered shape. It can then be removed using microsurgical forceps that can be manipulated in the pulp chamber because of their small size. Instruments large and small can be removed in this manner whether they are in the coronal, middle or apical third of a straight root. Instruments separated apical to severe curvatures are not good candidates for this procedure.3 (Carr, Gary B. 2010).

Management of canal impediments

A recent study showed that 74% of teeth with short root fillings were successfully advanced to an adequate length, and it was concluded that a short fill should not be considered a technical reason to avoid retreatment. The clinical situation typically arises after the previous root filling is removed, and apical advancement with small files is obstructed (Giuliani V et al.2008). After removing all root-filling materials, further advancement to the apical constriction may be hindered by a blockage or ledge in the apical portion of the canal. These obstacles are often caused by iatrogenic errors (Ruddle CJ et al.2002). A blocked canal may contain leftover pulp tissue (sometimes necrotic, often fibrosed or calcified) and packed dentinal debris in the apical part of the canal system. This material is frequently infected, leading to persistent disease, and should be removed when possible (Huttula AS et al.2006). When clinicians rush or become careless, complications arise. During treatment planning, blocks and ledges may be visible on radiographs as a root filling that falls short of the ideal working length. The patient should be informed that these obstacles may be impossible to navigate and could require future apical surgery or extraction (Fristad I et al 2004)

However, this should not discourage the clinician from attempting nonsurgical retreatment. The coronal portion of the canal should be enlarged to improve tactile sensation and eliminate blockages in the cervical and middle thirds of the canal. The canal should be irrigated, and instrumentation should proceed up to the obstruction using non-end-cutting rotary files, such as Lightspeed, Profile or GT instruments, or the K-3 file, in a crown-down technique (Grobecker-Karl T et al.2016) This process will enlarge the canal space coronal to the obstruction while reducing the risk of worsening any ledge present.

At this stage, the obstruction should be gently probed with a precurved #8 or #10 file to check for "sticky" areas, which may indicate the presence of a blockage. A directional rubber stop should be used to ensure the clinician is aware of the instrument’s orientation, which helps visualize the canal system in three dimensions. Often, evacuating the irrigant and using a lubricant, like RC Prep or Pro-Lube, will improve the ability to insert the small file into the apical canal segment (Hammad M et al.2008) If gentle apical pressure or "pecking" with the hand file creates resistance when withdrawing the instrument ("stickiness"), the clinician should continue pecking at the "sticky" area until further apical progress is achieved. This is typically a slow and meticulous process, which can be more efficient with precurved, stiff files, such as the C+ file. However, there is a risk of deviating from the original canal path, potentially creating a ledge or false canal, leading to perforation.

It is advisable to take a working radiograph once some apical progress is made to confirm the instrument's position at the suspected apical extent of the canal (Hassanloo A et al.2007) The clinician should avoid excessive rotation of the file. If a small instrument’s tip is tightly bound in the blocked section and has been worked with pecking motions, there is a risk of the file tip fracturing in the apical region, which complicates the case further.

A fractured file tip is often irretrievable, and may result in the need for surgery or extraction. To prevent this, the clinician should switch to a smaller file and use a very gentle reciprocal rotational motion ("twiddling") to advance through the blocked canal (He J et al.2017) As apical progress continues, an electronic apex locator may be used to estimate the proximity to the apical constriction. However, the apex locator may sometimes provide inaccurate readings in a blocked canal, and the persistent "sticky" sensation can lead to overextension, potentially causing postoperative flare-ups. To avoid this risk, a working length radiograph should be taken once the estimated working length is reached. When the apical working length is confirmed, patency should be checked, and short, gentle push-pull strokes (1-2 mm) should be applied until the file passes freely to the apical constriction (Hiraishi N et al.2007)

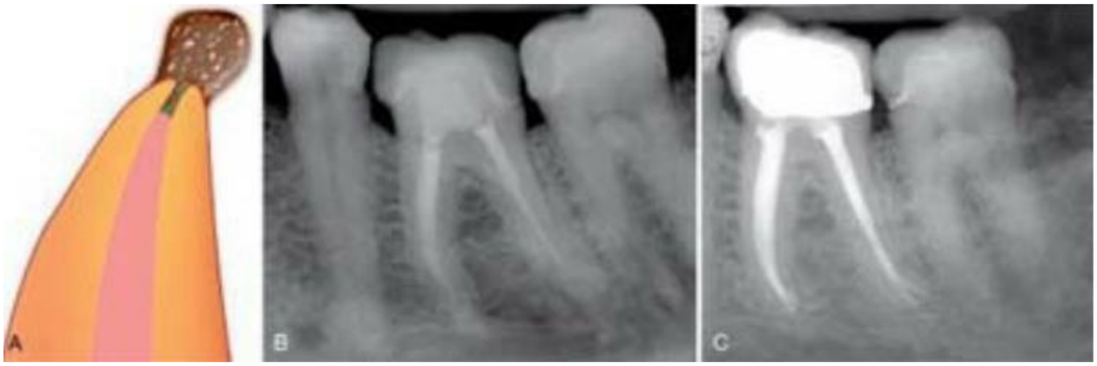

Figure *17 Diagrammatic representation of a canal block. B, Preoperative radiograph showing obturation short of ideal length. C, Three months posttreatment.*

If, after a reasonable amount of time, no "sticky" spot is located, the clinician should consider the possibility of a ledge, even if it wasn't visible on the preoperative radiograph. The primary issue with ledges is that instruments tend to follow them, while locating the original canal is often impossible. Ledges feel like a solid barrier and are typically encountered short of the desired length (Horan et al.2008). Caution is required to avoid worsening the ledge by carelessly working into it.

To manage a ledge, a small #08 or #10 file should be precurved slightly, 1 to 2 mm from the tip, forming an approximate 45-degree angle between the tip and the shaft of the instrument. The directional stop should be positioned to correspond with the bend, and the file is gently advanced toward the ledge. Since ledges often form on the outer curve of the canal, the directional stop (and thus the bent tip of the file) should be turned in the direction of the suspected apical curvature, away from the ledge (Hammad M et al.2008)**.**

The file tip is then carefully scraped along the internal wall of the canal just coronal to the ledge, searching for a new sticky spot. This spot will typically lead to the apical canal segment, and with gentle reciprocal rotation, the file can often be advanced to the canal terminus. A radiograph should be taken 4 to confirm progress. Once the ledge is bypassed, short push-pull strokes combined with rotational forces, keeping the file tip apical to the ledge, are necessary to clean and enlarge the apical canal space. When the file can move smoothly around the ledge, anti-curvature filing can be used to blend the ledge into the canal preparation. While it may not always be possible to fully smooth out the ledge, as long as the apical portion of the canal can be cleaned and sealed, the prognosis should not be negatively impacted. (Huttula AS et al.2006).

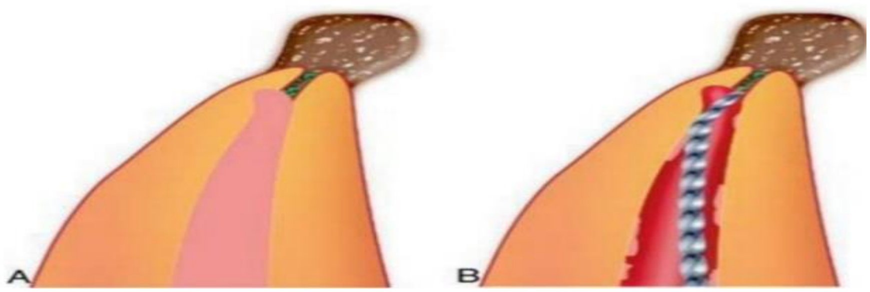

Figure18 *Diagrammatic representation of a ledged canal. B, Attempting to bypass the ledge with a small file having a 45-degree bend in the tip*.

The use of Greater Taper (GT) NiTi hand files (Dentsply Tulsa Dental) for the blending of ledges has been advocated. The advantage these instruments have is that they are non-end cutting, and their rate of taper istwo to six times that of conventional 0.02 tapered files, so they can do the work of multiple 0.02 tapered hand files. Once the ledge has been bypassed and the canal can be negotiated with a conventional size #15 or #20 K-file, a GT hand file is selected (Iqbal MK et al.2006) The K-file creates a pilot hole so that the tip of the GT file can passively follow this glide path beyond the ledge. The GT file must have a tip diameter of 0.2 mm (#20) and a taper that will vary depending on the requirements of the preparation. The largest taper that will enter the apical segment is used; however, these instruments must be precurved, which

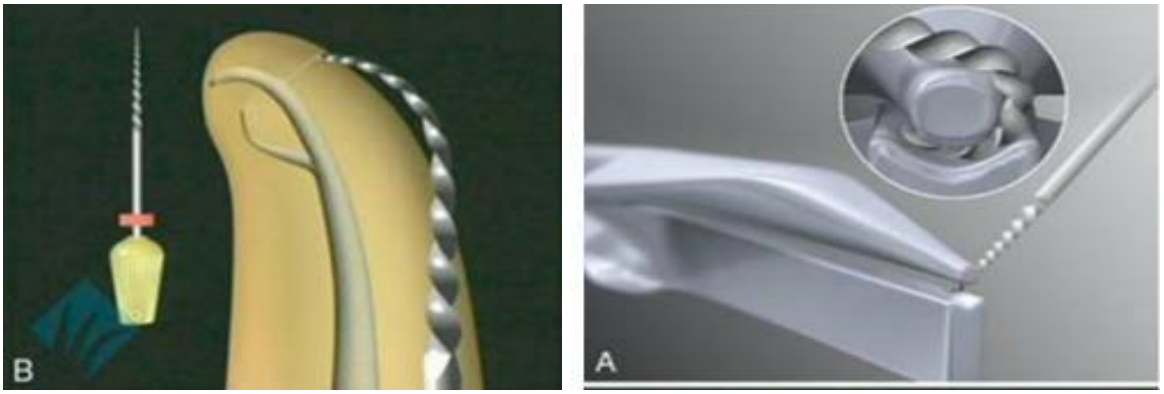

Figure19 *Endobender Pliers (Kerr Corporation) used to overbend a nickel-titanium hand GT file. B, GT hand file can hold a bend to allow it to bypass ledges*

presents a challenge since they are made from nickel titanium alloy. In order to precurve this superelastic shape memory alloy, a file-bending tool, such as the Endo Bender Pliers (Kerr Corporation, Orange, CA), is needed (Kang M et al.2015). The pliers grasp the tip of the instrument, and the file is over curved between 180 and 270 degrees to plastically deform the alloy. At this time, the appropriate tapered GT file is then carried into the canal, and the rubber stop is oriented so that the instruments precurved, working end can bypass and move apical to the ledge. The GT file is then worked to length, and the ledge is either reduced or eliminated (Levin A et al.2015). If the canal blockage or ledge cannot be negotiated, then the canal space coronal to the impediment should be cleaned, shaped, obturated, and coronally sealed. The patient must be informed of this complication, the guarded prognosis, and the need for regular reevaluation. If symptoms of posttreatment disease arise subsequently, apical surgery or extraction will be needed (Ludlow JB et al.2009).

Prognosis of Retreatment

When the proper diagnosis has been made, and all the technical aspects of retreatment are carefully performed, orthograde retreatment can be highly successful.The prognosis depends to a large extent on whether apical periodontitis exists prior to retreatment. In a systematic review of outcomes studies, Friedman and Mor report that in the absence of prior apical periodontitis, the incidence of healed cases after both initial treatment and orthograde retreatment ranges from 92% to 98% up to 10 years after treatment.When prior apical periodontitis is present, the incidence of healing drops to 74% to 86%, regardless of whether initial treatment or orthograde retreatment was performed. The authors state that this "similar potential to heal after initial treatment and orthograde retreatment challenges the historic perception of the latter having a poorer prognosis than the former (Friedman S et al. 2004). Unfortunately, these numbers mean that the desired outcome will not occur in potentially one-quarter of retreatment cases. Many techniques and devices for endodontic retreatment have been mentioned here to aid the clinician. However, none of this will guarantee success. Even when strict endodontic principles and fundamentals are followed, the result may be persistent posttreatment disease. When healing does not occur, the clinician is faced with the decision of what to do next. The choice is between four treatment options: observation, endodontic surgery, extraction-replantation, or extraction. Many times, a tooth that has persistent apical periodontitis may remain in asymptomatic function for an extended period of time, a state that has been referred to as functional retention of the tooth (Madarati AA et al.2008) If the patient's goal of treatment is not necessarily complete healing of the tooth, but simply to retain it in function and without pain, then regular evaluation by the clinician is warranted. If signs and symptoms of worsening infection such as progressive enlargement of a periapical radiolucency, pain, periodontal pocket formation, or sinus tract eruption occur, then further treatment may be needed. However, many teeth classified early on as uncertain healing may indeed be retained for many years (Ricucci D et al.2015) Endodontic surgery is a very predictable procedure that can be performed on most teeth Extraction-replantation, also referred to as intentional replantation, is another treatment option. This involves extraction of the tooth and performing the apicoectomy and root-end filling while the tooth is out of the patient's mouth, followed by replantation and splinting if indicated. This procedure is also discussed in detail in another chapter. Extraction and replacement should be the treatment of last resort, to be selected only when the tooth has been shown to be nonrepairable. If the decision is made to extract the tooth, usually replacement will be necessary to prevent shifting of the dentition with its attendant problems. Replacement can be with an implant, a fixed partial-denture, or a removable partial-denture (Roda RS et al.2018) The prognosis of fracture file removal file removal depends on various factors, including the location and severity of the fracture, the time elapsed since the fracture occurred, and the technique used for file retrieval. In cases where the fractured file is located in an accessible area and the fracture is not severe, the prognosis for successful removal and recovery is generally favorable. However, in more challenging cases, such as those with deep or complicated fractures, removal may involve more intricate procedures, potentially increasing the risk of further damage to the tooth structure or surrounding tissues (Liu et al., 2012). Studies have shown that, when performed by skilled practitioners using appropriate instruments, the success rate of file removal can be high, but the prognosis also depends on the clinician's experience and the specific circumstances of the fracture. Long-term outcomes often depend on factors such as the prevention of infection and ensuring the integrity of the tooth after the procedure (Martins et al., 2019).

Prognosis of Leaving a Fractured File in Place

The prognosis of leaving a fractured file in place during endodontic treatment can vary depending on factors such as the location of the file, the condition of the surrounding tissues, and the overall health of the tooth. In many cases, if the fractured file does not obstruct the cleaning, shaping, or sealing of the root canal, leaving it in place may not significantly affect the outcome. However, studies suggest that leaving a fractured file can increase the risk of complications, such as infection, poor sealing of the root canal, or difficulty in retreatment if necessary in the future (Pereira et al., 2014; Paiva et al., 2019). In cases where the file is deeply embedded or located in a critical area, removing it may cause further damage or compromise the integrity of the tooth, and leaving it in place might be a more viable option. The decision to leave a fractured file is often made based on a careful assessment of the risks and benefits, with the aim of preserving the tooth and ensuring the long-term success of the treatment (Gupta et al., 2018).

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