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Original Article

Rotary systems for root canal gutta-percha removal: A Review

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ABSTRACT

Gaining a predictable outcome in endodontics is complicated by handling an endodontically treated. Compared to primary root canal therapy, non-surgical endodontic retreatment typically entails the removal of previous root filling materials. This process may be necessary to enable access to contaminated canal space for recleaning and to remove obturation materials that may have been contaminated by marginal penetration of microorganisms and microbial toxins. The achievement of patency at the canal terminus and the extension of cleaning as close as possible to the apical terminus have been identified as healing prognostic criteria.

Gutta-percha (GP) is the current mainstay material utilised as an endodontic filling material, capable of performing comprehensive, three-dimensional sealing of the treated root canal system in a highly effective manner with considerable physical durability. Interestingly, since its initial discovery in the 17th century, GP remains to this day the ideal obturation material used across, in essence, all dental clinics globally due to its material properties and versatility for use in conjunction with sealer compounds.

The development of GP removal systems that can manage to remove GP in its entirety from root canals during non-surgical retreatment procedures is currently highly desirable for dental practices. This literature review investigated this current research niche and scrutinised two prevalently utilised rotary systems –Edgefile-XR and the XP-Endo shaper systems.

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INTRODUCTION

Removing any root canal filling material present is a crucial difference between initial and retreatment procedures. The deficiencies of the initial treatment can only be addressed when access to the canal system is established and the root canal system is accessible. Therefore, the optimal root canal filling material must be simple to remove (Duncan & Chong, 2008).

Regarding this, gutta-percha (GP) is the current mainstay material utilised as an endodontic filling material, capable of performing comprehensive, three-dimensional sealing of the treated root canal system in a highly effective manner with considerable physical durability (Vishwanath & Rao, 2019). GP is derived from the dried sap of the *Sapotaceae* tropical climate-based tree family, predominantly indigenous to the Malay Peninsula, Indonesia, Singapore, Sumatra, Philippines, Brazil, and other South American nations. Interestingly, since its initial discovery in the 17th century, GP remains to this day the ideal obturation material used across, in essence, all dental clinics globally due to its material properties and versatility for use in conjunction with multiple disinfectant compounds (Vishwanath & Rao, 2019).

The removal of root filling materials in a safe, efficient, and effective manner is a crucial component of non-surgical root canal retreatment. Since a variety of materials have been advocated for filling root canals, different removal approaches are necessary. As gutta-percha is the most often used and accepted root filling substance, its removal is highlighted in greater detail in this review. The management of widely encountered root filling materials during non-surgical retreatment, including the essential clinical procedures, was discussed.

LITERATURE REVIEW

Factors leading to endodontic treatment failures

Endodontic therapy objectives focus on eliminating irritation of the periapical tissues due to root canal infection, which can be achieved through chemo-mechanical debridement and complete sealing of the root canal system (Basrani & Malkhassian, 2015) (Bergenholtz et al., 1979). Previous studies reported that the success rate for root canal treatment typically ranged between 86% - 96%, depending on the pre-operative periapical status(Ulf Sjögren et al., 1990). However, 60% of cases of apical periodontitis developed on root-obturated teeth (El Ouarti et al., 2021; Georgopoulou MK, 2005). In addition, a separate study by Sundqvist and colleagues conclusively demonstrated that root-filled teeth were at an exacerbated risk of being lost compared to non-root-filled teeth (Sadaf, 2020; Sundqvist et al., 1998).

Researchers also confirmed that varying causes contribute to periapical radiolucency persistence following root canal treatment (P. N.R. Nair, 2006; Siqueira et al., 2014). These include intra-radicular infection within the complex apical root canal system, extra-radicular infection in the form of periapical actinomycosis, foreign body reaction, true cystic lesions, and scar tissue healing of the periapex. However, residual intra-canal infection is the predominant cause of persistent apical periodontitis (P. N.Ramachandran Nair et al., 1999; Siqueira, 2001; Siqueira et al., 2014). These challenges can occur due to failure to eradicate micro-organisms during initial treatment or to re-admission of micro-organisms into the root canal system following completion of root canal treatment. (Allen et al., 1989; Kim et al., 2018; U. Sjögren et al., 1997).

However, differing technical factors undoubtedly pave the path for such treatment failures. One additional iatrogenic factor leading to ET failure is an error in ET protocol execution by the performing dental surgeon (Yousuf et al., 2015). Poor obturation and coronal restoration procedures could also contribute to ET failure (Sarin et al., 2016)(Tabassum & Khan, 2016). The article published by Basrani and Malkhassian in 2015 also described that ET failures could be linked to the incorrect selection of required irrigation fluid, leading to eventual bonding issues (Basrani & Malkhassian, 2015). An additional issue leading to ET failure would be the

inability to prepare to length (Allen et al., 1989). Costa and colleagues also reported cases where the dental surgeon inadvertently missed specific root canals during the ET procedure (Costa et al., 2019). Finally, the issue of bacterial resistance to disinfectant compounds can also eventually drive ET failures within apical periodontitis patients' affected teeth (Molander et al., 1998).

Consequently, following the awareness of such failure-inducing factors, non-surgical retreatment should be indicated as the optimal therapeutic strategy in managing failure ET since such a technique remains the most conservative method (American Association of Endodontists, 2017).

Non-surgical retreatment procedures

Non-surgical retreatment, implemented following a previously failed root canal endodontic treatment, consists of the initial removal of all obturating material, such as GP, from the retreated root canal in a highly effective manner to avoid exposing the tooth to retreatment failures, particularly of an iatrogenic nature. (Duncan & Chong, 2008). Consequently, the most crucial step in determining the level of the non-surgical success rate of root canal retreatment procedure remains the thorough and effective removal of all GP and sealer present within the root-treated tooth (Heeren & Levitan, 2012). Following successful GP removal, retreatments proceed by thoroughly cleansing all canals to allow subsequent irrigation solutions to effectively disinfect the entire affected root canal system in a chemo-mechanical manner. Failure in total removal of GP residue can lead to such residues incurring microbial loads over time, consequently ushering insidious root canal infections and possible retreatment failure (Heeren & Levitan, 2012; Ng et al., 2011).

Differing methodologies for GP removal

The instrument and irrigating solution must reach the entire root canal system to clean and disinfect during root canal retreatment properly. Hence, mechanical barriers such as GP must be removed to ensure successful ET procedures. Any remaining residual GP could contain a substantial microbial load, eventually thwarting successful ET outcomes (Heeren & Levitan, 2012; Ng et al., 2011).

Presently, several methodologies exist for the successful removal of GP deposits prior to ET, adopting varying technologies and having a range of characteristics. According to the foundation methodology, these techniques are mainly categorised into mechanical, thermal and chemical-based GP removal protocols. Such methodologies are described in detail below:

1. Mechanical GP removal methodologies

a) Hedstrom files

The first scientific publication referring to the utility of Hedstrom files as practical endodontic tools dates back to 1977 (Segall et al., 1977). Since its inception, Hedstrom files (also termed as H-files) remain the current mainstay endodontic instruments for performing endodontic retreatment, with possible alternative tools not proving any significant increases in effectiveness for removing GP deposits from infected root canal systems (Çelik Ünal et al., 2009)(Aydin et al., 2009). Other similar studies include the investigation carried out by Kesim and colleagues in 2017 that performed a comparative analysis of the effectiveness of manual and mechanical-based endodontic tools, including Hedstrom files (Kesim et al., 2017). This investigation was conducted across eighty previously extracted mandibular premolar teeth, divided into four study groups according to the applied manual and mechanical methods. (Kesim et al., 2017). The results of this investigation demonstrated that none of the differing manual and mechanical methodologies had any additional efficacy-based advantage over the remainder groups, with Hedstrom files exhibiting a non-statistically significant success rate compared to the remainder study groups (Kesim et al., 2017).

However, Hedstrom files, a highly manual form of GP removal technique, carry disadvantages, mainly concerning dentin losses during the procedure. The study carried out by Ali and colleagues in 2021 aimed at

evaluating canal transportation, dentin loss and levels of remaining GP following endodontic retreatment protocols for differing techniques, including Hedstrom files, which are highly manual, full of disadvantages, especially dentin losses (Ali et al., 2021). This study utilised sixty extracted and obturated anterior maxillary teeth using GP, with three study groups (n=20 / group) undergoing endodontic retreatment using either the Hedstrom file, ProTaper Universal retreatment system or the R-Endo system (Ali et al., 2021). The results of this investigation indicated that the manual-based technique, including Hedstrom files, was equivalent in efficacy levels for removal of GP from root canal systems compared to the rotary-based technique, although at the expense of additional dentin losses and increased canal transportation (Ali et al., 2021).

One additional disadvantage with Hedstrom file methodology would be that since this technique is manual, there is an additional level of labour or physical effort required to remove GP from root canal systems. The study carried out by Ozyurek and colleagues in 2017 perfectly highlights this issue (Özyürek & Özsezer Demiryürek, 2017). This specific investigation analysed the effectiveness of ProTaper Next and ProTaper Universal RT techniques against Hedstrom files in removing GP from curved root canal systems (Özyürek & Özsezer Demiryürek, 2017). A total of 90 mandibular molar teeth were employed in the study, with the outcomes demonstrating that Hedstrom hand files took increased procedural timings for removing GP and sealer material in comparison to the rotary systems (Özyürek & Özsezer Demiryürek, 2017).

b) Nickel-Titanium (NiTi) rotary file system

These engine-driven rotary file instruments break up the gutta-percha and sealer mechanically via frictional heat to facilitate removal. The flutes should drive the root filling out of the canal when the rotary NiTi file is activated (Duncan & Chong, 2008).

The concept of utilising NiTi rotary file systems was first mentioned within the scientific literature in a study by Walia and colleagues in 1988 (Walia et al., 1988). This investigation analysed the torsion and flexibility levels for Nitinol files in root canal RT compared to stainless steel (Walia et al., 1988). This study demonstrated that Nitinol files were more adept for employment in curved root canal systems in comparison to the stainless steel counterparts, mainly since Nitinol files exhibited 2 – 3 x fold increased elastic flexibility in terms of torsional and bending ability, together with enhanced torsional fracture resistance levels (Walia et al., 1988). Later studies confirming such qualities include the investigation carried out by Canalda-Sahli and colleagues in 1996 (Canalda-Sahli et al., 1996). This investigation focused on the comparative analysis of NiTi (Flexogate) files and stainless steel files in terms of bending and torsion capacity across differing apical sizes (sizes 25 – 40; n = 10 / size) (Canalda-Sahli et al., 1996). The results of this particular study confirmed NiTi files to have increased flexibility and the highest angular deflection readings (Canalda-Sahli et al., 1996). Concerning NiTi rotary file systems' effectiveness in removing GP from root canal cavities, the study conducted by Barrieshi-Nusair and colleagues in 2002 aimed to analyse NiTi capacity against stainless steel counterpart files in this regard (Barrieshi-Nusair, 2002). The experimental design in this study allowed for the quantitative measurement of the degree of GP remaining on the root canal walls of 40 extracted teeth (canines) through pre and post-gutta retreatment radiography and manual tracing of radiographs for GP residues (Barrieshi-Nusair, 2002). The results of this particular study demonstrated that NiTi rotary file systems were on par with stainless steel counterparts in terms of the level of GP residues removed from individual root canal systems (the remaining GP degree on root canal walls was 13.6% for stainless steel versus 15.2% for NiTi)(Barrieshi-Nusair, 2002).

Different rotary NiTi systems have been evaluated previously, including ProFile (Dentsply Maillefer, Ballaigues, Switzerland), Quantec (SybronEndo, Orange, CA, USA), System GT (Dentsply Maillefer, Ballaigues, Switzerland) (29), RaCe (FKG Dentaire, La Chaux-de-Fonds, Switzerland), Hero SHAPER (Micro-Mega, Besancon, France), K3 (SybronEndo, Orange, CA, USA), ProTaper (Dentsply Maillefer, Ballaigues, Switzerland), Mtwo (VDW, Munich, Germany), EndoSequence (Brasseler, Savannah, Georgia, USA) (34), Liberator (Miltex, York, PA, USA), XP Endo Shaper (FKG, Switzerland), and Reciproc Blue (VDW Munich, Germany). Rotary file systems designed specifically for retreatment have also been evaluated; these include

ProTaper Universal (Dentsply Maillefer, Ballaigues, Switzerland) and R-Endo (Micro-Mega, Besancon, France). and EdgeFile XR (EdgeEndo USA).

In addition to such studies, Table 1 below lists studies conducted during the past 2.5 years that focused explicitly on evaluating varying rotary file system effectiveness in removing GP during endodontic retreatment procedures.

Table 1: List recent studies (2020 – 2022) that evaluated varying rotary file system effectiveness in removing GP during endodontic retreatment procedures.

Reference	Test File Systems	Study Title / Aims	Study Conclusions
(Tejaswi et al., 2022)	Mani GPR, Endostar Re Endo Hedstrom file	Evaluation of dentinal crack propagation, amount of gutta-percha remaining and time required during removal of gutta-percha using two different rotary instruments and hand instruments - An In vitro study.	*"All the groups showed a similar amount of crack propagation. Less number of cracks were observed in the coronal one-third, and a greater number of cracks were found in the apical third. Endostar RE Endo rotary instrument proved to be the most effective and least time-consuming. Hedstrom Files required more time and removed less material."*
(Cardoso et al., 2022)	Mtwo-R 15/.05 and 25/.05, Reciproc	Effectiveness of reciprocating and rotary retreatment files in removing endodontic filling material.	*"The results suggested no difference between the two systems' effectiveness at removing filling material."*
(Alsofi et al., 2021)	One Curve (OC) martensitic and One Shape (OS) austenitic	Characterising the differential efficacy of austenitic vs martensitic NiTi rotary files in non-surgical root canal retreatment: a micro-CT analysis.	*"…neither file system could completely remove the filling materials. However, OC resulted in less transportation than OS in the apical one-third ($P < 0.05$). Also, OC resulted from less AHTD than OS but with no statistical difference."*
(Ali et al., 2021)	ProTaper Universal Retreatment, R-Endo system Hedstrom files	Comparative Assessment of Canal Transportation, Dentin Loss, and Remaining Root Filling Material by Different Retreatment Files An In vitro Cross-Sectional Study.	*"No system completely removed the root filling material from root canals. Manual instrumentation resulted in more dentin loss and canal transportation than the rotary file system."*
(Dhaimy et al., 2021)	D-Race system, S1 Reciprocating System.	Efficacy of reciprocating and rotary retreatment nickel-titanium file systems for removing filling materials with	*"Classical removal of canal filling material may not be sufficient for root canal disinfection, although a complementary finishing*

	XP Endo Shaper (complementary approach)	a complimentary cleaning method in oval canals.	*approach improved the results. Nevertheless, all systems left some debris and caused apical extrusion."*
(Ozlek et al., 2021)	ProTaper Universal Retreatment, Protaper Next, Edgefile XR, Edgefile X3	Effectiveness of different rotary file systems in removing the root canal filling material: A micro-computed tomography study	*"There were no significant differences between the groups in the percentage of root canal filling material removal. However, a statistically significant difference was found between the groups in the time required to reach the apex and remove the entire filling material. The time required to remove the root canal filling material was higher in the EdgeFile® X3 group. "*
(Liu H et al., 2021)	XP-endo Shaper, XP-endo Finisher R	Efficacy of XP-endo instruments in removing 54-month-aged root canals filling material from mandibular molars	*" Although the combined use of XPS and XPFR instruments helped remove the bulk of aged root filling material from mandibular molars, material removal from canals filled using warm vertical condensation in the critical apical area remains a concern.* *Clinical Significance: Removal of the aged filling materials using XP-endo instruments from the apical area is challenging when instrumented root canals are filled using warm vertical condensation."*
(Purba et al., 2020)	Protaper Universal Retreatment, Mtwo Retreatment system, R-Endo system, Hedstrom file	Comparative evaluation of retreatment techniques by using different file systems from oval-shaped canals.	*"MTwo® R with solvent and ultrasonics, R-Endo®, and R-Endo® with solvent and ultrasonics were effective in gutta-percha removal from coronal third, middle third, and apical third, respectively. Significance: Non-surgical endodontic retreatment using rotary files helps gain access to infected teeth. During the*

			retreatment procedure, this helps disinfectant to reach critical areas of the root canal system, thereby decreasing the microbial load and achieving healthy periradicular tissues."
(Bago et al., 2020)	ProTaper Next rotary system, Protaper Universal Retreatment + Protaper Gold, Reciproc Blue, Reciproc System.	Evaluation of filling material remnants after essential preparation, apical enlargement and final irrigation in retreatment of severely curved root canals in extracted teeth.	*"The four tested instrumentation systems were equally effective in removing filling materials from curved root canals in extracted teeth. Additional apical enlargement with larger files improved the removal of filling remnants after basic retreatment."*

The NiTi rotary file system design variations lead to differing efficacy levels for performing the required tasks, with differing repercussions upon the intervened molar in terms of microcrack development during root canal preparatory procedures (Singh et al., 2022). Furthermore, the study carried out by Kosti and colleagues in 2006 focused on evaluating the effectiveness of the ProFile NiTi rotary file system in removing GP and several sealer materials from 48 single-rooted human teeth that underwent straight root canal procedures (Kosti et al., 2006). Following treatment using GP and one of four investigated sealers (Endion, Roth 811 and Roekoseal), the teeth were left for 12 months prior to GP / sealer removal using either H-files in conjunction with Gates-Glidden drills or through the utilisation of the ProFile NiTi rotary file system (Kosti et al., 2006). Following GP / sealer removal, the degree of remnant GP and sealer deposits were tracked and visually scored through a stereomicroscope to identify which GP removal methodology was more effective (Kosti et al., 2006). The results of this particular study revealed that H-file and the ProFile NiTi rotary file system both had similar effectiveness in the removal of GP from such root canal intervened teeth, following comparative analysis through the use of statistical significance determining methods such as the Kruskal-Wallis test (Kosti et al., 2006).

Perforation, obstructions, loss of working length, ledging, and fracture of the removal instrument are the primary difficulties that can arise when removing root filling materials. Early investigations on gutta-percha removal utilising various rotary NiTi file systems revealed a greater risk of instrument fracture when compared to hand instruments (Betti & Bramante, 2001)((N. Imura et al., 2000) (Giuliani et al., 2008). Later investigations utilising dedicated retreatment files or in extremely curved canals revealed that fractures are uncommon (Gergi & Sabbagh, 2007), yet they still occurred (Çelik Ünal et al., 2009).

Although mechanical gutta-percha removal devices with NiTi Rotary may be more efficient, rotational NiTi files are susceptible to fracture under certain conditions. However, the occurrence can be decreased with expertise and care, such as by avoiding excessive apical pressure and adhering to the selected rotary device's recommended speed and torque limits (Rossi-Fedele & Ahmed, 2017). However, there is insufficient evidence that any form of landed or non-landed, end-cutting or safe-ended rotary file increases the likelihood of problems (Duncan & Chong, 2008).

c) Gates-Glidden drill

Gates-Glidden (GG) drills have been established within the dental clinic since the early 1990s for their involvement in removing GP from endodontically-intervened extracted dental root canals (Teplitsky et al.,

1992). The GG system adopted a drilling mechanism for GP removal. It was initially identified as more effective in GP removal when compared to the heated plugger methodology at the 3 mm and 5mm dental depth levels (Haddix et al., 1990).

In addition, GG drills are typically involved in dental root canal non-surgical endodontic retreatment procedures in combination with other methodologies, such as H-files or the addition of xylene (for GP softening)(Kasam & Mariswamy, 2016; Kosti et al., 2006). The study conducted by Zuolo and colleagues in 2013 performed a comparative analysis of reciprocating and rotary methodologies for removing GP during root canal endodontic retreatment procedures (Zuolo et al., 2013). In this study, GG drills in combination with stainless steel hand files were compared against the NiTi Mtwo R files and the Reciproc instrument R50 for removing GP from a total of 54 extracted teeth. This study consequently revealed that the GG/hand file method was more effective in GP removal than the Mtwo R file methodology, with a statistically significantly reduced level of GP remnants left within retreated teeth post-procedurally (Zuolo et al., 2013).

d) Ultrasonic Tips

The use of ultrasonic tips for retreatment is reserved chiefly for stiff pastes/types of cement (Patel, 2016). However, the first study analysing the use of ultrasonic-based irrigation in conjunction with other GP removal methodologies, such as ProTaper or Reciproc, was described in 2017 by Gomes and colleagues (Gomes et al., 2017). This investigation probed the effectiveness of four different techniques –ProTaper alone, ProTaper + passive ultrasonic irrigation, Reciproc alone, and Reciproc + passive ultrasonic irrigation – in removing GP from a total of 40 maxillary molars previously treated with root canal preparation/obturation. Ultrasonic activation was carried out through a straight ultrasonic tip once the root canals were fully irrigated with 2.5% sodium hypochlorite and in conjunction with a reduced-power (20%) ultrasonic platform for 3 x 20s cycles. The results of this study, post-analysis of the level of GP remnants left upon root canal walls, demonstrated that the combinatory use of passive ultrasonic irrigation and Protaper or Reciproc systems were more effective than single-method approaches for GP removal (Gomes et al., 2017).

The study by Agrawal and colleagues in 2019 performed a comparative analysis on the effectiveness of three different GP removal methods (ultrasonic retreatment tips, R-Endo retreatment files, and Mtwo retreatment files) for GP and sealer removal within endodontic retreatment procedures from single-root mandibular premolar teeth (Agrawal et al., 2019). Following the stereomicroscopic investigation of such root canals post endodontic retreatment procedure, the ultrasonic retreatment tip method was found to have the most significant level of effectiveness in removing GP and sealer, with the least amount of GP remnant deposits being present on root canals that underwent ultrasonic tip, in comparison to the other probed study groups (Agrawal et al., 2019). Interestingly, ultrasonic tip methodology was also influential in GP removal within oval-shaped root canals and is particularly adept for endodontic retreatment procedures in cases where bioceramic sealers were present (Crozeta et al., 2016).

2. Heat and Chemical GP removal methodologies

a) Heat-based techniques

The condensed gutta-percha root filling may be heated directly with pluggers or heat carriers associated with warm gutta-percha root filling techniques. These hand instruments are heated over an open flame, and heat is delivered to the root filling by placing the instrument on it. This method of delivering heat to the root filling is ineffective. Hot tools must be handled with extreme caution and care to avoid inadvertently harming the patient. A further disadvantage is that the heated instrument begins to cool as soon as it is taken from the flame, necessitating regular warming. Gutta-percha is also a poor heat conductor. Thus only the most superficial layers of the root filling will soften. Electrically heated spreaders or pluggers may soften gutta-percha root filling (Duncan & Chong, 2008).

In addition to more efficient heat transfer, spreaders and pluggers that are electrically heated are more expeditious, simpler, and safer to operate. The spreader or plugger is introduced into the canal, positioned on the root filling, and then activated, eliminating the dangers associated with transporting a heated tool to the patient. When the instrument is withdrawn, any softened gutta-percha adhering to the cooling spreader or plugger will be removed. As stated previously, the remaining gutta-percha in the canal is then removed using either hand or rotary NiTi files. The remaining condensed gutta-percha is then re-softened with heat, and the technique is continued until all the root filling material has been removed.

In order to minimise damage to the periodontal ligament, care must always be taken while utilising a heated device within the root canal to avoid excessive heat. Therefore, the heated tool should only be utilised intermittently and in the straight portion of the root canal (Duncan & Chong, 2008).

b) Chemical-based techniques

In addition to the above-described GP removal techniques, alternative previous and current methods also exist for removing GP, using various chemical / organic solvent-based approaches. Such techniques include chloroform, methyl chloroform, halothane, xylene, eucalyptus oil, turpentine oil, orange oil, and benzene-based GP solvents (Dotto et al., 2021; Friedman et al., 1990; Maria et al., 2021).

However, the main issues with the use of such compounds essentially lie in the risk of hypersensitivity reactions that could be triggered within a selection of patients, together with the issue that several of such compounds, most notably chloroform and halothane, do have narcotic effects and could potentially affect patients that are vulnerable to such potent narcotic drugs (Charlier et al., 2022; Schuur et al., 2004).

In addition, according to microscopic and radiographic evaluations, the solvent used did not contribute to improving hand and rotary files in filling material removal. Solvents may contribute to forming a fine layer of softened gutta-percha that can cause sulcus, isthmus, lateral canals obliteration, and any irregularities that cause difficulty in removing filling material. In addition, chloroform-softened gutta-percha is likely to be distributed throughout the canal, leading to a ‘filmy appearance’ on the canal walls (Dotto et al., 2021; Ma et al., 2012).

Selected Tested File System (Edgefile XR and XP Endo Shaper)

Recent advances in dental technology have led to the development and practical availability of novel rotary files for enhancing efficacy and rapidity in removing GP from root canals before endodontic retreatment procedures. The instrument needs to be able to remove gutta percha in a short amount of time, as patient and operator fatigue may be affected (Taşdemir et al., 2008).

The ideal instrument for endodontic retreatment should permit complete gutta-percha removal in a short period, and no instrument separation occurs. (Azim et al., 2018). Therefore, selecting the proper instrument is crucial to the effectiveness of an endodontic retreatment process.

Recently, XP- endo Shaper and Edgefile XR were released on the market, and local institutions and several workshops have been performed on its widespread application.

However, usage evidence of these file systems is still in its infancy, with a scarcity of reports present in current scientific literature. Only a single study, Ozlek et al. 2021 evaluated Edgefile XR in gutta-percha removal. As stated in the methodology section, the author performs the endodontic retreatment procedure on single cone obturation root-filled teeth (Özlek & Gündüz, 2021a). This process is uncomplicated since there is a space between the gutta-percha and canal wall, resulting in a loose root filling. (Duncan & Chong, 2008). Thus, to establish the tested file's efficacy, the study will involve endodontic retreatment on condensed obturation.

This study proposal focuses on two principal novel methodologies that are gradually becoming essential tools for root canal retreatment procedures and are described in detail below.

1. Edgefile-XR

The American manufacturer Edge Endo developed the Edgefile-XR system, which is composed of a NiTi alloy (FireWire™), which promotes its distortion and strength properties, together with enhancing flexibility, performance, and durability for this specific filing system, thus increasing its efficacy and rapidity in performing during endodontic retreatment procedures (Uzunoglu & Turker, 2016). The Edgefile-XR system consists of four files (R1 - with size 25 and 12% tapered, R2 - size 25 and 8% tapered, R3 - size 25 and 6% tapered, and R4 - having size 25 and 4% tapered) that are typically employed depending upon the crown-down approach (Uzunoglu & Turker, 2016). Each file consists of a fixed-taper and parabolic cross-section, rotating 360 degrees at a speed of 300-350 rpm with a torque of 300 g/cm (Uzunoglu & Turker, 2016).

A recent study compared RT file systems' efficacy in eliminating root canal filling material, using Edgefile X7, ProTaper universal Retreatment, ProTaper Next, and Edgefile X3 (Özlek & Gündüz, 2021b). This study's results revealed no statistically significant variations for all investigated file system efficacy levels in removing root canal filling material from 40 premolar teeth (n=10/group). However, it was suggested that the Edgefile X7 could be an appropriate replacement for the ProTaper Universal Retreatment (Özlek & Gündüz, 2021b).

2. XP-endo Shaper (XPES)

FKG Dentaire introduced the XPES for 3D-based root canal shaping in 2016, consisting of MaxWire® alloy with a 4% taper and an ISO #30 apex, which is capable of phase transition at body temperature, imitating a 'snake-like' shape for expansion and contraction to conform in a bespoke manner onto individual root canal anatomy.

Additionally, XPES has a booster tip featuring six cutting blades for ideal file guidance within the root canal, whereby the tip diameter ranges from size 0.15 to 0.30 (Baranwal et al., 2020). When employed at body temperature, the instrument returns to the shape specified for austenite (800 rpm). Its exceptional flexibility allows it to comprise a taper of up to 8 % and a canal diameter of up to size 0.90, together with a 1% taper and operating with a torque of 100 g/cm minimum, minimising the possibility of developing dentin cracks (Baranwal et al., 2020). In order to address the risk of dentinal microcracks, the study conducted by Bayram and colleagues in 2017 evaluated the level of microcracks created through the employment of the ProTaper Universal, Self-Adjusting File and the XPES upon a total of 40 mandibular premolars (Bayram et al., 2017). This study concluded that the XPES did not introduce any additional dentinal microcracks within straight-root mandibular premolars, acting equivalently to the ProTaper Gold and Self-Adjusting File systems (Bayram et al., 2017). Furthermore, this was further validated through the later study conducted by Kapasi and colleagues in 2020, whereby the XPES system was employed on oval-shaped root canals (Kapasi et al., 2020).

Studies concerning the XPES system's efficacy for removing obturating compounds for root canal RT procedures remain scarce. However, the recent study performed in 2021 focuses on a comparative analysis of XPES against the Reciproc Blue system for their effectiveness in achieving such goals across 30 mandibular premolars (AlOmari et al., 2021). This study determined effectiveness by quantifying debris weight collected following the RT procedure and the overall procedure duration (AlOmari et al., 2021). This investigation demonstrated that the XPES system removed all GP from most root canals, though it had issues when removing sealer compounds (AlOmari et al., 2021).

Molar anatomy complexity and its influence upon non-surgical retreatment within the Malay population

Studies demonstrated that pooled, estimated failure rates for non-surgical retreatment reached approximately 35% (Signor et al., 2021). In addition, molars exhibit a lower percentage success rate in non-surgical retreatment when compared to other teeth (Noboru Imura et al., 2007). This stems mainly from the level of anatomical complexity present within molar teeth, which poses a significant challenge in eliminating root canal infections (Noboru Imura et al., 2007).

In addition, the study carried out by Pan and colleagues in 2019 demonstrated that the prevalence rate for a second mesiobuccal canal reached 36.3% within the first maxillary molar and 8.5% within the second molar among the Malaysian population (Pan et al., 2019). In addition, the mesiobuccal canal exhibits the highest level of root curvature, approximating 78% (Versiani et al., 2019). In addition to this issue, concrete evidence for the existence of a second palatal canal also was recorded to be 0.9% within maxillary first molar, with reports that 63.8% of mesiobuccal canal carry type 1, 28.9% carry type IV, 4.4% carry type II and 1.5% carry type V and III Vertucci classifications(Pan et al., 2019).

Regarding failure rates in non-surgical root canal retreatment procedures in maxillary molars, such anatomical issues are considered the leading causes for inducing such retreatment failures in this patient population (Iqbal, 2016; Olcay et al., 2018).

Cone Beam Computed Tomography (CBCT) in Endodontic Retreatment

According to 3D Imaging in Endodontic by Fayad (2016), “CBCT is a diagnostic imaging modality which provides a three-dimensional image of the maxillofacial region and is capable of providing images at a relatively low dose radiation dose and with a sufficient spatial resolution for application in endodontic diagnosis and planning” (Fayad & Johnson, 2016).

Several studies have demonstrated the drawbacks of using a periapical radiograph in detecting periapical pathosis compared with CBCT. Paula-Silva and colleagues assessed the accuracy of periapical radiograph and CBCT in diagnosing apical periodontitis using histopathological findings as a gold standard (Paula-Silva et al., 2009). Overall, 83 canine tooth roots were examined using periapical radiograph (PR), CBCT and histology (Paula-Silva et al., 2009). Their results showed that PR detected apical periodontitis (AP) in 71% of the root, while CBCT detected AP in 84% of roots, and histology was detected in 93% of the root. In conclusion, the sensitivity was 0.77 for PR and 0.91 for CBCT, suggesting that CBCT is more sensitive and accurate in detecting AP compared to PR, with PR also more likely to miss AP diagnoses when it was present (Paula-Silva et al., 2009).

Another study by Jorge et al. (2008) discovered that post-root canal infection, AP lesion was not found with PR on day 14, while 47% of the samples revealed a lesion on day 21. In AP detection by CBCT evaluation, 33% of samples were found on day 14 and 83% on day 21, respectively (Jorge et al., 2008).

One study compared variations in endodontic planning decisions between CBCT and periapical radiographs (Ee et al., 2014). Three board-certified endodontists participated in reviewing the 30 pre-operative radiographs and CBCT. Diagnosis and treatment planning were then compared in decision-making from periapical radiograph view to CBCT (Ee et al., 2014). Their research noted that there was a difference in treatment plans between the two imaging modalities in 19 of 30 cases (63.3%), 17 of 30 cases (56.6%) and 20 of 30 cases (66.7%) - for examiners 1, 2 and 3, accordingly (Ee et al., 2014). This finding supported the notion that CBCT could provide additional information compared to periapical radiograph, which would be beneficial in changing treatment plans where required (Ee et al., 2014).

The previous investigation proposes various techniques to assess the amount of root canal filling material remaining in the canals after retreatment. These procedures included radiographic inspection, stereomicroscope evaluation, scanning electron microscopy, cone beam computed tomography (CBCT), capturing digital images after longitudinally splitting teeth, cleaning processes, and micro-CT (Sharma et al., 2019).

Previous studies proposed the utility of CBCT imaging to accurately evaluate GP removal levels by determining residual GP volumes within root canal cavities (Marfisi et al., 2015; Pawar et al., 2016). Although micro-computed tomographic imaging provides a better resolution, the presence of a radiopaque substance within the root canal area can also result in beam-hardening artefacts similar to those observed with CBCT imaging, complicating data interpretation (Al-Rawi et al., 2010).

CBCT images may provide critical information for determining the volume of remaining root canal filling material for endodontic retreatment. Yilmaz and colleagues did a recent comparative examination of the accuracy of CBCT images in the volumetric assessment of residual root canal filling material with different voxel sizes against Micro-CT. Two calibrated observers evaluate forty-two retreating root canals of fourteen extracted human maxillary molar teeth using ProMax 3D Max CBCT at three different voxel sizes (0.1mm,0.15mm, 0.2mm). Micro CT readings were used as the gold standard. The study's findings indicate no statistically significant differences between mean residual gutta percha assessed using different CBCT voxel sizes (0.1 mm, 0.15 mm, and 0.2 mm) in contrast to micro-CT data for each observer. Thus, this study established that CBCT image volume measurements are strongly associated with micro CT volume. (Yılmaz et al., 2019).

Additionally, when clinical feasibility is considered, it is evident that CBCT is more suited than micro-CT (Neelakantan et al., 2013). Although root canal filling as a radiopaque substance can produce artefacts in CBCT, these artefacts can be minor with the appropriate machine settings and CBCT parameters. Smaller voxel sizes and narrow field-of-view scans are preferred in order to minimise the presence of artefacts (Brito-Júnior et al., 2014)

CONCLUSION

In root canal retreatment, the removal of the root filling material is an essential step. Most recent research has focused on the effect of modern rotary NiTi files or other revolutionary devices meant to facilitate the removal of gutta-percha. However, regardless of the root-filling substance, the availability of current devices and rotary instruments does not necessitate eliminating existing techniques and hand instruments. There is consensus that it is impossible to clean all of the material predictably, including sealer, even though one of the goals of retreatment is to remove the previously applied root-filling material (Alves et al., 2016; Dhaimy et al., 2021; Liu et al., 2021; Roshdy & AbdelWahed, 2021; Taşdemir et al., 2008).

Theoretically, failure to remove all the previous root filling material could impede chemo-mechanical cleaning of the root canal system and hinder restoring the problems associated with the initial root filling. Consequently, the quest for innovative removal techniques or a root filling material that can be entirely and readily removed continues today.

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