http://dx.doi.org/10.17159/2519-0105/2021/v76no1a4

Factors influencing apical debris extrusion during endodontic treatment - A review of the literature

SADJ February 2021, Vol. 76 No. 1 p28 - p36

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INTRODUCTION

The primary cause of a periapical inflammatory lesion is intra-radicular microbial infection.[1] Prevention and elimination of apical periodontitis is achieved through successful endodontic treatment.[2] Endodontic treatment is designed to maintain and restore the health of the periapical tissues and prevent periapical disease. It may be defined as the combination of mechanical instrumentation of the root canal system with bactericidal irrigation and obturation with an inert material.[3,4]

Technically, the goal of instrumentation and irrigation is to debride and entirely remove infected tissue debris from the root canal system and create a uniform conical shape that allows medicament delivery and adequate obturation.[4,5] Microbiologically, the goal of instrumentation and irrigation is to eliminate micro-organisms, reduce their survival in the root canal system and neutralise any antigenic potential of the microbial components remaining in the canal.[4,6,7]

Keywords
Apical debris extrusion, canal preparation, glide path preparation, instrument design, irrigation, kinematics.

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Clinical relevance of debris extrusion

During chemo-mechanical preparation, dentinal chips, pulpal fragments, necrotic debris, irrigants and micro-organisms may be inadvertently disseminated from the root canal into periapical tissues,[8] resulting in postoperative complications such as periapical inflammation, postoperative pain and delayed healing.[9-10]

The amount of material extruded through the apical foramen is one of the main concerns when using an instrumentation technique,[11] as periapical extrusion of debris, dentine mud or microbes is thought to play a role in postoperative flare-ups and, even more importantly, in endodontic treatment failures.[12-14] The frequency of these complications is reported to range between 1.4% and 16%.[10] Preventing debris extrusion therefore plays a significant role in the course of root canal treatment.[15]

All instrumentation techniques and files are associated with apical extrusion of debris (Figure 1); however, the amount of extruded debris may differ according to the preparation technique used.[8,16,17] The design of rotary files and the chosen kinematics contributes to accumulating dentinal debris into the flutes of the preparation instruments and directing it coronally toward the canal orifice, lessening apical compaction of debris.[18] Hence, a more favourable postoperative course can be obtained by choosing a technique that lessens apical debris extrusion.[19,20] Nair et al.[21] concluded that all instrumentation techniques produce apical extrusion of debris even when the preparation is maintained at the apical terminus.

Figure 1. Extrusion of apical debris through root canal foramen during root canal preparation.

Instrumentation techniques

Manual techniques

Ruiz-Hubard et al.[22] compared conventional step-back instrumentation to crown-down technique in plastic blocks in both curved and straight canals. The authors found that less debris were apically extruded using the crown-down pressure less technique than with step-back instrumentation. McKendry[23] found lesser amounts of apical debris extrusion after using a balanced forced technique, compared with step-back techniques. Similarly, Al-Omari and Dummer[24] found that step-back instrumentation with circumferential filing resulted in the most apical extrusion, whereas crown-down and balanced force techniques formed the smallest amount of debris.

Manual vs. rotary techniques

A mutual finding in the aforementioned studies is that a push-pull canal enlargement action such as filing produces more apical debris than instrumentation techniques that incorporate a rotational force. This led to the hypothesis that engine-driven rotary instruments using the balanced force technique will produce less debris than hand-filing techniques, decreasing potential for periradicular tissue irritation and postoperative sequelae.[25] To decrease the amount of apical extrusion of debris, Del Fabbro et al.[26] recommend the use of nickel-titanium (NiTi) instrumentation for root canal therapy.

Similarly, numerous studies report that using K-files for root canal instrumentation results in more postoperative pain than does rotary system use.[27-29] However, Çiçek et al.[30] obtained differing results, concluding that the modified step-back technique produced less pain in a 48-hour period than did rotational and reciprocal preparation techniques. Arias et al.[27] found that although an increased incidence of postoperative pain is anticipated after manual root canal instrumentation, postoperative pain after rotary canal preparation is expected to last longer. Kashefinejad et al.[28] observed a significant difference in postoperative pain when comparing Mtwo (VDW, Munich, Germany) rotary instrumentation to K-file hand instrumentation. In the rotary group, only 13.3% of patients required analgesics as opposed to 56.7% in the hand file group.

Continuous vs. reciprocating single-file systems

Previous studies on postoperative pain have reported inconsistent results from the use of continuous rotary systems and reciprocating systems.[20,31-33] In analysing postoperative pain, three different studies opted for One Shape (Micro-Mega, Besancon, France) as the file of choice for the rotary single-file instrument group in comparison with different single-file reciprocating instruments.[29,32,34] Among the three relevant articles, Jain et al.[34] and Mollashahi et al.[29] report that there was no significant difference in the intensity of postoperative pain between the rotary single-file groups and reciprocating single-file groups. In contrast, a study by Neelakantan and Sharma[32] states that compared to the One Shape rotary group, the reciprocating single-file groups exhibited significantly lower postoperative pain intensity.

Single-file vs. multi-file systems

A meta-analysis conducted by Sun et al.[35] compared a total of 12 studies on postoperative pain after treatment with engine-driven rotary and reciprocating instruments. The authors concluded that multiple rotary-file systems contributed to a lower incidence of postoperative pain than did reciprocating single-file systems.

A study by Robinson et al.[36] found that multiple rotary-file systems yielded cleaner canals with less debris accumulation remaining within the root canal than did reciprocating files. Using micro-computed tomography (micro-CT), this study compared the 3D distribution, quantity, and density of remaining inorganic debris in the mesial roots of mandibular molars after instrumentation. An average of 19.5% debris remained in the canal after single-file reciprocating instrumentation compared to 10.6% with the multi-file rotary technique, showing that reciprocating motion leaves more debris within the canal.

Relationship between bacterial extrusion and amount of debris

A study using a multipurpose analytic approach compared the levels of apically extruded bacterial and hard-tissue debris and intracanal bacterial reduction after root canal preparation. Apical extrusion of bacteria occurred in 90% for XP-endo Shaper (FKG Dentaire, La Chaux-de-Fonds, Switzerland) and 81% for Reciproc (VDW).

Intracanal bacterial reduction was greater when using the XP-endo Shaper. Both reciprocating and continuous rotation techniques produced similar volumes of hard-tissue debris extrusion. Hard-tissue debris extrusion was less frequent than bacterial extrusion and no correlation was observed between the volume of extruded debris and counts of extruded bacteria.[37]

These contradictory findings justify the need for further investigation of widely used systems.[11] Although all instrumentation techniques appear to force intracanal content through the apex into the periapical tissues,[11] the amount of debris extrusion may differ according to preparation techniques, kinematics and the design of the rotary file systems.[38-40] Since new instruments and techniques are saturating the market, evaluation of current practices is important.

Rotary kinematics

Three groups of instruments are available for root canal preparation: manually operated instruments, engine-driven rotary instruments and engine-driven reciprocating instruments.[41] The majority of commercially available rotary NiTi root canal systems are primarily driven in a continuous 360° rotation motion around a single axis (Figure 2).[42,43] Conventional continuous rotation has an increased risk of NiTi instrument fracture caused by torsional and flexural stresses.[44,45]

Torsional fatigue is the twisting of a metal shaft around its longitudinal axis at one terminus, while the other file terminus is static (Figure 3).[44] Torsional fracture occurs when a tip or any other part of the instrument binds and locks to the root canal walls, while the rest of the file continues in rotary motion. Hence it is possible for a practitioner to lessen the intensity of torsional stress by reducing apical force during canal instrumentation. Shaping root canals of smaller diameter generates more torsional stress than shaping larger diameter canals.[46]

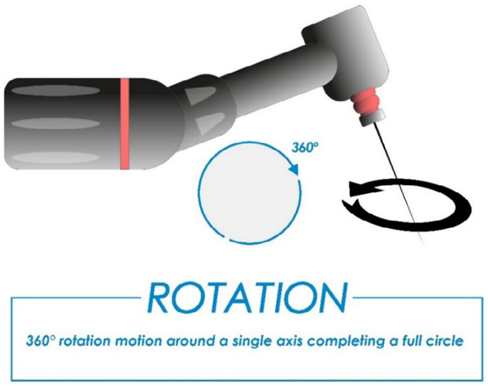

Figure 2. Engine-driven continuous rotation.

Cyclic fatigue ensues when a metal is subjected to recurrent cycles of tension and compression, causing its structure to deteriorate (Figure 4).[44] Fracture due to flexural fatigue occurs when an instrument that has previously been weakened by metal fatigue is placed under further stress. The instrument does not bind to the root canal walls, but rotates freely until it fractures at the point of maximum flexure.[46-48]

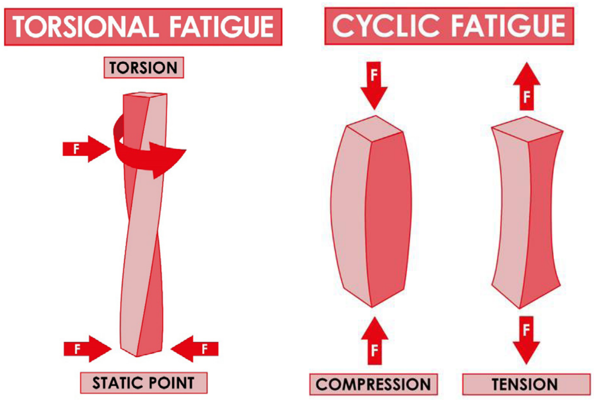

Fig. 3

Fig. 4

Figure 3. Schematic presentation of forces contributing to torsional fatigue.

Figure 4. Schematic presentation of forces resulting in material cyclic fatigue.

Cyclic fatigue is most likely to occur in a canal with a severe curve and a short radius of curvature,[44,49] whereas torsional stress might develop in straight canals.[50] Cyclic fatigue is considered to be the principal cause of NiTi instrument separation.[51]

Increasing resistance to file separation has been the main goal of manufacturers in developing the latest NiTi rotary instruments, aimed at improving safety by means of pioneering design and manufacturing processes.[52,53] To overcome the breakage of endodontic instruments caused by flexural fatigue, reciprocating movement was introduced.[54] Recent literature data confirms that reciprocating motion can extend the cyclic fatigue resistance of NiTi instruments for longer than continuous rotation.[54-56]

Reciprocation, defined as any repetitive back-and-forth (up and down or forward and reverse) movement, was originally introduced in endodontics in 1958.[42,43] Early reciprocating systems used an equal alternating motion of 90° angles and in more recent systems of 30° angles, none of which would complete a full rotation cycle.[43] Over time, smaller yet still equal angles of clockwise (CW) and counter-clockwise (CCW) motion were used in M4 hand pieces (SybronEndo, California, USA), Endo-Eze AET (Ultradent, Utah, USA) and Endo-Express (Essential Dental Systems, New Jersey, USA) systems.[42]

Most recent developments contributed to the introduction of systems based on a new mode of mechanical rotation, a multiple reciprocation motion completing a 360° cycle (Figure 5). In 2010, VDW launched Reciproc and in 2011 Dentsply Sirona launched WaveOne (Dentsply Sirona, Ballaigues, Switzerland), both of which are indicated for use as single-file techniques in automated reciprocation.[43]

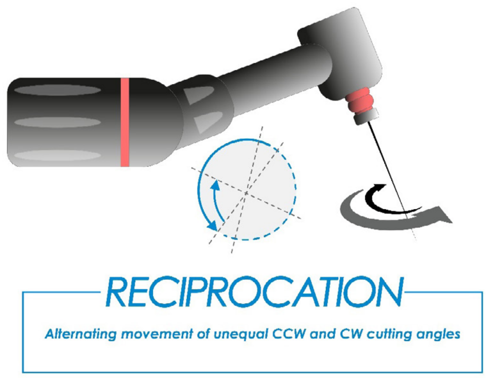

Figure 5. Engine-driven reciprocation.

The kinematics of reciprocating instrumentation is complex. Contrary to continuous rotary motion, the files rotate in a reverse balanced force turning back and forth.[57,58]

Reciprocating file systems use the alternating movement of unequal CW and CCW cutting angles (different to full sequence continuous rotation files) to prevent torsional fracture. Reciprocating movement aims to reduce this risk by engaging the file in a cutting motion, and then immediately disengaging it in a non-cutting motion.[59]

Reciprocating files currently available on the market are single-file systems designed to have a greater engaging CCW angle (left-cutting) than the disengaging CW angle (non-cutting).[60] The CCW rotation advances the instrument apically as the dentine of the root canal wall is engaged and cut. This action is followed by a reduced angle CW rotation, which ensures that the instrument disengages before excessive torsional stress is transferred onto the metal alloy, preventing the instrument from binding onto the root canal walls.[58]

A number of studies have compared apical debris extrusion of continuous rotation systems with reciprocating systems. Multiple authors report that reciprocating files extruded more apical debris than rotary files.[61-64] In contrast, numerous authors found that reciprocating instruments produced less apical debris extrusion than rotary instrumentation.[65-68] Various studies also showed no significant difference between the two systems.[69-72]

A recent study investigated the amount of apically extruded debris created by the reciprocating file Reciproc blue (VDW) versus continuous rotation files HyFlex EDM (Coltene, Altstätten, Switzerland) and XP-endo Shaper (FKG Dentaire) during root canal preparation at body temperature. The XP-endo Shaper group extruded a significantly smaller amount of debris than Reciproc blue, whereas no significant difference was registered between the HyFlex EDM files and the other NiTi files tested.[73] The reasons for the conflicting results could be variability in file design, the number of files used and the canal anatomy differences between the studies.[74]

Apical patency

Throughout canal instrumentation, both pulpal and dentinal debris can block the apical portion of the root canal and lead to procedural errors.[24] A recognised practice for avoiding the accumulation of apical debris is maintaining apical patency, thereby preserving an open pathway between the apical orifice and the periodontal ligament.[75]

Establishing apical patency is the initial step in root canal treatment. The patency file ought to be used prior to irrigation to loosen compacted tissue remnants.[76] Apical patency is defined as the ability to easily and reproducibly place a small hand file through the minor constriction of the apical foramen. It is followed by glide path preparation, after which root canal enlargement commences.[77,78] Apical patency is maintained by repetitive recapitulation through the apical constriction with a small K-file with the aim of keeping the root canal free of debris.[79]

Lambrianidis et al.[80] assessed the role of apical constriction on periapical extrusion of debris/material. They concluded that an enlarged apical constriction resulted in less material being extruded through the foramen. In con trast to this finding, a study by Tinaz et al.[39] showed an increase in the amount of apically extruded material with an increase in the diameter of the apical patency. The conflicting findings can be attributed to the study design. In the study by Lambrianidis et al.[80] the canal instrumentation was executed in two stages using a step-back technique. The root canals were initially only instrumented up to the apical constriction. In the second phase of canal preparation, the apical constriction was intentionally enlarged. The canals were already enlarged in phase one and this could have allowed easier elimination of debris, as the coronal portion of the canal space was wider in phase two.

A patency file should be used with care, because it may force accumulated debris apically with the risk of inoculating microbes into the periapical region.[81] However, newly available evidence indicates that maintaining apical patency does not increase postoperative pain or the rate of postoperative flare-ups.[82]

Glide path

Glide path preparation is an adjunctive preliminary procedure prior to canal instrumentation.[78] Although there is no current consensus on the definition of a glide path,[83] it is commonly described as "a smooth radicular tunnel from the canal orifice to the physiologic terminus (apical foraminal constriction)".[84] Before canal preparation, a reproducible glide path should be created to minimise procedural accidents and improve the shaping ability of the final canal shaping system.[2,85] Initial glide path creation assists in minimising preparation times and preserves the original anatomy with little modifications and aberrations to the root canal curvature,[83] improving the outcome of endodontic treatment.[78]

Manual and rotary glide path instruments are the first files to negotiate narrow and calcified root canal systems, hence they encounter high levels of torsional stress.[44] If the instrument tip cross-section is larger than the canal width, instrument blades can bind into the root canal walls. This is known as taper locking. Creating a glide path decreases the contact area between the shaping file and root canal walls, reducing the likelihood of taper locking and subsequently decreasing torsional stress.[86]

The creation of a glide path has been recognised as crucially important in reducing the incidence of instrument fracture due to reduced torsional and flexural stress on the root canal instrument.[87] Glide path preparation increases the efficacy of root canal preparation, as it produces a reproducible tunnel in which rotary preparation instruments can run smoothly with reduced incidences of instrument fracture or canal aberrations.[83,87-89]

One of the risks of any instrumentation technique is apical debris extrusion, which increases the possibility of postoperative inflammatory reaction.[90] Post-treatment complications are decreased because much of the pulp, bacteria and related irritants are removed during pre-enlargement procedures. Passing files through underprepared canals coronally pushes more irritants beyond the apex and generates more postoperative exacerbations. On the other hand, passing files through a cleaned pre-enlarged preparation equates to less debris being unintentionally inoculated periapically.[25]

Topçuoglu et al.[91] demonstrated that creating a glide path prior to canal instrumentation reduced the amount of apically extruded debris during canal preparation in curved canals. More recently, Gunes and Yeter[92] found that glide path preparation before root canal preparation with a Primary WaveOne Gold file (Dentsply Sirona) had no effect on apical debris extrusion.

The study compared the amount of apically extruded debris after using multiple glide path files, before preparing curved root canals with the reciprocating Primary WaveOne Gold single file. They found that K-files showed a significantly higher amount of debris extrusion than One G glide path files (Micro-Mega), which could be explained by the fact that the tip diameter of One G files (0.14mm) is smaller than the other glide path files used in the study.

However, there was no significant difference between the K-files and the other rotary glide path files in terms of apical debris extrusion.[92] These results could correlate with the finding of Tinaz et al.[39] that the quantity of apically extruded debris increased in teeth with a greater apical patency during both manual instrumentation with K-files and engine-driven rotary instrumentation with ProFile .04 Taper Series 29 (Dentsply Sirona). Regardless of the techniques used, there was a tendency for greater apical debris extrusion as the diameter of apical patency increased.

More debris is generally extruded during the main shaping procedure, than during the glide path preparation procedure. However in the latter, although the amount of debris may be small, this initially extruded debris may contain higher toxicity than debris extruded later by the shaping instrument.[11]

Instrument design

The objective of biomechanical preparation is to remove vital and necrotic pulp tissue, infected radicular dentine, micro-organisms and microbial toxins from the root canal system.[93] Most current mechanical root canal instrumentation systems propose single- or multiple-file systems to prepare root canals to a minimal dimension.[94] The standard enlargement of the root canal is typically associated with an ISO tip size of 25 and either a variable taper or a continuous 6% taper.[5,95]

It is important to note that the design of rotary files and the selected motion contribute to collecting dentinal debris in the flutes of the instruments and directing it coronally toward the canal orifice, lessening the compaction of debris in the root canal.[18] Inconsistency has been noted between different mechanical systems in terms of debris extrusion.[40] Apical debris extrusion variability is presumed to be caused by differences in cross-section and cutting blade design, taper, tip type, configuration, concepts of use, flexibility, alloy, number of files used, kinematics, and cutting efficacy.[96]

In search of superior NiTi alloy properties, manufacturers have used new manufacturing methods, postproduction material heat treatments and different cross-sectional designs. NiTi alloys used for endodontic files can be grouped into instruments that primarily comprise the austenite structural phase (conventional NiTi, M-Wire, R-Phase) and those predominantly comprising the martensite structural phase (CM Wire, Gold and Blue heat-treated NiTi).[97]

Heat-treated NiTi alloys include M-Wire, R-Phase and CM-Wire. M-wire has three crystalline phases: deformed and micro-twinned martensite, R-Phase, and austenite. M-Wire and R-Phase instruments show greater resistance to cyclic fatigue and superior flexibility than conventional NiTi files. CM-Wire uses the stable martensite phase because the austenite finishing temperature is above working temperature. CM-Wire reverts to its original shape after heat application or autoclaving.[98]

Currently available rotary NiTi file endodontic systems cater for both continuous rotation and reciprocating motion. The most widely used continuous rotation systems are ProTaper Universal (Dentsply Sirona), ProTaper Next (Dentsply Sirona), Revo-S (Micro-Mega), One Shape (Micro-Mega), One Curve (Micro-Mega), HyFlex CM (Coltene), HyFlex EDM (Coltene) and TruNatomy (Dentsply Sirona). WaveOne (Dentsply Sirona), WaveOne Gold (Dentsply Sirona), Reciproc (VDW) and Reciproc blue (VDW) are the main endodontic file brands that are used in reciprocation.[99]

Clockwise/forward/right-cutting reciprocation

Reciprocating motion is an evolution of the balanced force technique offering an alternative method to prevent procedural errors during root canal instrumenation.[100] In theory, the alternating changes in the direction of rotation reduce the number of cycles of the instrument and therefore the cyclic fatigue on the instrument compared with that imposed when instruments are used in a consistent rotating motion.[55,101] Based on several studies, root canal shaping with reciprocating motion has been postulated to offer superior fracture resistance.[54,101-104]

Paqué[105] demonstrated that the F2 ProTaper Universal in reciprocating motion is as efficient as the conventional ProTaper Universal full sequence (Dentsply Sirona) technique in continuous motion. A study by Espir[106] produced comparable results, showing that CW reciprocation motion with Mtwo (VDW) results in effective canal preparation.

All continuous rotation systems are designed to cut in a CW direction (right-cutting). The rotary CW cutting instrument may neither cut nor infiltrate the canal walls if used in CCW reciprocating motion. Since the reciprocating file systems have been designed to cut in a CCW direction (left-cutting), the CCW angle of motion is greater that the CW angle.[107] Reciprocating motion with CW rotation greater than the CCW motion could allow the use of a larger number of conventional rotary file systems, as the flutes of the majority of systems are designed for continuous CW rotation.[106]

In 2016, two studies evaluated the effects of kinematics on apical debris extrusion. These studies assessed the same instruments, used in the same sequence. Movement kinematics was the only variable between different groups, therefore excluding other variables such as the instrumentation sequence, instrument alloy and instrument design. The authors concluded that movement kinematics significantly affected the amount of apically extruded debris.[108,109] Karatas et al.[108] evaluated the influence of different movement kinematics (TF Adaptive motion, 90° CW–30° CCW, 150° CW– 30° CCW and continuous rotation) on apical debris extrusion using Twisted File Adaptive instruments (SybronEndo). According to their findings, when the reciprocation range increased apical debris extrusion decreased.

The decreased reciprocation range in the 90° CW–30° CCW group produced more debris extrusion. The increased reciprocation range in the 150° CW–30° CCW group could have generated less extrusion because more debris was transported coronally by the file acting as a screw conveyor due to the enlarged reciprocation range. Arslan et al.[109] measured the amount of apically extruded debris using Reciproc (VDW) instruments with various kinematics (150° CCW–30° CW, 270° CCW–30° CW, 360° CCW–30° CW and continuous rotation). The results of their study revealed that the 150° CCW–30° CW and 270° CCW–30° CW reciprocating motions extruded significantly less debris than continuous rotation.

Solutions and debris extrusion

Irrigation is an essential part of the debridement sequence. Both dentine debris and the smear layer adhering to the canal walls are created by the engagement of endodontic instruments during preparation,[110] and should be eliminated from the root canal system to improve outcome prognosis. Although debris and smear layer removal is primarily achieved by irrigation,[111] approximately half of the debris created during instrumentation cannot be removed from the canal system.[110]

Irrigant infiltration of the apical portion of the canal is essential in order to clean and keep it free of debris,[82] reducing the risk of blockages and apical debris extrusion.[9] Irrigants often do not reach the apical third of the canal due to the vapour lock effect. An effective hydrodynamic effect can be produced by agitating the irrigant and significantly improving the exchange and efficiency of any desired solution.[112]

In a recent study by Gupta et al.[113] different irrigation agitation techniques showed apical extrusion of both debris and irrigant. The mean amounts of apically extruded irrigant and debris were greater in agitation groups than in the no-agitation control groups. This could be due to greater turbulence caused within the canal as a result of improved irrigant displacement.

Elimination of dentine and pulpal debris is thought to be improved with frequent and abundant irrigation.[114] Debatable results were found when investigating the relationship between the amount of apically extruded debris and irrigant use. Hinrichs et al.[115] and Ferraz et al.[116] found a positive correlation, while Myers and Montgomery[117] and Tinaz et al.[39] reported no correlation.

Sodium hypochlorite (NaOCl) solution has the ability to dissolve organic material,[118] hence displaying great potential to remove the debris produced during chemo-mechanical root canal preparation.[119] It also exhibits antimicrobial properties, leading to successful decontamination of the root canal system.[120] Although highly cytotoxic to the periapical tissues in high concentrations,[76] it is the most widely used irrigant in endodontic treatment.[121]

In addition to dentinal debris collection within the root canal, endodontic instrumentation techniques produce a smear layer that accumulates on the root canal walls and blocks the openings of dentinal tubules. The smear layer consists of organic and inorganic substances including dentinal filings, fragments of odontoblastic processes and micro-organisms.[122]

Ethylenediaminetetraacetic acid (EDTA) is a chelating agent used as a final irrigant to remove the potentially infected smear layer and open calcified canals due to its decalcifying properties. Although NiTi instrument manufacturers recommend using EDTA preparations for lubrication during canal instrumentation, contact between EDTA and the periapical tissue cannot be excluded.[123]

A study by Cruz et al.[124] investigated whether the use of a paste containing EDTA during cleaning and shaping of the root canal helped to eliminate debris. In the first group, NaOCl was used during canal preparation and final irrigation was achieved with 17% liquid EDTA. In the second group, NaOCl was also employed as the irrigating solution, but Glyde Root Canal Conditioner (Dentsply Sirona) was used with every instrument. Likewise, final irrigation was performed with 17% liquid EDTA. The authors concluded that the use of Glyde Root Canal Conditioner (Dentsply Sirona) during mechanical instrumentation resulted in increased accumulation of debris in the apical third of the root canals.

De Deus et al.[125] took high-resolution 3D micro-CT scans of teeth to register and quantify the amount of accumulated hard-tissue debris within the root canal system following canal instrumentation. Hard-tissue debris occupied 34.6% of the canal volume when no irrigant was used during canal preparation. Irrigation with bidistilled water resulted in 16% volume of debris, while irrigation with NaOCl followed by EDTA resulted in 11.3% volume of debris remaining within the root canal system. Markedly more debris accumulated in the non-irrigated specimen, undoubtedly due to the lack of liquid flow.

CONCLUSION

Apart from instrumentation techniques, instrument design and irrigation methods, kinematics plays an important role in apical extrusion of debris and should be viewed as a key factor in the complex aetiology of debris extrusion. Careful selection of endodontic instruments and the utilization of alternative rotary kinematics in a clinical setting might aid in the reduction of debris extrusion and subsequently limit irritation to peripapical tissue.

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