Evaluation of the cleanliness of root canals and the adaptability of root canals filling material after using the XP Endo finisher and passive ultrasonic irrigation during retreatment

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Dedication

To my parents and brothers, the pillars of my life for their endless support and help.

To my wife, for continuous assistance, encouragement and sacrifices throughout the completion of my studies.

To my lovely sons, Rodaina and Jasser

I dedicate this work……

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No.	Abbreviations	Meanings
1	Cl	Cleanliness
2	PUI	Passive Ultrasonic Irrigation
3	XP-F	XP Endo Finisher
4	BS	Bond Strength
5	DOM	Dental Operating Microscope
6	NaOCl	Sodium Hypochlorite
7	n	number
8	C	Control
9	mm	Millimeter
10	cm	Centimeter
11	Ncm	Newton centimeter
12	rpm	rotation per minute
13	EDTA	Ethylene Diamine Tetracetic Acid
14	min	minute
15	s	Second
16	UI	Ultrasonic irrigation
17	H-file	Hedstrom file

18	**SAF**	**Self Adjusting File**
19	**A-phase**	**Austenitic phase**
20	**M-phase**	**Martensitic phase**
21	**SEM**	**Scanning Electron Microscope**
22	**microCT**	**micro Computed Tomograghy**
23	**MPa**	**MegaPascal**
24	**^{o}C**	**Centigrade**
25	**kHz**	**kilohertz**

Introduction

Although root canal treatment has demonstrated a success rate of higher than 90% when properly treated, failure may occur and are often associated with poorly treated canals[1]. These failure are attributed to insufficient cleaning and shaping of the canal, complex canal anatomy, file breakage, perforations, insufficient apical or coronal seal which can result in persistant infection. In case of endodontic failure, retreatment becomes necessary. It can be done non-surgically or surgically, there are some indications of the surgical retreatment in spite of its invasive nature. More recently with technologies like microscopy and ultrasonic, non-surgical retreatment has become more common. Non-surgical retreatment involves the removal of root canal filling material from the root canal system followed by cleaning and shaping and refilling of the canals to ensure a favorable outcome[2].

Several methods can be used to remove the root canal filling materials. The most common root canal filling material is gutta percha combined with sealer. Examples of instruments that can be used to remove gutta percha and sealer are stainless steel hand files, nickel-titanium rotary instruments, heat-bearing instruments[3] that are sometimes used in conjunction with an organic solvents to facilitate softening and removal of the gutta percha and sealer[4]. Another effective method for removal of gutta percha and sealer from the root canal is passive ultrasonic irrigation (PUI), which has been proven to minimize the amount of gutta percha and sealer remnants in the canal even from anatomic areas that are difficult to access[5]. The rapid and continuous movement of irrigant around vibrating files seems to enhance the potential of the irrigant to contact greater surface area of the canal walls[6]. Additionally, acoustic streaming that is created in solutions by ultrasonic activation has been shown to produce sufficient shear forces to dislodge debris from canal walls[7].

Although the efficacy of different methods of removal varies, studies have shown that is almost impossible to remove gutta percha and sealer completely [8-10] especially in curved root canals[9]. This gutta percha and sealer remnants may result in reduced the bond strength between new root canal filling material and root canal walls that be placed after retreatment that may consequently reduce the successful prognosis of the retreatment due to ingress of bacteria and its products in the root canal space.

Recently, a new cleaning instrument has been introduced in the dental market by FKG company called the XP Endo Finisher (XP-F). The company advocates that it can be used to clean canals after conventional cleaning and shaping. According to the manufacturer, once activated, the sickle shape curvature of the instrument will touch a higher percentage of root canal walls than conventional rotary instruments[11] and so clean the canals more and more.

To date, there is no studies have been done to compare the efficacy of the XP-F and PUI with regards to removal of gutta percha and sealer remnants during retreatment and also there is no studies have been done to compare the bond strength of root canal filling material to root canal walls after using the XP-F and PUI during retreatment. The null hypothesis of this study that there in no significant difference between the efficacy of the XP-F and PUI with regards to removal of gutta percha and sealer remnants during retreatment and also there in no significant difference between the efficacy of the XP-F and PUI with regards to the bond strength of root canal filling material to root canal walls after using them during retreatment.

Review of literature

<u>Section Outline:</u>

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Review of literature

2.1. Review of cleanliness studies:

Primary endodontic treatment is generally successful but research have proven that there are varying degree of failure 10%-14%[12-16]. It is obvious that some cases may not respond to primary endodontic treatment. When primary endodontic treatment fails, three treatment options exist: retreatment, periradicular surgery or extraction[17]. Whenever possible the retreatment option is favord to solve the problem because it is the most conservative method[18]. The main objective of retreatment is recreating the pathway to the apical foramina by complete removal of the root canal contents allowing for repeated cleaning and shaping of the root canal system and reobturation[19,20].

2.1.1.Causes of Endodontic Failure:

Primary endodontic treatment failure can result in apical periodontitis, abccess or cyst formation, periradicular bone destruction which may also manifest clinically[21].

The causes of primary endodontic failures are related to the lack of elimination of intracanal endodontic infection[22]. It has been established that there is no technique or instrument that can effectively reach all parts of the root canal space during mechanical preparation[23-28]. Furthermore intracanal endodontic infection may persist after primary endodontic treatment due to procedural errors such as missed canals[21], broken instruments[29] and ledges[30] that prevent complete cleaning and shaping of the canal. Moreover iatrogenic underfilling[31] is also another cause of endodontic failure.

The first step in successful retreatment is the complete removal of the root canal filling material[19,20]. Combination of gutta percha and sealer cement is the most common root canal filling material[32]. Difficulty of its removal depends on the type of the sealer used[33,34].

2.1.2. Methods of removing gutta percha and sealer

Gutta percha and sealer can be removed from the root canal manually using K-files or H-files[24] to engage the bulk of gutta percha and also to dislodge the remnant material from the root canal walls.

Furthermore, different types of rotary instruments have also been suggested to remove gutta percha and sealer such as gates glidden drills[35] and peezo reamer drills[36] that are mainly used to remove gutta percha from the coronal and middle thirds of the canal. Additionally nickel-Titanium (NiTi) rotary instruments have also been suggeted for removal of gutta percha to the full working length even in curved canals[37]. Other NiTi files have even been designed specifically for retreatment purposes for example the ProTaper®Universal Retreatment files and D-Race® files[38].

All previously mentioned methods can be used in combination with different types of chemical solvents to dissolve the gutta-percha and sealer to facilitate its removal from the canal[39], but the main drawback of using these solvents is that they leave a layer of softened gutta percha and sealer on the canal walls and in irregularities of the canals that make it difficult to efficiently clean and disinfect the canal[40,41]. Moreover heat transfer Devices with specific tips have also been used to soften gutta percha and simplify removal like the Endotec[42] and System B[35]. Ultrasonic units with specific tips[43] and lasers i.e. Nd:YAG laser[44] can be used to soften gutta percha and simplify removal.

All these methods remove the bulk of gutta percha and sealer but leave remnants that need adjunctive methods to remove them. These adjunctive methods may be manual or may be machine assisted. Syringe irrigation is a basic irrigation method in endodontic treatment that flushes debris out of the canal[45]. Furthermore brushes have also been used for debridement of the canal walls or agitation of the root canal irrigant such as the NaviTip FX needle[46], Endobrush[47], Ruddle brush[48] and CanalBrush[49]. Another method, the manual dynamic irrigation that utilizes a well-fit gutta-percha master cone pumped up and down in short 2 to 3 mm strokes within the prepared canal to agitate the irrigant in the canal[50]. Additionally the combination of paper points and solvent is a very useful method to remove remnant material, described as "the wicking technique"[41].

Moreover Continuous irrigation systems provide irrigation during preparation of the canal to effectively remove the remnant gutta percha from the canal like self adjusting file[23] (SAF). Several studies reported the pressure alternation device like the EndoVac system to remove remnant material from the canal[51]. Additionally sonic and ultrasonic agitation with special tips were reported to remove the remnant gutta percha effectively from the canal[52-55].

Ultrasonic agitation was first used by Weller et al[55] to describe an irrigation scenario where there was no instrumentation or contact of the canal walls with an endodontic file or instrument that namely described as passive ultrasonic irrigation (PUI). When special ultrasonic tip vibrates freely inside the canal, it generates acoustic streaming and cavitation in the irrigant that effectively remove the debris and intracanal medicament from the canal[56,57] and has also been used to remove remnant gutta percha from the canal[58].

Recently a new cleaning file has been introduced into the dental market by (FKG Dentaire SA, La Chaux-de-Fonds, Switzerland) named as the XP Finisher instrument (XP-F). The company advocates that it can be used to further clean canals after conventional cleaning and shaping, The XP-F is an ISO size #25 instrument with a 0% taper made out of a martensitic alloy (Maxwire alloy). The instrument is straight but once placed into the canal (at body temperature) it reverts to its austenitic phase which is curved. According to the manufacturer, once activated, the curved instrument will clean canals and can touch a higher percentage of root canal walls than conventional rotary instruments[11,59]. It can be used to remove intracanal material remnants from the canals during retreatment [60-62].

2.1.3.Evaluation methods of the cleanliness studies:

There are several methods used to evaluate cleanliness of canals. Optical microscopy such as stereomicroscope, digital microscope, dental loupes and an operating microscope[63] that uses visible light and a system of lenses to magnify images to observe the debris. The tested samples are either sectioned or cleared to facilitate visibility of the canal contents. The limitations of using an optical microscopy that it can't observe details smaller than half of white light's wavelength, or about 0.275 microns, the tested samples are destructed by sectioning or clearing techniques. The Scanning Electron Microscope (SEM) is another method to evaluate cleanliness of canals that is used to magnify details too small for an optical microscopy up to 2000x but its main drawbacks that it needs special costly sample preparation and it is not possible to observe color, only black/white images in addition to destruction of the samples. Furthermore radiography is another method to evaluate cleanliness of canals without destruction the sample. It may be done using digital radiography in 2 dimensional images with its limitation of overlapping the root filling material remnant while Computed Tomograghy (CT) and more accurately micro Computed Tomography (microCT) can provide a qualitative data due to its dealing with the volume of the root filling material remnant. Unfortunately microCT is an expensive equipment and not available in Egypt. Several studies have been established using these different methods.

2.1.4. Cleanliness studies:

A. Optical microscopy studies:

In 2003, **Viducic D et al.**[34] published an article in the international Endodontic Journal evaluating the efficacy of an Nd:YAG laser in removing gutta percha and sealer from root canals with or without using solvents. After retreatment the samples placed on a graduated paper and were examined under binocular loupe (15x) and photograohed using a camera. The samples were evaluated using percentage of gutta percha and sealer remnants covering the canal walls in mm^2. They found that an Nd:YAG laser can remove gutta percha and sealer from root canals either with or without using solvents with no significant difference between groups.

Furthermore, **Ezzie E et al.**[64] in 2006 compared the effectiveness of Profile files with chloroform or the system B device in removing gutta percha and sealer from canals of single rooted teeth using stereomicroscopy (20x) and photograohed using a digital camera for evaluation the amount of gutta percha and sealer remnants using a scoring system. The results demonstrated that there was no significant difference between using the System B or chloroform in combination with Profile files with regard to the removal of gutta percha and sealer from the canals.

Moreover, **Tasdemir T et al.**[65] in 2008 published an article in the International Endodontic Journal comparing the efficacy of the ProTaper Universal rotary system, R-Endo, Mtwo and Hedstrom files in removing gutta percha and sealer from canals of single rooted teeth. The samples were examined using a dental operating microscope (DOM) at 6x and photographed using a digital camera after clearing the teeth. The samples were evaluated using percentage of gutta percha and sealer remnants covering the canal walls in mm^2. The results demonstrated that using the ProTaper Universal rotary system was significantly more effective than the use of Mtwo in terms of the gutta percha and sealer remnants and there was no significant difference found amongst the ProTaper, R-Endo and Hedstrom groups. The latter finding have been related to other results that were reported by **Schirrmeister J et al.**[66] in 2006 and **Takahashi C et al.**[40] in 2009 that found the similarity between rotary files and manual ones with regard to gutta percha and sealer remnants after retreatment. In contrast to **Maciel A. and Scelza M.**[67] in 2006, found that ProTaper system and K3 files were more effective in removing gutta percha and sealer from canals of single rooted teeth than manual files using a stereomicroscopy at 6x and photographed using a digital camera. The samples were evaluated using percentage of gutta percha and sealer remnants covering the canal walls in mm^2. This finding have been related to other results that were reported by **Hulsmann M & Bluhm V**[68] in 2004 and **Saad A et al.**[69] in 2007 that found superiority of rotary files on manual ones in removing gutta percha and sealer from the canals.

Additionally, **de Mello Junior J** et al. in 2009[70] studied the efficacy of using passive ultrasonic irrigation (PUI) and the DOM as adjunctive methods in removing gutta percha and sealer remnants during retreatment from canals of maxillary central incisors. After retreatment, the samples were examined using the DOM with a digital camera at 5x. The samples were evaluated using percentage of gutta percha and sealer remnants covering the canal walls in mm^2. They found that the using of PUI and the DOM resulted in cleaner canals.

Moreover**, Baechtold M et al.** [34] in 2012 studied the efficacy of ProTaper Universal retreatment rotary system in combination with SAF in removing gutta-percha and sealer from the mesiobuccal canals of maxillary first molar teeth. The amount of gutta percha and sealer remnants was evaluated according to a scoring system using stereomicroscope (40x) and photographed using a digital camera. The results showed the additional use of the SAF improved the removal of gutta percha and sealer remnants significantly.

Additionally, **Rios M et al.**[71] in 2014 compared the effectiveness of the ProTaper Universal retreatment rotary system, Reciproc and Wave One in removing gutta-percha and sealer from the canals of maxillary central incisors. The amount of gutta percha remnants was visualized under the DOM (5x) and photographed using a digital camera. The samples were evaluated using percentage of gutta percha and sealer remnants covering the canal walls in mm^2. They found that there was no statistically significant difference between the ProTaper, Reciproc and WaveOne groups. On the other hand **Ozyurek T. and Demiryurek O.**[72] in 2016 evaluated the efficacy of using the ProTaper Universal retreatment rotary system and Reciproc in removing gutta percha and sealer from canals of maxillary central incisors during retreatment using stereomicroscopic analysis at 8x and photographed using a digital camera. The samples were evaluated using the percentage of gutta percha and sealer remnants covering the canal walls in mm^2. The results showed that the ProTaper Universal retreatment rotary system was more effective with a significant difference than Reciproc in removing of gutta percha and sealer from the canals.

Moreover, **Keskin C et al.**[61] in 2017 that evaluated the effect of supplementary use of the XP-F, PUI, EndoActivator, CanalBrush and syringe irrigation in removing calcium hydroxide paste from simulated internal resorption cavities in the canals of single rooted teeth that were visualized under stereomicroscopy at 20x and photographed using a digital camera. The samples were evaluated using a scoring system. The results showed that the XP-F and PUI removed significantly more calcium hydroxide than other groups while similarly to Uygun's study, there was no statistically significant difference between the XP-F and PUI groups.

Furthermore, **Ozyurek T. and Demiryurek O.**[62] in 2016, compared the effectiveness of the XP-F, EndoActivator, PUI, Conventional needle irrigation in removing gutta percha and sealer remnants from the canals of mandibular canine during retreatment. The amount of gutta percha and sealer remnants was evaluated using the percentage of gutta percha and sealer remnants covering the canal walls in mm^2 using stereomicroscopy with a digital camera at 8x. The results showed that there was significantly less gutta-percha and sealer remnants in the XP-F group than in the other groups.

Recently, **Karamifar K et al.**[73] in 2017 evaluated cleanliness of canal walls of mandibular premolars following gutta percha and sealer removal with hand Files, Race and Race plus the XP-F by stereomicroscopic analysis at 6x and photographed using a digital camera. The samples were evaluated using the percentage of gutta percha and sealer remnants covering the canal walls in mm^2. They found that cleanliness of canals in Race plus the XP-F group is better with statistically significant difference.

In 2017, **Bueno C et al.**[74] published an article comparing the efficacy of the ProTaper Universal retreatment system, Reciproc and Wave One with or without using PUI in removing gutta percha and sealer remnants from canals of maxillary incisors during retreatment. In this study the samples were evaluated using the percentage of gutta percha and sealer remnants covering the canal walls in mm^2 that were visualized under the DOM at 5x and photographed using a digital camera. They found that there was no significant difference between all groups and the use of PUI did not improve the removal of gutta percha and sealer remnants from the canals, regardless of the previously used instrumentation systems. They explained that the DOM was used to evaluate the presence of root canal filling material in all groups, and both rotary and reciprocating instruments were used until no material could be seen inside the root canal space under magnification. They concluded that a microscopic evaluation of the remnants, followed by proper procedures for their removal, is an effective way to maintain low levels of residual filling material in straight, short canals with round cross-sections.

B. Scanning Electron Microscopy (SEM) studies:

Scelza M et al [75] in 2008 compare the efficacy of chloroform, orange oil and eucalyptol in removing of gutta percha and sealer from canals of straight maxillary canines using SEM at 500x with calculating the number of dentinal tubules free of filling materials per mm^2 in each group. They found that there was no significant difference between three solvents with regard to removal of gutta percha and sealer from the canals.

Furthermore, **Xu L et al.**[76] in 2012 evaluated the efficacy of ProTaper, K3 and H file in removing of gutta percha and sealer from canals of straight mandibular premolars using SEM with a scoring system. The results showed that H file was more effective significantly than ProTaper and K3 with regard to removal of gutta percha and sealer from the canals. In contrast, **Meyappan R et al** [77] in 2014 compared the efficacy of ProTaper, R Endo, GPX files and H file in removing of gutta percha and sealer from the canal of maxillary central incisors using SEM at 2000x with scoring systems. The results demonstrated that there was no statistically significant difference between ProTaper, R Endo and GPX files while they were more effective than H-file significantly with regard to removing of gutta percha ans sealer from the canals.

In the same year, **Keles A et al** [78] evaluated the efficacy of SAF after using R Endo files in removing of smear layer and filling material remnants from oval canals of maxillary premolars using SEM at 2000x with scoring system. They found that SAF enhanced the cleanliness of canals significantly in middle third only when using after R Endo files while there was no significant difference in coronal and apical thirds with regard to removing of smear layer and filling material remnants from the canals.

Moreover, Busanello F et al. [79] in 2015 evaluated the efficacy of PUI in removing calcium hydroxide paste from root canal of premolars when used for 1, 2 and 3 minutes using scanning electron microscopy at 500x with calculating the percentage of calcium hydroxide remaining in the canals in mm^2. The results showed that there was no significant difference between different lengths of time of PUI in removing calcium hydroxide paste from the canals. They concluded that there was no benefit to extend the time duration of ultrasonic activation more than 1 minute when removing of calcium hydroxide paste from the canals.

Furthermore, **Abdul Lateef A et al** [80] in 2016 evaluated the effectiveness of PUI on the cleanliness of dentinal tubules in curved root canals of maxillary molars with curvature of $15\text{-}30^{o}$ during retreatment with and without solvents using SEM at 2000x with calculating the ratios of number of open tubules / total number of tubules in mm^2. They found that using of PUI without solvent is the best group significantly when compared to PUI+solvent group and groups without PUI.

Additionally, **Bernardes R et al** [81] in 2016 published an article in the International Endodontic Journal comparing the efficacy of ProTaper retreatment system, Reciproc and manual files with gates glidden drills in removing of gutta percha and sealer from canals of mandibular incisors with and without PUI. The samples were evaluated under SEM at 1000x with a scoring system. They found that Rciproc with and without PUI and ProTaper retreatment system with PUI were significantly better than other groups and also found that PUI enhanced significantly cleanliness of the canal from gutta percha and sealer remnants.

Recently, **Turkaydin D et al** [82] in 2017 compared the efficacy of XP-F, PUI and needle irrigation in removing triple antibiotic paste (TAP) from straight canals of immature teeth using SEM at 1500x with a scoring system. They found that XP-F cleaned the canals from TAP more effectively in significant difference than PUI and needle irrigation.

<u>C. Radiography studies:</u>

Ferreira J et al [83] in 2001 compared the efficacy of Profile 0.04 taper and hand files in combination with chloroform in removing gutta percha and sealer from canals with curvatures ranging between 25 and 45^{o}. The samples were evaluated with scoring system using radiography from buccolingual and mesiodistal directions. The results demonstrated that there was no significant difference between Profile 0.04 taper and hand files but Profile is faster than hand files with regard to the removal of gutta percha and sealer from the canals.

Furthermore, **Marifisi K et al** [84] published an article in the international Endodontic journal in 2010 comparing the efficacy of ProTaper Retreatment files, Mtwo Retreatment files and Twisted files in removing of gutta percha/AH plus sealer and Resilon/Real Seal sealer from single root canals. The samples were evaluated under Cone Beam Computed Tomography (CBCT) and a microscope using percentage of filling material remnants covering the canal walls in mm^2 and scoring system respectively. They found regardless method of evaluation used that there was no significant difference between instrumented files with regard to the removal of gutta percha and sealer from the canals regardless the filling material used. Additionally the Resilon/RealSeal sealer remnants were less than gutta percha/AH plus sealer remnants in the canals regardless the instrument used. They concluded that Resilon/RealSeal sealer was easier in removing from canals than gutta percah/AH plus sealer.

Furhtermore, **Rodig T. et al** [85] in 2012 compared the efficacy of D Race, ProTaper Universal Retreatment instruments and H file in removing of gutta percha and sealer from curved root of mandibular molars using mciroCT. The samples were evaluated with percentage of gutta percha and sealer remnants volume in the canals. The results showed that D-RaCe instruments were significantly more effective than ProTaper Universal

Retreatment instruments and H files in removing of gutta percha and sealer from the canals during retreatment.

Concomitantly, **Rechenberg D et al.** [86] studied the impact of cross-sectional root canal shape on efficacy of Profile system in removing of gutta percha and sealer from round canals of maxillary premolars and oval distal canals of mandibular molars using microCT to evaluate the percentage of gutta percha and sealer remnants volume from the canals. They found that significantly less gutta percha and sealer remnants after retreatment in premolars compared with distal canals of mandibular molars. They concluded that there was a high correlation between cross sectional root canal shape and the percentage of gutta percha and sealer remnants volume in the canals after retreatment.

Furthermore, **Cavenago B. et al** [5] in 2014 compared the efficacy of PUI and Xylene in removing gutta percha and sealer remnants from mesial canals of mandibular molars using microCT. They found that there was no significant difference between PUI and Xylene with regard to gutta percha and sealer remnants volume in the canals after retreatment.

Furthermore, **Beshr K. et al** [87] in 2015 compared the efficacy of K3, ProTaper and R Endo files in removing of gutta percha/AH plus sealer, RealSeal points/sealer and EndoRez points/sealer from canals of single rooted mandibular premolars using CT to evaluate the percentage of filling material remnants volume in the canals. The results demonstrated that there was statistically significant difference amongst gutta percha, RealSeal and EndoRez removal from canal walls at apical third only irrespective of the technique used. There was a greater amount of gutta percha/AH plus sealer remnants in significant difference than RealSeal or EndoRez remnants. A greater amount of filling material remnants in the apical third than in the middle and coronal thirds. Also they found only in the apical third that there was statistically significant difference between K3, ProTaper and R Endo files. K3 showed the lowest mean remnants percent.

Moreover, **Alves F et al.**[88] in 2016 compared the effectiveness of reciprocating single instrument system (Reciproc) and a rotary multi instrument system (Mtwo) followed by a supplementary approach with the XP Finisher instrument from canals of mesial roots of mandibular molars using microCT to evaluate the percentage of gutta percha and sealer remnants volume in the canals. They found that the Mtwo system was better than Reciproc in removing of gutta percha and sealer from the canals in significant difference and the XP Finisher enhanced the removal of gutta percha and sealer remnants from the canals.

In 2017, **Silva E et al.**[89] compared the efficacy of XP Finisher and XP Finisher R instruments in removing of gutta percha and sealer remnants from single oval canals using microCT. The samples were evaluated in percentage of volume and surface area of gutta percha and sealer remnants in the canals after retreatment. They found that both types of XP Finisher instruments were highly and similarly effective in removing of gutta percha and sealer remnants from the canals after retreatment.

2.2. Review of the adaptability studies:

2.2.1.Relation between the adaptability and bond strength:

Successful endodontic treatment depends on the complete cleaning and disinfection of the root canal space as well as complete filling and sealing of this space[90]. The physical properties for achieving a complete sealing include adaptation and adhesion of the root canal filling material to the root canal walls[91]. It has been suggested that the ability of the root canal sealers to adhere to the core material and to the root canal walls may result in better sealing ability, prevention of sealer dislodgement under the mechanical stresses that may be caused by operative procedures, tooth flexure and post space preparation leading to reduction of the coronal and apical leakage and consequently success of the endodontic treatment [92-94].

Longevity of the root canal filling material is predicted to some extent by its adhesive ability, and this in turn can be measured by bond strength tests. The push-out bond strength test is a common reliable test for evaluation of the bond strength between the root canal filling material and the root canal walls[95]. This test was initially used to evaluate bonding between bone and orthopaedic implants[96]. Its first application in dental research was to investigate bonding of restorative materials to the coronal dentin[97]. Since then, the test has widely used in endodontic research to evaluate the bond strength of the posts and root canal filling materials to the root canal walls[98].

2.2.2. Factors affecting push out bond strength test:

Many factors influence bond strength test results. These factors may be related to substrate (Dentin) as the presence or abscense of the smear layer and its quality [99,100], dentinal tubules orientation[101], Tooth donor age[102] due to reduction of the dentinal tubules diameter and so on its permeability and also storage conditions and time may affect the bond strength results that it was found that storage the teeth in sodium hypochlorite (NaOCl) resulted in lower bond strengths, while sterilization with the autoclave negatively affected the bond strength [103,104].

There are other factors affect the bond strength results such as specimen size and its relation to the plunger diameter, the thickness of the specimens and also the speed of application the load on the specimens[105].

2.2.3. Push out bond strength studies:

Shokouhinejad N et al.[106] in 2010 evaluated push-out bond strength of Resilon/Epiphany Self-etch to intraradicular dentin after retreatment using Mtwo with or without chloroform and Endosolv R in single rooted teeth. They found that there was no significant difference when root canal retreated using Mtwo files, either alone or combined with Endosolv R from that of nonretreated specimens. Chloroform used for retreatment had an adverse effect on the bond strength of Resilon/Epiphany SE after root canal reobturation.

Furthermore, **Guiotti F et al.**[107] in 2014 found that the calcium hydroxide had adverse effect on the canals that obturated using AH sealer at coronal and apical thirds while it had no significant effect at the middle third of AH group and MTA Fillapex and Sealapex sealers groups. They explained that there was no significant difference in the middle third that the dentinal tubules and collagen fibers in this root third are more homogeneously distributed than in other root thirds.

In the same year, **Rached-Junior F et al.**[108] studied the Impact of remaining zinc oxide-eugenol–based sealer on the bond strength of AH plus sealer to dentin after root canal retreatment in maxillary incisors using different retreatment modalities. The specimens were evaluated using push out bond strength test. They found that there was significantly difference between the specimens that were filled with AH plus sealer after obturation with zinc oxide eugenol sealer and the canals that were filled with AH plus sealer from the first time. They concluded that the zinc oxide eugenol based sealer affects negatively on the bond strength of AH Plus sealer to root canal walls, regardless of the retreatment technique.

Moreover, **Cakici F et al.**[109] in 2016 evaluated the bond strength of AH plus, Acroseal, and Adseal sealers to the root canal dentin in mandibular premolars using the push out bond strength test. The sealers was dispersed firstly using ultrasonic tip then obturation was done. The results demonstrated that there was no significant difference between groups at the middle and coronal thirds while the apical third had significantly higher bond strength values than the middle and coronal thirds regardless the group.

Additionally, **Palhais M et al.**[110] in 2017 studied the influence of xylol, orange oil and eucalyptol solvents on the bond strength of resin sealer to intraradicular dentin after retreatment of maxillary canines using ProTaper Universal rotary retreatment system. The evaluation was done using push out bond strength test. They found that there was no significant difference between ProTaper Universal rotary retreatment system group when used alone or with xylol or orange oil while it differed significantly from the group that retreated with eucalyptol.

Aim of the study

The aim of the study was to evaluate of the cleanliness of root canals and the adaptability of root canals filling material after using the XP Endo finisher and passive ultrasonic irrigation during retreatment.

Materials and Methods

<u>**Section outline:**</u>

4.1. Selection of the teeth.

4.2. Preparation of the teeth and construction of the blocks.

4.3. Cleaning and instrumentation of the canals.

4.4. Grouping of the blocks.

4.5. Cleanliness study:

- **4.5.1. Sectioning and reassembling of the blocks.**
- **4.5.2. Reinstrumentation of the canals.**
- **4.5.3. Obturation of the canals.**
- **4.5.4. Bulk removal of gutta percha and sealer.**
- **4.5.5. Cleaning of the canals:**
  - **A. Cleaning of the canals using the XP Endo Finisher.**
  - **B.Cleaning of the canals using the passive ultrasonic irrigation.**
- **4.5.6. Evaluation of the cleanliness.**

4.6. Adaptability study:

- **4.6.1. Obturation of the canals.**
- **4.6.2. Bulk removal of gutta percha and sealer.**
- **4.6.3. Cleaning of the canals:**
  - **A. Cleaning of the canals using the XP Endo Finisher.**
  - **B. Cleaning of the canals using the passive ultrasonic irrigation.**
- **4.6.4. Reobturation of the canals.**

4.6.5. Evaluation of the adaptability.

4.7. Statistical analysis of the data

4.1. Selection of the teeth

A total of 135 recently extracted single and straight rooted mandibular premolar teeth with apical foramen that opened apically were collected from the outpatient clinic of the Oral Surgery Department, Faculty of Dental Medicine, Al Azhar university. The extracted teeth were selected from patients aged between 20 and 40 years old. They were evaluated under a dental operating microscope (DOM)[1] at 8x magnification to exclude any external defects (immature apices, external root resorption, root perforations or fractures) then radiographs were taken from buccolingual and mesiodistal directions using a digital sensor[2] to exclude any internal defects (internal root resorption, calcified root canals or pulp stones).The root length (under cementoeanamel junction) of the selected teeth were 13 or 14 mm in length. 53 teeth were used in this study while 82 teeth were excluded from the study. The selected teeth were immersed in 5.25% sodium hypochlorite[3] (NaOCl) for 10 mintues for disinfection and dissolution of the soft tissues on the surfaces of the teeth. The selected teeth were then cleaned off calculus and soft tissue remnants using a periodontal curette and then stored in distilled water at room temperature until the time of use in the study.

4.2. Preparation of the teeth and construction of the blocks (n=53)

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[1]Class 1 device, Zumax, China
[2]RVG 5100, Carestream Health, Inc
[3]Colorox, House bleaching agent

Resection of the crowns of the selected teeth was done using a diamond disc mounted in a straight contra hand piece[4] with water coolant. The root portions were adjusted to be 13 mm in length for standardization the working length and to facilitate the instrumentation of the canals. The mesiodistal and buccolingual dimensions of the canals were checked to be smaller than 0.98 mm on the resected root surface using a digital caliper. Canals with dimensions more than that were excluded from the study and replaced with another one. Prior to instrumentation, working length of the canal of the root portion was determined by introducing a size #10 k-file[5] into the canal till it appeared at the apical foramen then substracting 1 mm from this length.

A circular plastic mold **(Figure 1)** (12 cm in diameter and 1.3 cm in thickness) containing 10 square shape holes (1.4 cm in width and length) was fabricated for construction of an acrylic blocks. The sides of the mold were marked according to the root surfaces as buccal, lingual, mesial, distal, coronal and apical sides.

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[4] NSK, Japan

[5] Mani, Inc., Tochigi, Japan

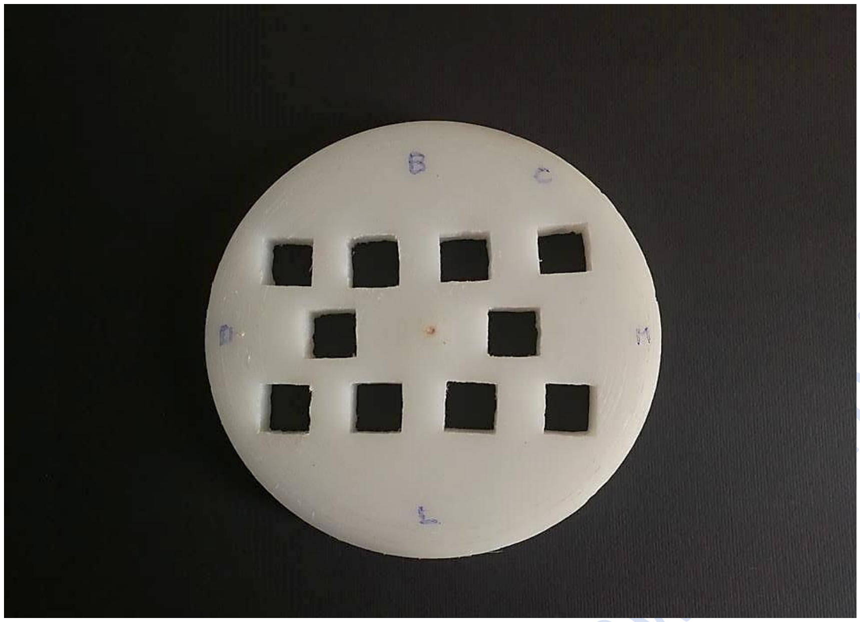

Figure (1): A photograph showing a circular plastic mold.

Then, the mold was placed on a square glass slab (14x14 cm) and separating medium was brushed inside of each square holes. Then, a chemically cured acrylic resin[6] was mixed and poured into the holes of the mold. After that, the root portions were embedded in the soft acrylic resin after covering the exit of apical foramen by wax to prevent entrance of the soft acrylic resin in the canal lumen. The coronal surface of the root portions were flushed with the coronal surface of the mold using a glass slab. The root portions were orientated to be parallel to the corresponding surfaces of the mold.

4.3. Cleaning and instrumentation of the canals (n=53)

Cleaning and instrumentation were done using i-Race rotary nickel titanium files[7]using a torque limited control motor[8] at a torque 1.5 Ncm and

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[6]Acrostone, Egypt
[7]FKG, Dentrie Switzerland
[8] X Smart device, Dentsply Mallifer, USA

speed 600 rpm as recommended by the manufacturer with a sequence R1 (size 15 taper 0.06), R2 (size 25 taper 0.04), R3 (size 30 taper 0.04) then the canals were enlarged using bio-Race[9] with a sequence size 35 taper 0.04, size 40 taper 0.04, size 45 taper 0.02 and finally using size 50 taper 0.04. The canals were irrigated with 2 ml of 5.25% sodium hypochlorite (NaOCl) in between each file using a 30 gauge endodontic irrigating needle[10] placed within 1-2 mm of the working length. After completion of cleaning and instrumentation, the canals were irrigated with 2 ml of 17% EDTA[11] and left for 1 minute and subsequently rinsed with 2 ml of distilled water. Each set of i-Race and bio-Race instruments was used to prepare 5 canals and then discarded. The canals were dried with paper points[12] size 50 taper 0.02.

4.4. Grouping of the blocks

After cleaning and instrumentation of the canals were done, the blocks were divided into two main groups according to the evaluation method used as follow;

Cleanliness group (Cl): (n=14) the canals in this group were evaluated for the cleanliness. This group was subdivided into two subgroups according to the cleaning method of the root canals as follows:

- **Cl_{XP-F} subgroup: (n=7)** the canals in this subgroup were cleaned using the XP Endo Finisher instrument (XP-F).
- **Cl_{PUI} subgroup: (n=7)** the canals in this subgroup were cleaned using the passive ultrasonic irrigation (PUI).

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[9] FKG, Dentrie SA
[10] Max I probe, Dentsply Mallifer, USA
[11] Dentsply Mallifer, USA
[12] Meta Biomed company, Korea

Adaptability group (Ad): (n=39) the canals in this group were evaluated for the adaptability of the root canal filling material to the root canal walls. This group was subdivided into three subgroups according to the cleaning method of the root canals as follows:

- **Ad_{XP-F} subgroup: (n=13)** the canals in this subgroup were cleaned using the XP-F.
- **Ad_{PUI} subgroup: (n=13)** the canals in this subgroup were cleaned using the PUI.
- **Ad_{C} subgroup: (n=13)** the canals in this subgroup had no retreatment procedures representing a positive control group.

4.5. Cleanliness study:

4.5.1. Sectioning and reassembling of the blocks (n=14) (Cl_{XP-F} and Cl_{PUI} subgroups)

After cleaning and instrumentation of the canals were done, the blocks in Cl_{XP-F} and Cl_{PUI} subgroups were sectioned longitudinally in buccolingual direction at the center of the canal to create two halves using isomet 4000[13] **(Figures 2,3 and 4)**.

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[13]Linear Precision Saw, Buehler, Germany

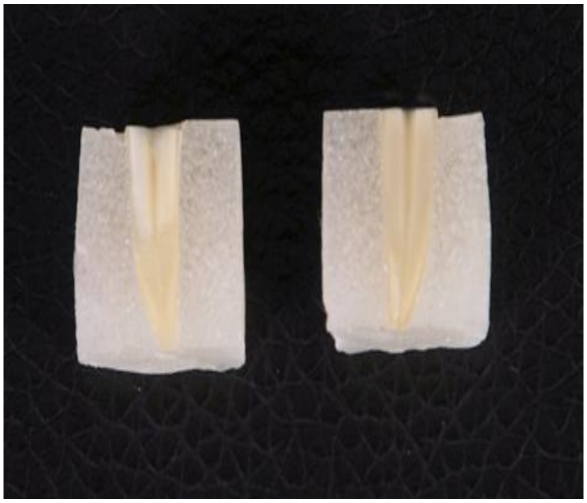


Figure (2): A photograph showing isomet 4000 (linear precision saw) containing acrylic block.

Figure (3): A photogragh showing isomet disc during buccolingual longitudinal sectioning of the block at the midline.

Figure (4): A photograph showing two halves of the block after buccolingual longitudinal sectio ning.

Before reassembling of the block, a special rectangular copper mold was fabricated **(Figure 5)**. It consisted of an external copper rectangular box (external

Figure (5): A photograph showing a copper mold with its screws and plate.

diameter of 23 mm in length and 19 mm in width while internal diameter of 19 mm in length and 15 mm in width respectively) with two screws on one side of the rectangular box that was 19 mm in width in external diameter. Copper plate was fabricated (2 mm in thickness and 15 mm in width) with two shallow depressions that were corresponding to the screws of the rectangular box. The rectangular mold and the plate had the same height of 13 mm. The copper plate was inserted in the rectangular mold next to the side that had two screws while the two shallow depressions facing the two screws, then the two screws of the rectangular box were rotated in clockwise direction to fit in shallow depressions and press the copper plate against the block to prevent any separation of the two halves during further procedures. Then the two halves of the block were reassembled using a small amount of glue[14] at the periphery of each half and quickly mounted the reassembled block in the rectangular copper mold to achieve the most adaptation **(Figure 6)**.

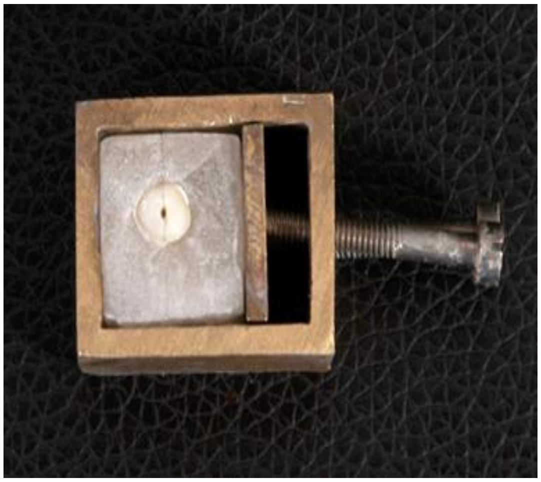


Figure (6): A photograph showing the reassembled block after mounted in the copper mold and held in place using the plate and screws.

[14]Amir alpha glue

4.5.2. Reinstrumentation of the canals (n=14)

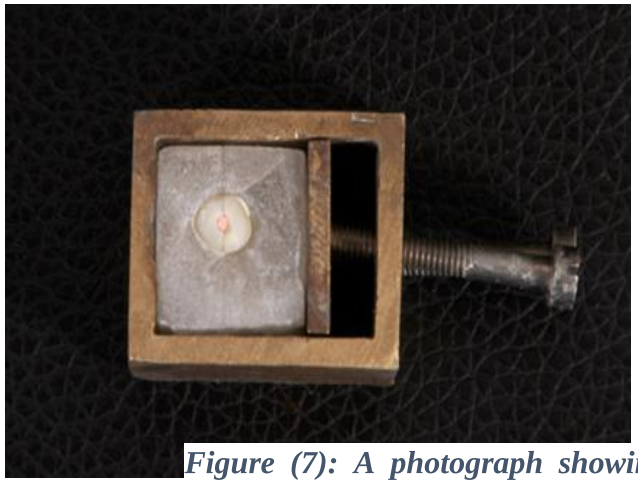


Figure (7): A photograph showing the reassembled block mounted in the copper mold after reinstrumentation of the canal.

After mounting the reassembled block in the rectangular copper mold, the canal was reinstrumented to enlarge again to a master apical file size 50 taper 0.04 **(Figure 7).** The canal was reinsrumented as mentioned previously in **page (26)**. After the reinstrumentation of the canal was completed, the reassembled block was removed from the copper mold to replace with another one.

4.5.3. Obturation of the canals (n=14)

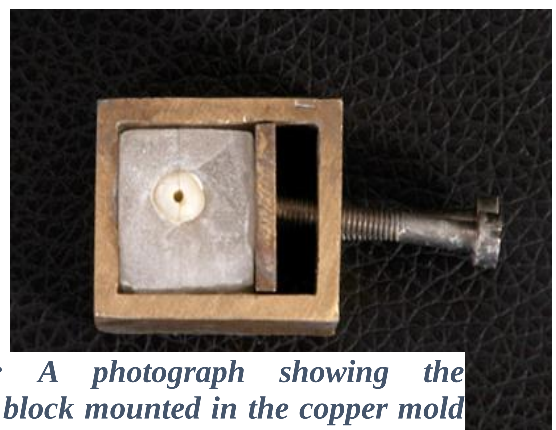


Figure (8): A photograph showing the reassembled block mounted in the copper mold after obturation of the canal.

Before obturation of the canal, the reassembled block was remounted in the rectaugular copper mold. Obturation was accomplished using a master gutta percha cone[15] size 50, taper 0.02 coated with sealer[16]. Lateral compaction was done using a spreader size 50 for master cone and a

[15]Meta Biomed company, Korea
[16]Adsael^{TM}, Meta Biomed company,Korea

spreader size 25, taper 0.02 for accessory gutta percha cones size 25, taper 0.02. Excess coronal gutta percha was removed with a heated plugger **(Figure 8)**. After obturation of the canal was completed, the reassembled block was removed from the rectangular copper mold to replace with another one. The root canal orifice was covered with temporary filling material[17]. Radiographs were then taken from the buccolingual and mesiodistal directions using digital sensor to ensure quality of the obturation. Root with short obturation or not condensed obturation was excluded from the study and was replaced with another one. The blocks were then stored in an incubator at 37^{o}C and 100% humidity for 4 weeks to allow for the complete setting of the sealer. Canals cleaning, instrumentation and obturation were performed by a single operator to avoid interoperator variability.

4.5.4. Bulk removal of gutta percha and sealer (n=14)

After complete setting of the sealer, temporary filling material was removed and the reassembled block was remounted in the rectaugular copper mold then the bulk of gutta percha and sealer was removed from the canal using the D-RaCe retreatment instruments[18] mounted in a torque limited control motor. The instruments were used with a sequence: DR1 (size 30, taper 0.1 at 1000 rpm and 1.5 Ncm) , DR2 (size 25, taper 0.04 at 600 rpm and 1.5 Ncm) then instrumentation of the canals was done using the bio-Race instruments with a sequence : size 30 taper 0.04, size 35 taper 0.04, size 40 taper 0.04, size 45 taper 0.02 and finally using size 50 taper

[17]Orafill, India
[18] FKG, Dentrie SA

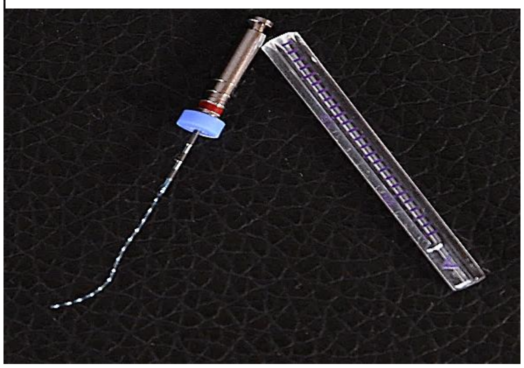
0.04. The canal was irrigated with 2 ml 5.25% NaOCl in between each file. After bulk removal of gutta percha and sealer from the canal was completed, the reassembled block was removed from the rectangular copper mold to replace with another one. In the present study, the DR1 file was used in three canals and DR2 was used in two canal and then discarded.

4.5.5. Cleaning of the canals (n=14)

A. Cleaning of the canals using the XP-F (n=7) ($Cl_{XP\text{-}F}$ subgroup)

The canals in this subgroups were cleaned using the XP-F[19] (size 25, taper zero) **(Figure 9)** mounted in a torque limited control motor. The root canal was filled with warmed 5.25% NaOCl at 37^{o}. XP-F was operated in the canal at 800 rpm and 1 Ncm as recommended by manufacturer's instructions up to the full working length. The reassembled blocks were placed in a water bath at 37^{o}C to intimate the clinical setting that make the XP-F instrument in austenitic phase with its specific sickle shape. The XP- F was applied for 30 seconds within the canal in a slow up and down motion, the canal was then flushed with 3 ml of warmed 5.25% NaOCl and it was applied again for 30 s using the same method with flushing another 3ml of warmed 5.25% NaOCl. A total of 6 ml of warmed 5.25% NaOCl was used and the total activation time was 1 min then paper points (size 50, taper 0.02) were used to dry the canal. Each instrument was used to clean 5 canals then it was discarded.

Figure (9): A photograph showing the XP Endo Finisher out of its plastic sheath.



[19] FKG, Dentrie SA

B. Cleaning of the canals using the passive ultrasonic irrigation (n=7) (Cl_{PUI} subgroup)

The canals in these subgroups were cleaned using the PUI. Irrisafe instrument[20] #25/21 mm **(Figure 10)** was mounted on an ultrasonic unit[21] to use in the PUI. The blocks were placed in a water bath at 37°C to standardize the study conditions with the Cl_{XP-F} subgroup. The root canal was filled with warmed 5.25% NaOCl at 37° and the tip of the irrisafe was inserted into the canal to the full working length and activated for 30 s. The irrisafe tip was moved in a slow up and down motion using a power setting of 5 according to manufacturer's recommendations. The canal was then flushed with 3 ml of warmed 5.25% NaOCl and activated using the same method for 30 s again with flushing another 3ml of warmed 5.25% NaOCl. A total of 6 ml of warmed 5.25% NaOCl was used, and the total activation time was 1 min. then paper points (size 50, taper 0.02) were used to dry the canal. Each instrument was used to clean 5 canals then it was discarded from the study.

Figure (10): A photograph showing the irrisafe tip.

4.5.6. Evaluation of cleanliness (n=14)

Prior to evaluation, each block in these subgroups was separated manually into the previous two halves. An image of each root half was captured at 30x using a digital microscope[22] **(Figure 11)**, and the amount of remnants in the

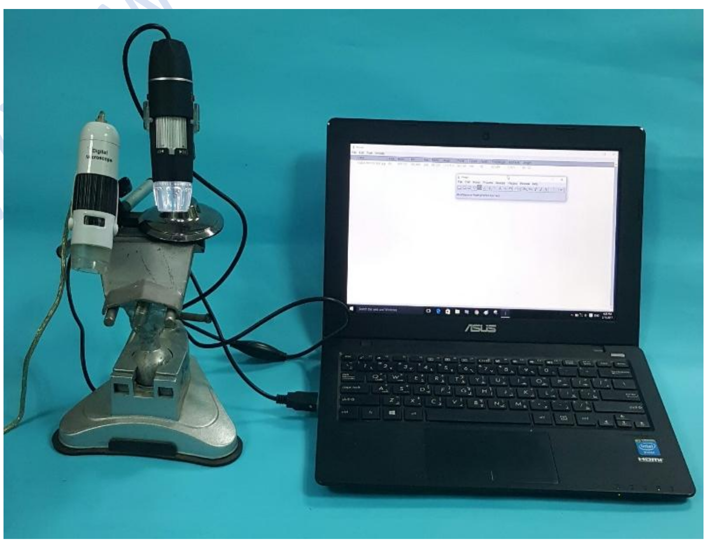
[20] Acteon, France
[21] Suprasson P5 Booster, France
[22] Scope capture, guandong, China

canal was quantified using the NIH Image J V1.56 software program[23]. This program allowed transformation of the canal contents to black or white pixels, which were then counted and compared. The remnants were expressed as a percentage of the canal lumen area at each root third i.e. coronal, middle and apical.

Figure (11): A photograph showing a digital microscope.

4.6. Adaptability study:

4.6.1. Obturation of the canals (n=39) (all Ad subgroups)



[23] Image J 1.43U, National Institute of Health, USA

Obturation was accomplished as previously mentioned in cleanliness study using a master gutta percha cone[24] size 50, taper 0.02 coated with sealer[25] using lateral compaction technique and accessory gutta percha cones size 25, taper 0.02. The blocks were then stored in an incubator at 37^{o}C and 100% humidity for 4 weeks to allow for the complete setting of the sealer.

4.6.2. Bulk removal of gutta percha and sealer (n=26) (Ad$_{XP-F}$ and Ad$_{PUI}$ subgroups)

After complete setting of the sealer, temporary filling material was removed and the bulk of gutta percha and sealer was removed from the canal using the D-RaCe retreatment instruments[26] and BioRace files as previously mentioned in cleanliness study.

4.6.3. Cleaning of the canals (n=26) (Ad$_{XP-F}$ and Ad$_{PUI}$ subgroups)

A. Cleaning of the canals using the XP-F (n=13) (Ad$_{XP-F}$ subgroup)

The canals in this subgroup were cleaned using the XP-F with a total flushing of 6 ml of warmed 5.25% NaOCl at 37^{o} and the total activation time 1 min as previously mentioned.

B.Cleaning of the canals using the PUI (n=13) (Ad$_{PUI}$ subgroup)

The canals in these subgroups were cleaned using PUI with a total flushing of 6 ml of warmed 5.25% NaOCl at 37^{o} and the total activation time 1 min as previously mentioned.

4.6.4. Reobturation of the canals (n=26) (Ad$_{XP-F}$ and Ad$_{PUI}$ subgroups)

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[24]Meta Biomed company, Korea
[25]Adsael^{TM}, Meta Biomed company,Korea
[26] FKG, DentrieSA

After cleaning of the canals, they were reobturated with a master gutta percha cone size 50, taper 0.02 that was coated with sealer using lateral compaction technique and accessory gutta percha cones size 25, taper 0.02 as previously mentioned. The blocks were then stored in an incubator at 37°C and 100% humidity for 4 weeks to allow for the complete setting of the sealer.

4.6.5. Evaluation of the adaptability (n=39) (all Ad subgroups)

After complete setting of the sealer, the specimens were prepared to evaluate the adaptability of the root filling material to the root canal walls using the push out bond strength test. They were sectioned using isomet 4000 **(Figure 12)**. Sections were prepared at 3 mm, 6 mm and 9 mm from the apical side of the block to produce 3 specimens slice of 2 mm thickness each for representing the apical, middle and coronal thirds of the canal respectively.

Figure (12): A photograph showing isomet disc during horizontal sectioning of the block.

After sectioning, each specimen slice was marked from both sides to determine the apical and coronal sides with a marker. Then each specimen slice was photographed from both sides using a digital microscope to measure the apical and coronal radii using image analysis software. After mounting in loading fixture, each specimen slice was subjected to compressive loading via a computer controlled materials testing machine[27] **(Figures 13,14)** with a load cell of 5kN and data were recorded using computer software[28] and loaded at a crosshead speed of 0.5 mm/min. Load applied by a plungers of different sizes (0.5 mm for apical and middle specimens & 0.7 mm for coronal specimen) in an apico-coronal direction (toward the larger diameter), thus avoiding any limitation to the root canal filling movement possibly owing to the canal taper. The selected diameter of the plunger was positioned so that it only contacts the root canal filling material to displace it downward. This way, it was guaranteed that the overlaying root dentin was sufficiently supported during the loading process.

Figure (13): A photograph showing Instron testing machine.

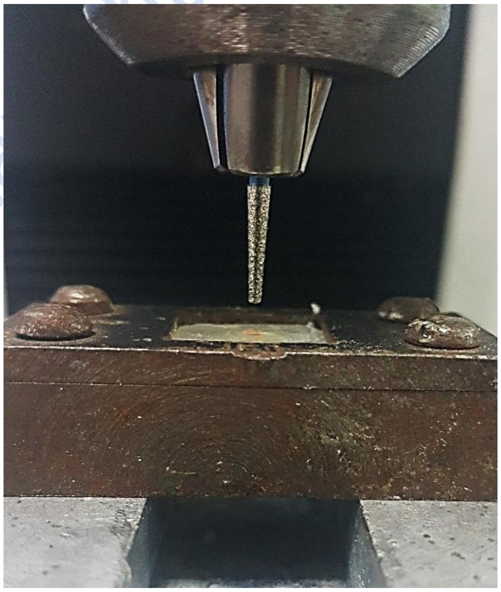

Figure (14): A photograph showing a specimen slice when it was tested using Instron testing machine.

The maximum failure load was recorded in N and converted into MPa. The bond strength was calculated from the recorded peak load divided

[27] Model 3345; Instron Industrial Products, Norwood, MA, USA
[2828] Blue hill Lite Software; Instron®

by the computed surface area [as calculated by the following formula (Lopes et al. 2010[29]): **Bond strength (MPa) = F/A**

Where **F** is the load recorded in Newton

And **A** is the bonding surface area

The bonding surface area was calculated from the following formula:

$$[A = (\pi h (r_1+r_2)],$$

Where, π is the constant 3.14, r_1 apical radius, r_2 coronal one and **h** is the thickness (height) of the sample in millimeters

Failure manifested by extrusion of root canal filling material and confirmed by sudden drop along load-deflection curve recorded by computer software[30].

4.7. Statistical analysis of the data.

Data analysis was performed in several steps. Initially, descriptive statistics for each subgroup results. One way ANOVA followed by pair-wise Tukey's post-hoc tests were performed to detect significance between main subgroups (in push out bond strength test results) and root thirds. Student t-test was done between main subgroups in cleanliness test results. Two-way ANOVA was done to detect effect of each variable (Subgroup & thirds) using Microsoft excel. Statistical analysis was performed using Grapg-Pad Instat statistics software for Windows (www.graphpad.com). P values < 0.05 are considered to be statistically significant in all tests.

[29] Lopes G., Ballarin A., Baratieri L.: Bond strength and fracture analysis between resin cements and root canal dentin. Aus Endod J; 2010:1-7
[30] Bluehill Lite Software; Instron®

Results

<u>Section outline:</u>

5.1. Cleanliness study results:

5.1.1. Comparison between the corresponding root thirds in each cleaning method subgroup.

5.1.2. Comparison between different cleaning methods subgroups in each root third.

5.1.3. Comparison between different cleaning methods subgroups through whole root canal length.

5.2. Adaptability study results:

5.2.1. Comparison between the corresponding root thirds in each adaptability subgroup.

5.2.2. Comparison between different adaptability subgroups in each root third.

5.2.3. Comparison between different adaptability subgroups through whole root canal length.

5.1.Cleanliness study results:

5.1.1.Comparison between the corresponding root thirds in each cleaning method subgroup:

Data in this section was statistically analyzed using one way ANOVA test. For pair wise comparison, Tukey's post hoc test was used. The mean and standard deviation values of percentage of gutta percha and sealer remnants for each cleaning methods subgroups and its root thirds are summarized in **table (1)** and graphically drawn in **figure (15)**.

$Cl_{XP\text{-}F}$ subgroup:

The results showed that the highest mean ± SD value of percentage of gutta percha and sealer remnants was recorded at the **middle third** (27.307±5.196 %) followed by **apical third** (26.689±7.044 %) while the lowest mean ± SD value was recorded at the **coronal third** (24.449±2.828 %) with no statistically significant difference among the root thirds (P value =0.7651 > 0.05) as shown in **table (1)** and in **figure (15)**.

Cl_{PUI} subgroup;

The results showed that the highest mean ± SD value of percentage of gutta percha and sealer remnants was recorded at the **apical third** (32.833±4.637 %) followed by **middle third** (28.218±4.159 %) while the lowest mean ± SD value was recorded at the **coronal third** (23.563±5.768 %) with statistically significant difference among the root thirds (P value = 0.0423 < 0.05) while there was no significant difference (p>0.05) between

coronal and **middle** thirds and also between **apical** and **middle** thirds as shown in **table (1)** and in **figure (15)**.

Table (1) The mean values ± SDs of percentage of gutta percha and sealer remnants for the corresponding root thirds in each cleaning method subgroup

Variables		**Root third**			**ANOVA**
		Coronal	**Middle**	**Apical**	**P value**
Subgroup	**Cl_{XP-F}**	24.449_a^A±2.828	27.307_a^A±5.196	26.689_a^A±7.044	**0.7651ns**
	Cl_{PUI}	23.563_a^B±5.768	28.218_a^{AB}±4.159	32.833_b^A±4.637	**.0423 ***
t-test	**P value**	**0.7721 ns**	**0.7715 ns**	**0.021 ***	

Different large letter in the same row indicating statistically significant difference of the root third

Different small letter in the same column indicating statistically significant difference of the subgroup

*; significant (p < 0.05) ns; non-significant (p > 0.05)

5.1.2. Comparison between different cleaning methods subgroups in each root third:

Coronal third: The results showed that the highest mean ± SD value of percentage of gutta percha and sealer remnants was recorded with **Cl_{XP-F} subgroup** (24.449±2.828%) while the lowest mean ± SD value was recorded with **Cl_{PUI} subgroup** (23.563±5.768%) with no statistically significant difference among two cleaning methods subgroups at the coronal third (P value =0.7721 > 0.05) as shown in **table (1)** and in **figure (15)**.

Middle third:

The results showed that the highest mean ± SD value of percentage of gutta percha and sealer remnants was recorded with **Cl_{PUI} subgroup** (28.218±4.159 %)while the lowest mean±SD value was recorded with **Cl_{XP-F} subgroup** (27.307±5.196 %) with no statistically significant difference among two cleaning methods subgroups at the middle third (P value =0.7715 > 0.05) as shown in **table (1)** and in **figure (15)**.

Apical third:

The results showed that the highest mean ± SD value of percentage of gutta percha and sealer remnants was recorded with **Cl_{PUI} subgroup** (32.833±4.637 %)while the lowest mean±SD value was recorded with **Cl_{XP-F} subgroup** (26.689±7.044%) with statistically significant difference among two cleaning methods subgroups at the apical third(P value =0.021 > 0.05) as shown in **table (1)** and in **figure (15)**.

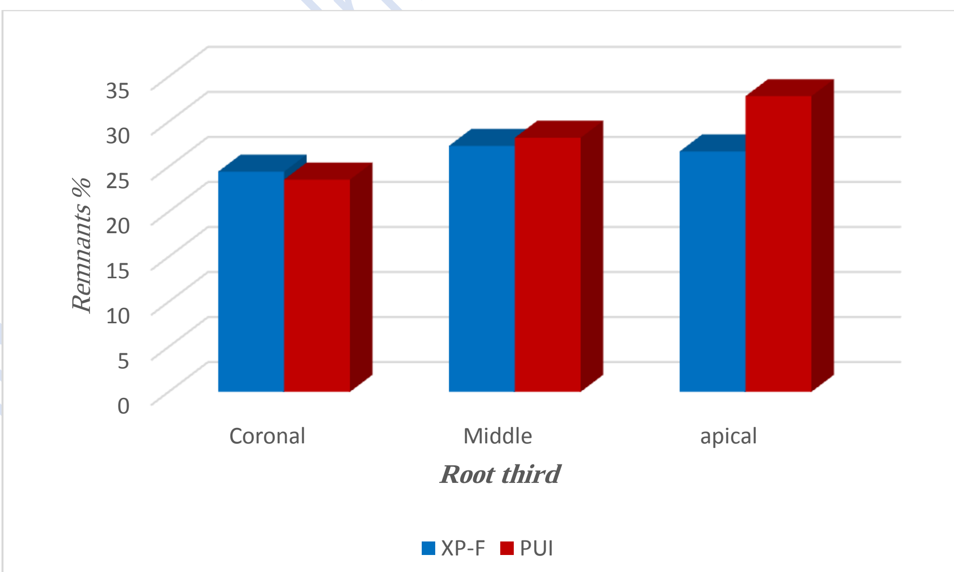

Figure (15) A histogram showing the mean values of percentage of gutta percha and sealer remnants for different cleaning methods subgroups in each root third

5.1.3. Comparison between different cleaning methods subgroups through whole root canal length:

Regardless to root third, the results showed that the highest mean ± SD value of percentage of gutta percha and sealer remnants was recorded with **Cl_{PUI} subgroup** (28.205±3.094 %) while the lowest mean ± SD value was recorded with **$Cl_{XP\text{-}F}$ subgroup** (26.148±1.133 %) with no statistically significant difference among two cleaning methods subgroups (P value =0.3473>0.05) as shown in **table (2)** and in **figure (16)**.

Table (2) The total mean values ± SDs of percentage of gutta percha and sealer remnants for different cleaning methods subgroups through whole root canal length

Variables		**Mean ± SDs**	**Rank**	**Statistics**
Subgroup	**$Cl_{XP\text{-}F}$**	**26.148±1.133**	A	**P value**
	Cl_{PUI}	**28.205±3.094**	A	**0.3473 ns**

Different letter in the same column indicating statistically significant difference ($p < 0.05$)
*; significant ($p < 0.05$) ns; non-significant ($p>0.05$)

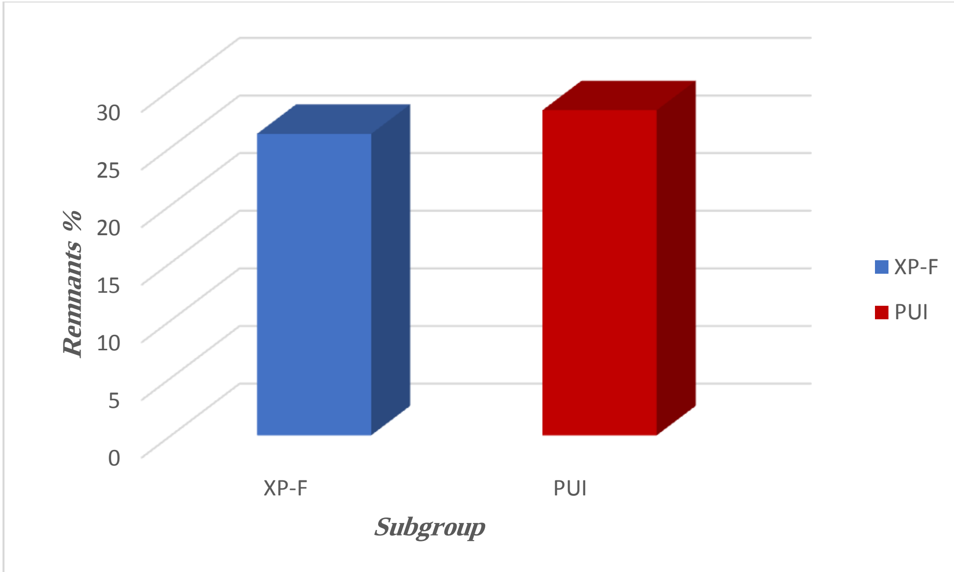

Figure (16) A histogram showing the total mean values of percentage of gutta percha and sealer remnants for different cleaning methods subgroups through whole root canal length

5.2. Adaptability study results:

5.2.1. Comparison between the corresponding root thirds in each adaptability subgroup:

Data in this section was statistically analyzed using one way ANOVA test. For pair wise comparison, Tukey's post hoc test was used. The mean values and standard deviation of push out bond strength test results for all subgroups and their root thirds are summarized in **table (3)** and graphically drawn in **figure (17)**.

Ad $_{XP\text{-}F}$ subgroup:

The results showed that the highest mean ± SD value of push out bond strength was recorded at the **coronal third** (10.949±2.22 MPa) followed by the **apical third** (10.581±1.84 MPa) while the lowest mean ± SD value was recorded at the **middle third** (6.892±1.22 MPa) with statistically significant difference among the root thirds (P value = <0.0001<0.05) while there was no statistically significant difference (p>0.05) between **coronal** and **apical** thirds as shown in **table (3)** and in **figure (17)**.

Ad$_{PUI}$ subgroup:

The results showed that the highest mean ± SD value of push out bond strength was recorded at the **coronal third** (9.421±0.818 MPa) followed by **apical third** (8.609±1.467 MPa) while the lowest mean ± SD value was recorded at the **middle third** (5.892±0.830 MPa) with statistically significant difference among the root thirds (P value=0.0007<0.05) while there was no significant difference (p>0.05) between **coronal** and **apical** thirds as shown in **table (3)** and in **figure (17)**.

Ad$_C$ subgroup;

The results showed that the highest mean ± SD value of push out bond strength was recorded at the **apical third** (12.348±3.41 MPa) followed by **coronal third** (9.641±1.621 MPa) while the lowest mean ± SD value was recorded at the **middle third** (7.645±1.81 MPa) with statistically significant difference among the root thirds (P value = 0.0013<0.05) while there was no significant difference (p>0.05) between **coronal** and **apical** thirds and between **coronal** and **middle** thirds as shown in **table (3)** and in **figure (17)**.

Table (3) The mean values ± SDs of bond strength for the corresponding root thirds in each adaptability subgroup

Variables		Root third			ANOVA
		Coronal	Middle	Apical	P value
Subgroup	**Ad_{XP-F}**	10.949^{A}_{a}±2.22	6.872^{B}_{ab}±1.22	10.581^{A}_{ab}±1.84	**<0.0001***
	Ad_{PUI}	9.421^{A}_{a}±0.818	5.892^{B}_{b}±0.83	8.609^{A}_{b}±1.467	**0.0007***
	Ad_{C}	9.641^{AB}_{a}±1.621	7.645^{B}_{a}±1.81	12.348^{A}_{a}±3.41	**0.0013***
ANOVA	**P value**	**0.1484 ns**	**0.0404***	**0.0125***	

Different large letter in the same row indicating statistically significant difference of the root third
Different small letter in the same column indicating statistically significant group difference of the subgroup

*; significant ($p < 0.05$) ns; non-significant ($p>0.05$)

5.2.2. Comparison between different adaptability subgroups in each root third:

Coronal third:

The results showed that the highest mean ± SD value of push out bond strength was recorded with **Ad $_{XP-F}$ subgroup** recorded (10.949±2.22 MPa) followed by **Ad $_{C}$ subgroup** (9.641±1.621 MPa) while the lowest mean ± SD value was recorded with **Ad $_{PUI}$ subgroup** (9.421±0.818 MPa) with no statistically significant difference among the adaptability subgroups at the coronal third (P value = 0.1484>0.05) as shown in **table (3)** and in **figure (17).**

Middle third:

The results showed that the highest mean ± SD value of push out bond strength was recorded with **Ad_C subgroup** (7.645±1.81 MPa) followed by **Ad_{XP-F} subgroup** (6.872±1.22 MPa) while the lowest mean ± SD value was recorded with **Ad_{PUI} subgroup** (5.892±0.830 MPa) with statistically significant difference among the adaptability subgroups at middle third (P value = 0.0404<0.05) while there was no significant difference (p>0.05) between **Ad_{XP-F}** and **Ad_{PUI} subgroups** and also between **Ad_{XP-F}** and **Ad_C subgroups** as shown in **table (3)** and in **figure (17).**

Apical third:

The results showed that the highest mean ± SD value of push out bond strength was recorded with **Ad_C subgroup** (12.348±3.41 MPa) followed by **Ad_{XP-F} subgroup** (10.581±1.84 MPa) while the lowest mean ± SD value was recorded with **Ad_{PUI} subgroup** (8.609±1.467 MPa) with statistically significant difference among the adaptability subgroups at apical third (P value = 0.0125<0.05) while there was no significant difference (p>0.05) between **Ad_{XP-F}** and **Ad_{PUI} subgroups** and also between **Ad_{XP-F}** and **Ad_C subgroups** as shown in **table (3)** and in **figure (17).**

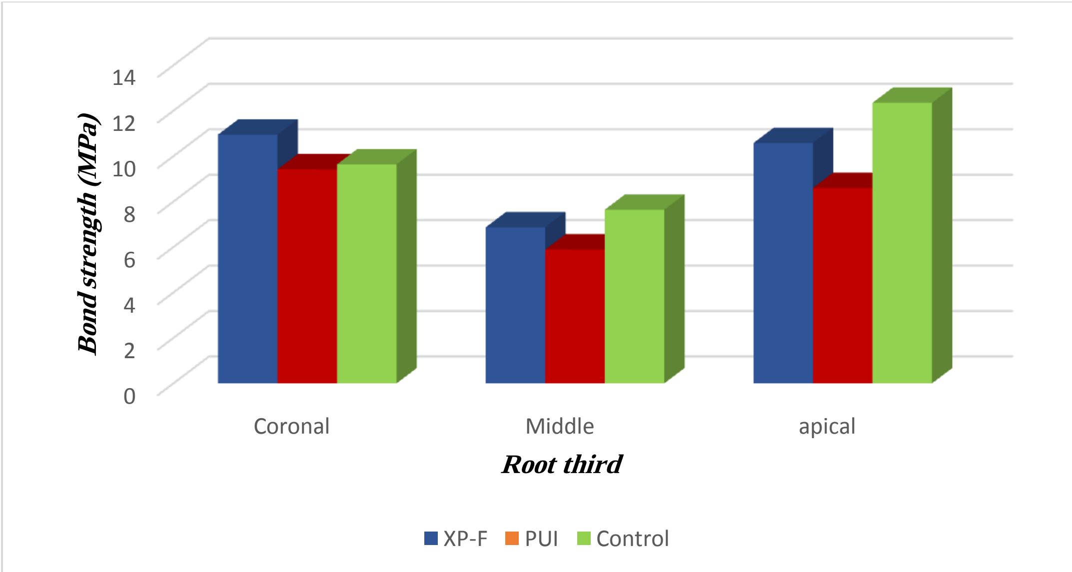

Figure (17) A histogram showing mean values of bond strength for different adaptability subgroups in each root third

5.2.3. Comparison between different adaptability subgroups through whole root canal length:

Regardless to root thirds, the results showed that the highest mean ± SD value of push out bond strength was recorded with **Ad_C subgroup** (**9.878±1.647** MPa) followed by **$Ad_{XP\text{-}F}$ subgroup** (**9.467±1.731** MPa) while the lowest mean ± SD value was recorded with **Ad_{PUI} subgroup** (**7.793±1.387** MPa) with statistically significant difference among the adaptability subgroups (P value = 0.0086<0.05) while there was no significant difference (p>0.05) between **$Ad_{XP\text{-}F}$** and **Ad_C subgroups**. as shown in **table (4)** and in **figure (18)**.

Table (4) The total mean values ± SDs of bond strength for different adaptability subgroups through whole root canal length

Variables		Mean ± SDs	Rank	Statistics
Subgroup	**Ad_{XP-F}**	**9.467±1.731**	A	**P value**
	Ad_{PUI}	**7.973±1.387**	B	**0.0086***
	Ad_{C}	**9.878±1.647**	A	

Different letter in the same column indicating statistically significant difference ($p < 0.05$)

*; significant ($p < 0.05$) ns; non-significant ($p>0.05$)

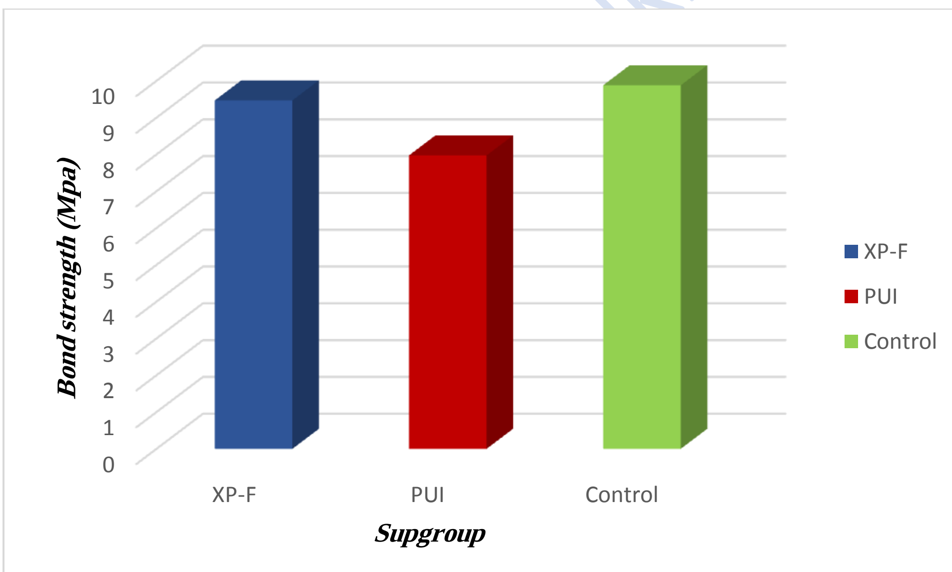

Figure (18) A histogram showing the total mean values of bond strength for different adaptability subgroups through whole root canal length

Figure (19): A photograph showing two halves of specimen in Cl_{XP-F} subgroup that was magnified at 30x

Figure (20): A photograph showing two halves of specimen in Cl_{PUI} subgroup that was magnified at 30x

Figure (21): A photograph showing the coronal view of the $Ad_{XP\text{-}F}$ specimens after extrusion of the root canal filling material.

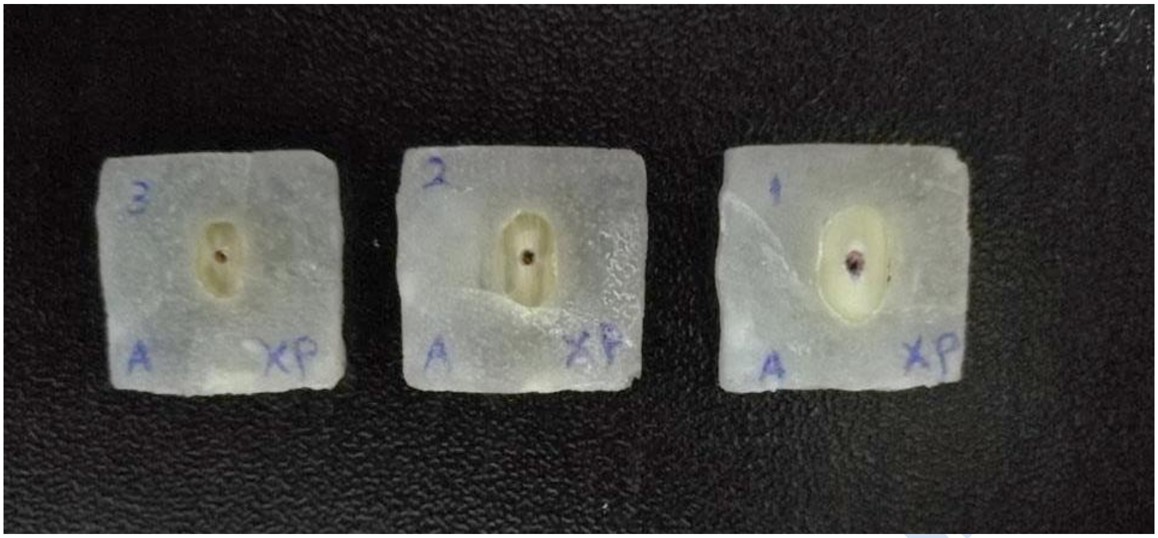

Figure (22): A photograph showing the apical view of the $Ad_{XP\text{-}F}$ specimens after pushing of the root canal filling material.

Figure (23): A photograph showing the coronal view of the Ad_{PUI} specimens after extrusion of the root canal filling material.

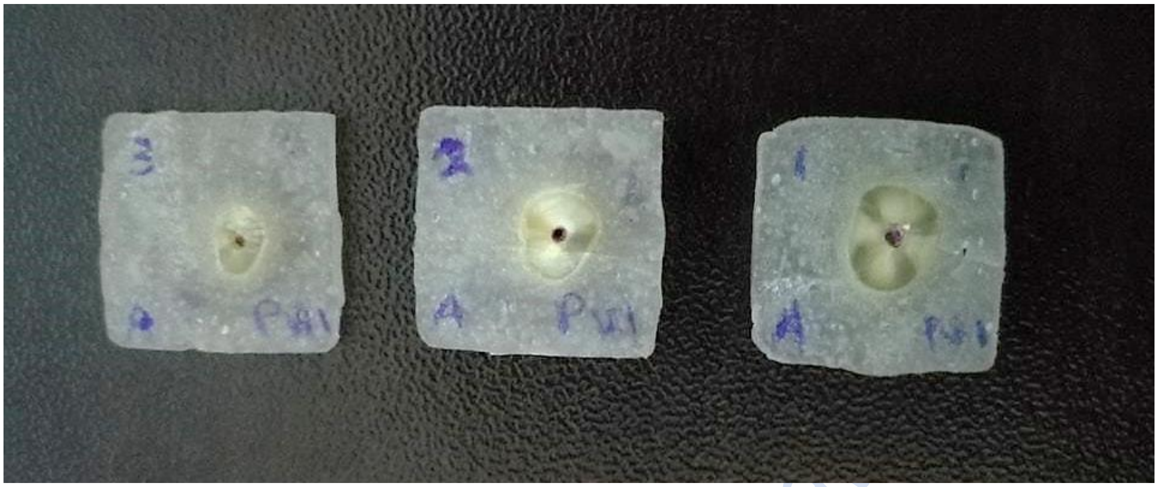

Figure (24): A photograph showing the apical view of the Ad$_{PUI}$ specimens after pushing of the root canal filling material.

Figure (25): A photograph showing the coronal view of the Ad$_{C}$ specimens after extrusion of the root canal filling material.

Figure (26): A photograph showing the apical view of the Ad_C specimens after pushing of the root canal filling material.

Discussion

For successful endodontic retreatment, it is mandatory to remove as much root canal filling material as possible to allow access to residual necrotic tissue and bacteria that might be responsible for root canal treatment failure[111,112]. There are different methods used to remove root canal filling materials during retreatment [24,35,38,39] and other adjunctive methods to remove the remnants [45,50,56]. However several studies have proven that there is no method that can remove all root canal filling material from the canal[25,28,73,87]. Furthermore efficient removal of the old root canal filling material from retreated canals will probably improve the adaptability of the new root canal filling material to the root canal walls by ensuring a clean surface. This study was done to evaluate the cleanliness of root canals and the adaptability of root canal fillings after using the XP Endo finisher and passive ultrasonic irrigation during retreatment.

A total of 135 recently extracted mandibular premolars were collected, 82 premolars were excluded and 53 premolars were used in the study **(Table 7)**. Mandibular premolars were selected for ease of standardization because they commonly have a single straight canal in a bulky root. This is similar to other research done in this field[73,87]. The teeth were collected from patients with ages ranging between 20 and 40 years to minimize variation in dentin nature as a result of secondary and sclerotic dentin deposition[113]. The crowns of the premolars were removed to standardize the reference point and to facilitate the instrumentation of the canals. The root portions were adjusted to be 13 mm in length for standardization the working length. The mesiodistal and buccolingual dimensions of the canal lumen were measured on the resected root surface with a digital caliper. Root portions with canal lumens with dimensions larger than 0.98 mm were excluded from the study and replaced with other ones **(Table 7)**. This dimension (0.98 mm) is equal to the diameter of the master apical file at D12.

Table (7): Different causes and amounts of excluded teeth within the study.

Cause of exclusion	Amount
Fracture lines on the root surfaces	3
Roots more than 14 mm in length	17
Apical Foramen that opens laterally	13
Canals other than type I (Vertucci's classification)	4
Calcified canals	2
Internal root resorption	1
MD and BL dimensions more than 0.98 mm	39
Apical perforation during instrumentation	3
Total	**82**

The i-Race, Bio-Race and D-Race systems were used for insrumentation and retreatment of the canals because they are readily available and they have proven to be effective[73,62,81]. Canals were enlarged to a size #50 taper 0.04 because during specimen sectioning, a lumen size smaller than this would have resulted in complete obliteration of the canal space. Furthermore, this diameter was chosen so that the apical part of the canal was enlarged enough to correspond to the available plunger size during evaluation of the adaptability.

When preparing specimens for cleanliness evaluation, sectioning and reassembling of the blocks was done before application of the different treatment modalities. This is unlike most research done in this field, in which sectioning is done after application of the treatment modalities[62,114,115] which has disadvantages such as contamination of the specimens or displacement of the gutta percha and sealer remnants during sectioning[66]. The former has the advantage of avoiding these disadvantages. The longitudinal sectioning method was chosen for cleanliness evaluation because it enables a direct examination of the root canal space and it is also cheap and available. The canals were obturated using the lateral compaction metho because it is a common technique for obturation that has been used in many similar studies[73,67,115]. After obturation, the blocks were left for 4 weeks at 37^{o}C in 100% humidity to ensure the sealer setting[116].

During use of the XP-F and PUI for cleaning the canals from gutta percha and sealer remnants, it was done in a water bath at 37^{o}C to simulate the intra oral temperature. For the XP-F instrument, this allowed transformation from martensitic phase to austenitic phase which results in a change of instrument into a sickle shape[11,62]. The ultrasonic tip was activated for 1 minute. This is similar to other studies done in this field[62,79].

In the present study when evaluating cleanliness, neither the XP-F nor PUI were capable of entirely removing gutta percha and sealer remnants from the root canals. When comparing between the Cl_{XP-F} and Cl_{PUI} subgroups totally with regards to cleanliness, there was no statistically significant difference between them. This finding is similar to the results of other studies done to evaluate the efficacy of XP-F and PUI with regards to cleanliness of the root canals [60,61]. In contrast, Ozyurek and Demiryurek[62] in 2016 found that the XP-F was more effective than PUI in removing gutta percha and sealer remnants from the root canals. This difference may be attributed to several reasons, firstly they evaluated mandibular canines that had different cross sectional shape from the evaluated teeth in the present study and it has been established that the cross sectional shape of the canal affects the cleanliness of the root canal during retreatment[86]. Secondly they enlarged the canals to a size #40 taper 0.06 that differ from this study (size #50 taper 0.04). Furthermore, they obturated the canals using warm vertical compation technique not lateral compaction technique. Moreover, the splitting of the root portions was done after retreatment that may have resulted in displacement of gutta percha and sealer remnants during splitting and finally they removed the root filling material using D-Race system only that meaning more remnants of root canal filling material in the root canal before application the instruments than the canals of the present study.

When comparing between root canal thirds with regards to cleanliness in the $Cl_{XP\text{-}F}$ subgroup, there was no statistically significant difference. This may be due to the fact that the XP-F instrument is a sickle shape rotary NiTi instrument that has radius of 3 mm. This may enable the instrument to physically touch more area of the canal while the instrument is rotating in the canal that may have resulted in cleaner dentinal surface and more patent dentinal tubules[11]. This finding is similar to another study done in this field[62]. Furthermore when comparing between the root canal thirds of the canal in the Cl_{PUI} subgroup, the coronal third was significantly cleaner than the apical and middle thirds. It may be due to the fact that the ultrasonic tips vibrate more freely in the coronal third than the apical and middle thirds[6] and also it was the most accessible third that was exposed to large volume of the irrigant. Also when comparing between apical thirds in $Cl_{XP\text{-}F}$ and Cl_{PUI} subgroups, the XP-F was more effective than PUI in cleanliness of the canal, it may be attributed to good efficacy of XP-F in the apical third compared to reduced efficacy of ultrasonic tip in this third due to limited free movement of the tip. This finding is similar to other study done in this field[82].

When evaluating the post retreatment adaptability using the push out bond strength test it was found that the Ad_{C} & $Ad_{XP\text{-}F}$ subgroups had significantly higher values of bond strength when compared to the Ad_{PUI} subgroup. The control subgroup was a positive control that was used to simulate optimum adaptability of the root canal filling materials to the root canal walls. This is reflected very clearly in the results of the study. The reason why the Ad_{XP-F} subgroup had a higher average bond strength value than the Ad_{PUI} subgroup regardless of the third of the canal being evaluated may be attributed to the fact that it may be more efficient in cleaning the canals as mentioned previously[62]. To date there is no research available in which post retreatment obturation bond strength has been evaluated after using the XP-F instrument. Although there was a statistical significant difference when comparing the Ad_{XP-F} and Ad_{PUI} subgroups regardless of the third being evaluated, we found that there was no statistical significant difference when comparing each third separately. This may be due to statistical reasons as the number of the specimens when comparing all thirds together was 39 while it was only 13 when comparing each third separately.

Finally when comparing between the thirds in both the Ad_{XP-F} and Ad_{PUI} subgroups, it was found that the push out bond strength values of the middle third were significantly lower than the apical & coronal thirds. In a novel paper that was published by Chen et al.[105] in 2013, they evaluated the relationship between the plunger diameter and the cross sectional diameter of the root canal filling material and its impact on the push out bond strength test results. They concluded the plunger diameter should not be too small as to puncture the root canal filling material and not displaced it. Furthermore Panes et al.[98] in the same year reported that the bond strength was lower when the plunger diameter was 50-60% of the root filling material diameter. In the present study, the available plungers had diameters of 0.5 mm that was used for testing the apical and middle specimens and 0.7 mm that was used for testing the coronal specimens. The ratio of the plunger diameter/the root canal filling material diameter in the apical specimen was 86.2 while in the middle specimen was 67.6 and finally in the coronal specimen was 85.4. The previous finding may explain why the middle specimen had a lower average bond strength value.

The relationship between cleanliness and adaptability is a strong one. Although there was no statistical correlation between cleanliness and adaptability, a lot of reasoning for differences in the push out bond strength test may be attributed to the differences in the cleaning capability of the instruments that used in this study.

Summary

For successful endodontic retreatment, it is mandatory to clean the retreated canals from any residual of the root canal filling material to enable achieveing good adaptability and sealing of the root canal space that prevent ingress of bacteria and its products in the root canal space.

A total of fifty three recently extracted mandibular premolars were collected from the outpatient clinic of the oral and dental surgery department- Al-Azhar university. Teeth were decoronated at 13 mm and the root portions were embedded in mold filled with the soft acrylic resin. After that the canals were instrumented to a size 50 taper 0.04 then the root portions were grouped into two groups according to evaluation method as follows; **G1**: Cleanliness group and **G2**: Adaptability group. The blocks in cleanliness group were sectioned longitudinally into two halves then reassembled and reinstrumented to a size 50 taper 0.04. After that the canals were obturated and the root filling material was removed then the canals were cleaned either with the XP-F or PUI. Then the specimens were evaluated using a digital microscope to image the gutta percha and sealer remnants in the canals.

While the blocks in bond strength group remained without sectioning. The canals were obturated and the root filling material was removed then the canals were cleaned either by the XP-F or PUI. Then the canals were reobturated and sectioned horizontally into slices. These slices were examined by instron testing machine using push out bond strength test to evaluate the adaptability of the root filling material to the root canal walls. The results showed that there was no statistically significant difference

between the XP-F and PUI in the cleanliness of the canals. On the other hand, the results showed that the XP-F is better significantly than PUI with regards to improve the adaptability of the root canal filling material to the root canal walls.

Conclusions

Within the parameters of this study, the following conclusions may be drawn:

1- Neither the XP-F nor PUI instruments could remove all gutta percha and sealer remnants from the canal.

2- Both the XP-F and PUI perform the same with regards to effectively removing gutta percha and sealer remnants.

3- The XP-F instrument is effectively cleaning the canal.

4- Overall; when using the XP-F instrument, the adaptability of the root canal filling material to the root canal walls improved.

Recommendations

1- The XP-F instrument is a useful tool in endodontic retreatment.

2- Further research should be done to evaluate the optimum time needed for using the XP-F instrument to effectively eliminate the maximum amount of gutta percha and sealer remnants from the canal.

3- Further research should be done to evaluate the ability of the XP-F instrument to eliminate gutta percha and sealer remnants from curved canals.

4- When doing studies using push out bond strength test, care should be taken to standardize the ratio of plunger diameter/root filling material diameter.

5- Further research should be done with emphasis on the statistical correlation between the cleanliness of the canal and the adaptability of the root filling material to the root canal walls.

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الملخص العربي

للوصول إلى درجة النجاح في حالات إعادة علاج الجذور فمن الضروري تنظيف القنوات المعاد علاجها من أي بقايا لمادة حشوة قناة الجذر للتمكين من الحصول على تطابق وانسداد جيدين لفراغ قناة الجذر ، وذلك لمنع دخول البكتريا ومنتجاتها في فراغ قناة الجذر.

تم جمع ثلاثة وخمسون ضاحك سفلي منزوع حديثا من العيادة الخارجية لقسم جراحة الوجه والفكين بجامعة الأزهر ثم تم فصل تاج الضرس عن الجذر عند طول ١٣ مم ثم تم غرس أجزاء الجذور في حاويات مملوءة بالأكريليك اللين ، وبعد ذلك تم تحضير القنوات لمقاس ٥٠ تحدب ٠,٠٤ مم وبعدها تم تقسيم البلوكات لمجموعتين تبعا لطريقة التقييم كما يلي : ج١:مجموعة النظافة ، ج٢: مجموعة التطابق .

بالنسبة لمجموعة النظافة فقد تم شق البلوكات طوليا إلى نصفين وإعادة تجميعهم ثم إعادة تحضيرهم لمقاس ٥٠ تحدب ٠,٠٤ مم ، وبعد ذلك تم حشو القنوات ثم إزالة الحشو وتنظيف القنوات إما بالاكس بي اندو فنشر أو بالري السلبي بالموجات فوق الصوتية ، بعدها تم فحص العينات باستخدام الميكروسكوب الرقمي لرؤية بقايا الجتا بركا ومادة السدادة في القنوات.

بينما البلوكات في مجموعة قوى التلاصق فقد بقيت بدون شق . وقد تم حشو القنوات ثم ازالة مادة حشوة الجذر وبعد ذلك تم تنظيف القنوات إما بالاكس بي اندو فنشر أو بالري السلبي بالموجات فوق الصوتية ثم تمت اعادة حشو القنوات وقطعهاعرضيا إلى شرائح . هذه الشرائح تم اختبارها بواسطة جهاز الاختبار انسترون باستخدام اختبار الدفع الخارجي لتقييم التطابق بين مادة حشوة الجذر وجدران القناة. وقد أظهرت النتائج عدم وجود فرق مهم إحصائيا بين الاكس بي اندو فنشر والري السلبي بالموجات فوق الصوتية في نظافة القنوات بينما أظهرت النتائج أن الاكس بي اندو فنشر أفضل من الري السلبي بالموجات فوق الصوتية بالنسبة لتحسين التطابق بين مادة حشوة قناة الجذر وجدران قناة الجذر.