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YEDİTEPE UNIVERSITY
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DEPARTMENT OF ENDODONTICS

COMPARATIVE EVALUATION OF THE EFFICACY OF 3 CONTEMPORARY RETREATMENT SYSTEMS USING THE AUTO-CAD SYSTEM

DOCTOR OF PHILOSOPHY THESIS

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APPROVAL

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DECLARATION

I hereby, declare that this thesis is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree except where due acknowledgment has been made in the text.

30.10.2023

Yağmur Çelik

DEDICATION

I dedicate this thesis to my beloved family especially my mummy...

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LIST OF SYMBOLS AND ABBREVIATIONS

AP: Apical periodontitis

Ni Ti: Nickel titanium

E. faecalis: Enterococcus faecalis

PTUR: Protaper Universal Retreatment

CBCT: Cone beam computer tomography

H file: Hedströem file

PT: protaper

M2: MTwo

M2r: M two retreatment

CT: Computer tomography

GP: Gutta-percha

WO: WaveOne

SAF: Self adjusting file

PTR: ProTaper

SEM: Scanning electron microscope

Micro-CT: micro computer tomography

RCB: Reciproc Blue

CW: Clockwise

CCW: Counter clockwise

WOG: Wave One Gold

PUI: Passive ultrasonic irrigation

XPES: XP Endo Shaper

XPEF: XP Endo Finisher

ISO: International Standars Organization

EA: Endo Activator

IS: Irrisafe

NaOCl: Sodium hypochlorite

ABSTRACT

Çelik, Y (2023). Comparative Evaluation of the efficacy of 3 contemporary retreatment systems using The Auto-Cad System. Yeditepe University Institute Of Health Sciences, Department Of Endodontics. Phd Thesis. Istanbul. (2023)

The purpose of this study was to investigate the efficacy of 3 contemporary retreatment systems when used for the retreatment performed by utilizing 3 methodologies. 90 extracted human teeth with single roots were selected. Teeth were separated from their crowns under water cooling by using a diamond separator and their root lengths were adjusted to 16 mm. Root canal preparation of the specimens was performed using Hyflex EDM Nickel-Titanium rotary instruments. The 90 samples were divided into 3 groups of 30 and filled with the following methods:

Group 1: Calamus Dual 3D Systems + AH Plus Root Canal Sealer

Group 2: Thermafil Obturators + AH Plus Root Canal Sealer

Group3: Lateral Condansation +AH Plus Root Canal Sealer

The groups were further divided into 3 subgroups, consisting of 10 teeth and 3 different retreatment procedures were conducted as follows:

A. Protaper Universal System D Series (n:10)

B. Wave One Gold System (n:10)

C. XP-endo Retreatment System (n:10)

Grooves were created on the samples in the bucco-lingual direction by using a double-sided diamond disc and sectioning was performed longitudinally using a chisel. Root halves were examined under dental operating microscope at X 15 magnification and images were transferred to an image analysis software (Autocad 2004; Microsoft, Redmond, Washington, USA) to calculate residual filling material as well as walls of root canal. The remaining filling material in root canal walls (A) was calculated by the formula: A = (area of the remnant · 100)/area of the root canal.

The results showed that no system was able to entirely clean canal filling material. When area of remaining filling material was compared in the Calamus group, no statistically significant was determined between the Protaper Universal Retreatment System, WaveOne Gold system and XP-Endo system. In Thermafil group, no significant difference was determined between PTUR, WaveOne Gold system and XP-Endo systems. In the lateral condensation group, a statistically significant difference was determined between PTUR system and WaveOne Gold. The residual filling in Protaper system was significantly higher in comparison to WaveOne Gold. When the amount of filling material was compared between methodologies, a significant difference was found between Calamus and Thermafil. The residual filling in Calamus group was found to be significantly higher compared to Thermafil.When all the groups were compared with each other using multiple comparisons, PTUR system in teeth whose filling was performed with Calamus resulted in significantly higher amount of filling material in comparison to PTUR in teeth filled with Thermafil and retreatment using WaveOne Gold in teeth filled with lateral condensation.

Conclusion: Further studies are necessary which not only assess innovative systems but also hybrid techniques which incorporate the combined usage of instruments to draw more reliable conclusions.

Keywords: endodontic retreatment, residual filling, Auto-Cad software

ÖZET

Çelik, Y (2023). 3 güncel döner alet sisteminin etkinliğinin Auto-Cad sistemi kullanılarak incelenmesi. Yeditepe Üniversitesi Sağlık Bilimleri Enstitüsü. Doktora Tezi. Istanbul (2023)

Bu çalışmanın amacı 3 güncel retreatment sisteminin uzaklaştırılmasındaki etkinliğinin incelenmesidir. Çalışmada 90 tek köklü çeşitli nedenlerle çekilmiş insan dişi kullanılmıştır. Dişler elmas bir seperatör yardımıyla su soğutması altında kuronlarından uzaklaştırılmış ve kök boyları 16 mm. olacak şekilde ayarlanmıştır. Örneklerin kök kanalları Hyflex EDM Nikel-Titanyum döner alet sistemleri kullanılarak üreticinin önerileri doğrultusunda hazırlanmıştır. 90 adet örnek kullanılan dolgu tekniğine göre 3 gruba bölünmüştür.

Grup 1: Calamus Dual 3D Systems + AH Plus Root Canal Sealer

Grup 2: Thermafil Obturators + AH Plus Root Canal Sealer

Group3: Lateral Condansation +AH Plus Root Canal Sealer

Her grup her biri 10 dişten oluşan 3 alt gruba bölünmüştür ve 3 farklı retreatment işlemş aşağıdaki yöntemler kullanılarak gerçekleştirilmiştir:

A. Protaper Universal System D Series (n:10)

B. Wave One Gold System (n:10)

C. XP-endo Retreatment System (n:10)

Deneysel dişlerde çift taraflı elmas bir frez yardımıyla bukko-lingual yönde oluklar açıldıktan sonra bir keski ile dikey olarak ikiye ayrılmışlardır. Her iki diş yarısı operasyon mikroskopu altında X 15 büyütmede incelenmiştir ve elde edilen görüntüler imaj analiz yazılım programına aktarılmış (Autocad 2004; Microsoft, Redmond, Washington, USA) ve kanal duvarlarındaki rezidüel dolgu material miktarı ölçülmüştür. Kanal duvarlarında kalan dolgu maddesi yüzdesi aşağıdaki formül kullanılarak ölçülmüştür: A= (kalan dolgu maddesi alanı.100)/ kök kanalının alanı.

Çalışmanın sonuçları hiçbir sistemin kök kanal sisteminden kanal dolgusunu tamamiyle uzaklaştırmada etkili olmadığını ortaya koymuştur. Calamus grubundaki kalan dolgu

maddesi miktarı karşılaştırıldığında, ProTaper Universal Retreatment Sistem, WaveOne Gold system ve XP-Endo sistemleri arasında istatistiksel olarak anlamlı bir fark saptanamamıştır. Thermafil grubunda, ProTaper Universal retreatment sistemi, WaveOne Gold sistemi ve XP-Endo sistemleri arasında anlamlı bir fark belirlenememiştir. Lateral kondensasyon grubunda, ProTaper Universal retreatment sistemi ve WaveOne Gold sistemleri arasında istatistiksel olarak anlamlı fark belilenmiştir. ProTaper sistemindeki rezidüel dolgu miktarı WaveOne Gold sistemine kıyasla anlamlı derecede yüksek bulunmuştur. Rezidüel dolgu materyalleri dolgu yöntemleri arasında karşılaştıırldığında, Calamus ve Thermafil grupları arasında anlamlı fark belirlenmiştir. Calamus grubundaki rezidüel dolgu materyali miktarının Thermafil grubuna göre anlamlı derecede yüksek olduğu belirlenmiştir. Tüm gruplar çoklu karşılaştırma yöntemi ile karşılaştırıldığında, Calamus ile doldurulmuş dişlerde Protaper Universal retreatment sistemi kullanılarak yapılan retreatment işlemi, Thermafil ile doldurulmuş dişlerde PTUR sistemi ile gerçekleştirilen retreatment işlemi ve lateral kondensasyon ile doldurulmuş dişlerde WaveOne Gold kullanılarak yapılan retreatment işlemine oranla anlamlı derecede yüksek rezidüel kanal dolgu miktarı kalmasına yol açmıştır.

Anahtar sözcükler: endodontik tedavi tekrarı, rezidüel dolgu, Auto-CAD yazılımı

1. INTRODUCTION AND PURPOSE

The goal of endodontic treatment can be defined as prevention of apical periodontitis or to provide sufficient conditions for healing in case of the presence of a periapical disease (1). Success of endodontic treatment is dependent on a variety of factors. Originally, debridement, disinfection and obturation comprised the major factors responsible in the success of endodontic treatment and these constituted generally accepted "endodontic triad" (2). Nowadays, success of endodontic treatment includes a wider spectrum of contributing factors, such as correct diagnosis and an acceptable treatment planning, thorough knowledge of anatomical and morphological properties of teeth, complete debridement, disinfection and obturation, a successful coronal restoration that does not allow leakage and a regular follow-up and imaging of the treated tooth (2).

Root canal treatment is generally a predictable procedure with having high rates of success. Studies have shown high levels of success ranging between 85-95%, specifically in cases where treatment is carried out in vital teeth, where infection is restricted to the pulp chamber (3). The criteria for success has mostly been based on the appropriateness of both radiographic and clinical findings. The criteria proposed by Strindberg is widely accepted to define success and failure in endodontic treatment (4).

In spite of the relatively high success ratio of root canal treatment, there are situations where endodontic treatment may fail and apical periodontitis ensues. Apical periodontitis (AP) can be described as an inflammatory reaction related to pathogenic organisms and their toxins and by-products which invade root canal (5,6). A recent paper reported that global prevalence of individuals with at least 1 tooth with AP ranges from 16% to 86% (7). In a cross-sectional study evaluating the periapical status and quality of root canal treatment in a selected Turkish population, 53.5% of root-filled teeth were found to present apical periodontitis and 91 percent of endodontically treated teeth with periapical pathosis were identified as having unsatisfactory root filling (8). This places emphasis on the fact that very strict measures should be taken during root canal treatment by adhering to the basic standards of care.

Endodontic retreatment is the non-surgical procedure performed when initial endodontic treatment has failed. The essential purpose of nonsurgical retreatment is to bring periapical tissues into a healthy condition by removing previously placed material, additional cleaning and shaping, and filling of canals in a 3-dimensional manner (9). Retreatment is a methodology which includes the complete removal of the previous material and filling the

new prepared root. canal system. Initially, endodontic retreatment was performed using hand files in combination with solvents (9). In recent years, there have been attempts to produce rotary Ni-Ti instruments which are specifically produced for endodontic retreatment (10,11). It has been proposed that these instruments are more effective compared to hand instruments and they reduce the time spent at the clinic and prevent practitioner and patient fatigue (12). There are quite a number of rotary instruments available in the market which are designed for root canal retreatment and investigations related with their effectiveness are continuously carried out. This study aimed to evaluate the performance of 3 rotary retreatment techniques with different filling systems using the AutoCad software.

2. LITERATURE REVIEW

2.1 Endodontic Retreatment

2.1.1. Definition

The American Association of Endodontists, Glossary of Contemporary terminology for Endodontics has made a description of endodontic retreatment as: A procedure which aims to remove root filling materials from the tooth, followed by cleaning, shaping and obturation of canals (13). Previously, endodontic treatment was described as a procedure performed in failed endodontic cases; however, it was suggested that using the terminology "failure" was not very appropriate since there are many cases in which treatments performed very successfully result in an unfavorable outcome as well as cases which are successful although root canal treatment has been performed below a specific standard (14). For this reason, it was stated that "post-treatment disease "would be a better way of expressing cases which were previously described as failures.

2.1.2. Etiology Of Post-Treatment Disease

The etiological factors of post-treatment disease have been classified as follows:

1. Persistent microorganisms or those which are reintroduced

2. Extraradicular infection

3. Foreign body reaction

4. True cysts (15)

2.1.2.1 Persistent Or Reintroduced Intraradicular Microorganisms

Insufficient cleaning, shaping and filling and an inadequate final restoration in an endodontic treatment may result in posttreatment disease. Extreme care must be exercised to clean the root canal space thoroughly or entomb remaining bacteria so that they cannot exert any toxic effects. If this is not accomplished, bacteria which persist in the canal system may cause continuation of infection and apical periodontitis. It has been reported that persistent or reintroduced microorganisms in the root canal are major reasons causing posttreatment disease (16). *Enterococcus faecalis* has gained specific attention in recent years as a cause of post-treatment disease. The prominence of *E. faecalis* in endodontically treated teeth having apical periodontitis has made this microorganism a focus of attention (17). It is a Gram (+) bacterium which is resistant to intracanal medicaments (14). Additionally, *Candida albicans,*

a fungus has also been identified in canals of teeth with previous filling with post-treatment infection (18).

2.1.2.2 Extraradicular Infection

In some cases, due to insufficient cleaning and disinfection and failure in providing a successful apical seal, failure may be observed in endodontic treatment and remaining infection can result in a persistence of infection in the apical areas (19).

Extradicular infection is one of the etiological factors responsible of the loss of dental structure after failure of endodontic treatment and non-surgical retreatment (20).

Two species of bacteria identified in extraradicular infections are Actinomyces and Propionibacteium (21).

Some studies in the literature have identified these species. Ricucci *et al.* histologically evaluated cases of persistent infection which showed sufficient endodontic treatment radiographically (22). In histological examination, filamentous bacteria which occupy extraradicular surfaces of teeth were observed. Other authors also confirmed that Actinomyces species was present in persistent lesions following endodontic treatment (23-25).

2.1.2.3 Foreign Body Reaction

Foreign materials present in periapical region has also been held responsible for persistent endodontic infection. Among these materials, lentil bans and cellulose fibers from paper points have been reported (26,27). It is a general opinion that a filling material which is extruded is associated with lower success rates and healing. Gutta-percha and sealers are generally accepted to be well tolerated by periapical tissues in case they are not infected by microorganisms (14).

2.1.2.4 True Cysts

There are 2 types of cysts: 1. Periapical pocket cysts and 2. True cysts. True cysts have a bordered lumen having epithelial lining and they have no connection with the tooth. In other words, they are completely isolated. In pocket cysts on the other hand, the cyst lumen has a connection with the problematic tooth (14). It is presumed that true cysts are unable to heal after non-surgical endodontic treatment due to their self-sustaining characteristics and a surgical intervention is necessary. In general, the prevalence of periapical cysts was reported

to range between 15-42 % (28). It is not possible to differentiate a periradicular cyst from a granuloma by conventional radiography (

2.2 Non-Surgical Endodontic Retreatment

Retreatment of a previously treated tooth suffering from post-treatment comprises a significant portion of endodontic practice. In principal, same principles of primary root canal treatment have to be followed during retreatment, which are a correct diagnosis, provision of root canal antisepsis by cleaning and shaping, a successful disinfection procedure, hermetic root filling followed by a good coronal restoration (29).

The following definition by Ruddle summarizes and clearly reflects clinical conditions that are common during retreatment: Endodontic retreatment can be described as a procedure performed for a tooth which shows inadequate treatment, and the situation of the tooth necessitates the performance of additional root canal treatment to acquire a successful outcome (30). The goals of retreatment are to clean the previous filling materials from the root canal and correct deficient procedures or repair pathologic or iatrogenic errors. Furthermore, retreatment procedures are able to identify mechanical errors, unidentified canals as well as radicular fractures. Nonsurgical endodontic retreatment has high success rate if case selection is done carefully and qualified equipment and armamentarium is utilized (30).

Some authors reported that the clinical success of retreatment appears to be related with whether deficiencies exist due to previous treatment (31). A survey of literature also shows a variety of studies which focused on success rate of retreatment. Sundqvist *et.al*, reported an overall success ratio of 74% of 50 cases following non-surgical endodontic retreatment (32). The authors also reported a marked relationship with the success of retreatment and presence of bacteria within root canals. Sjögren *et al*. correlated theUN clinical success of endodontic retreatment with the magnitude of existing periapical lesion and indicated that the success rate significantly decreases as the size of a lesion is greater (33). Farzaneh *et al.* suggested that perforation errors done previously, quality of filling and lack of definitive final restoration were the major factors defining the success of endodontic retreatment and although apical periodontitis was also a strong predictor of success, it was secondary compared to these three causes (34).

The techniques and methodologies used for non-surgical retreatment has undergone significant evolution over the years. Previously, hand instruments were used to fulfil this goal.

In recent years, manufacturers have developed specific rotary instrumentation systems that specifically address the removal of root filling. This fact has led researchers to continuously conduct research to investigate ability of the root canal filling removal associated with each technique.

2.2.1. Protaper Universal Retreatment Technique (D Series)

The ProTaper Universal (PTUR) (DentsplyMaillefer, Ballaigues, Switzerland) retreatment system consists of 3 main instruments.

The D1, D2 and D3 are specifically produced for the removal of filling materials. They possess various different tapers and diameters at the tip portion and these are size 30, 0.09 taper, size 25, 0.08 taper and size 20, 0.07 taper. The lengths of files are as follows: 16 mm for D1, 18 mm for D2 and 22 mm for D3. D1, D2 and D3 are suggested to be utilized with the purpose of removing materials from the coronal, middle and apical parts of canals respectively. The cross section of retreatment series is convex. On the other hand, D1 has a working tip that enhances the initial penetration of the instrument into filling material. No radial lands exist in D1 and negative cutting angles are present which allows a cutting action rather than cleaning. F4 and F5 finishing files can be used for for additional finishing procedures. (35).

An active tip is present in D1 to facilitate initial penetration into the filling material; The D2 instrument is designed so that it removes material in the middle third of the root. The D3 provides removal of apical filling (36).

The protocol for using the PTUR system is as follows:

Following radiographic evaluation and the opening of the access cavity, the type of filling material is determined by a probe (gutta-percha, filling material). Filling is removed starting from coronal, progressing towards apical. The instruments should be used with slight pressure by a forward and backward motion. The instruments should be taken out of the root canal and filling remnants as well as debris in blades should be cleaned. In case resistance is felt within the root canal and no further movement can be done, hand instruments should be used. It is not recommended to reach the working length with a D3 instrument in curved root canals. Following hand instrumentation, the procedure is finished by F1, F2 and F3. The suggested speed is 500-700 rpm for gutta-percha, Thermafil and ProTaper obturator and 250-300 rpm for zinc-oxide eugenol containing root filling materials (37).

2.2.1.1 Studies Evaluating The Retreatment Capacity Of Protaper Universal Retreatment Technique

ProTaper retreatment series is a well-recognized system and has been widely studied in term of retreatment by a variety of researchers. Some studies focus on the time spent for retreatment whereas other focus on the quality of retreatment by calculating the amount of removed materials from the canal.

Gu *et al.* (2008) evaluated time required for the cleaning of gutta-percha from canals using the PTUR and concluded that it was an efficient methodology for the removal of materials from the anterior teeth (38). The favorable clinical performance of PTUR in straight canals was attributed to progressive taper and length characteristics of D1, D2 and D3. The authors indicated that these characteristics may enable the instruments to both gutta-percha and dentine during removal of filling.

So *et al*. performed a study in which they investigated the efficacy of the PTUR and hand files for the removal of material during root canal retreatment procedures. Furthermore, they evaluated the impact of sealer on the presence of debris in canals where reinstrumentation was performed. The authors filled the canals of 60 palatal roots belonging to first molar teeth using gutta-percha in combination with a zinc oxide eugenol or a resin-based sealer and performed reinstrumentation in canals using the following systems: G1, EndoFill/hand files; G2, AH Plus/hand files; G3, EndoFill/ProTaper; G4, AH Plus/ProTaper. They split roots with the purpose of examining the root canal surfaces utilizing an optical microscope, and evaluated the debris on each 3 portions of the root canals and the total canal surface by using digitized images (AutoCad 2004 software). The authors found no significant difference among the root canal portions in terms of the amount of residual filling within each group. EndoFill/ProTaper G4 showed significantly more amount of filling residue in comparison with EndoFill/hand files in the cervical portion. In the middle third portion, AHPlus/hand files and AH Plus/ProTaper showed more debris than EndoFill/hand files. The techniques showed similar results in the apical portion. Debris was present in all 3 portions after the canals were reinstrumented. The authors commented that manufacturer of the ProTaper Universal system does not approve the system's use in canals filled with resin based sealers. Because they exhibit strong adhesion to root canal walls, and attributed the presence of more filling in EndoFill/ProTaper and AH Plus/ProTaper due to this factor. They further indicated that because it is possible to precurve hand files and transferres to areas where hand sensation

suggests presence of filling, hand and rotary instruments used in a combined manner seems a preferable method to enhance cleaning and shaping of the apical region. (39).

Takahashi *et al.* investigated the effectiveness of the PTUR when used in conjunction with a solvent. They used upper anterior teeth and following preparation and filling, they divided them into 4 groups in which retreatment was performed using Gates-Glidden and K-files, Gates-Glidden and K-files in combination with chloroform, PTUR system, and PTUR with chloroform. After recording the operating time, they sectioned and photographed the longitudinally split portions and analysed them at x5 magnification using the Image Tool software. The authors mentioned that all methods were successful for cleaning previous filling material, and yielded similar results. They added PTUR utilized without using chloroform solvent was a speedier methodology. They also commented on the difficulty of removing the filling material when solvent solutions are selected due to the occurrence of a thin layer of soft gutta-percha that is created by the solvent and adheres to walls of root canal (40).

In another investigation by Unal *et al.* which focused on the evaluation of the effectiveness of the PTUR in curved molars, teeth were filled using System B and Obtura II and removal of the filling material was performed by using hand K-files and Hedstroem files (Dentsply Maillefer), ProFile (Dentsply Maillefer), R-Endo (Micro–Mega) or PTUR (Dentsply Maillefer). Eucalyptol was selected in all retreatment techniques as a solvent. Digital images taken were evaluated using the AutoCad -2000 software. The authors concluded that PTUR and R-Endo instruments were less successful in removing material from canal walls compared to hand instruments and ProFile system. The authors also observed that the apical third portion was where higher filling material remained compared to middle and cervical portions no matter which technique was utilized. They attributed this common finding to the anatomical variations which are greater in apical portion (41).

In a study performed by Bramante *et al.* evaluating the effectiveness of MTwo (VDW, Munich, Germany) and PTUR and hand instruments, it was concluded that PTUR caused the highest temperature increase on root surfaces. Images were captured under the stereomicroscope at x 12.5 magnification and examined by utilizing Sigma Scan Pro5 software (SPSS Science, Chicago, IL). All instruments tested caused debris to stay and Mtwo R system was the least effective in terms of cleaning. PTUR left lower amount of debris compared to Mtwo R. The authors commented that PTUR instruments possess greater taper and consequently higher amount of metallic core portion compared to Mtwo R resulting in in

higher heat generation and gutta-percha plasticizing which enhances dislodgement in a shorter period (11).

Marfisi *et al.* compared performance of PTUR using CBCT. Other systems used were MTwo Files and Twisted Files and the filling materials were Resilon and gutta-percha. The results revealed that no system was able to clean filling from the root canals totally. It took less time for Mtwo Retreatment files to remove material compared to other instruments used. Resilon was removed significantly more efficiently compared to gutta-percha, no matter which rotary system was preferred (36).

Siotia *et al.* (42) compared efficacy of PTUR when 3 different filling materials were used. These were: gutta-percha and AH Plus, gutta-percha and zinc oxide eugenol sealer, and GuttaFlow. They used the AutoCad in order to identify amount of debris and material at the 3 different parts of the root canal. According to the authors, ProTaper retreatment system was unable to provide totally clean canals in any of the tested groups. On the other hand, it exhibited the highest potential in the removal of GuttaFlow, a silicone based obturating material. Protaper retreatment system also displayed better cleaning efficacy in the cervical third. Gutta-percha in combination with with epoxy resin-based sealer resulted in maximum debris in the canal (42).

Another study using the Auto-Cad software was conducted by DaSilva *et al.* in which PTUR, D-RaCe, and Mtwo Retreatment were compared in retreatment capacity. They used these 3 systems for filling material cleaning in 3 groups and they used additional files in the 3 other groups along with the aforementioned systems. These were: F4, size 40, .04 taper RaCe, and size 40, .04 taper Mtwo, for PTUR, Race and MTwo systems, respectively. No significant differences were noted between groups when complementary instruments were utilized. The amount of remaining material was the lowest in PTUR and showed a statistical difference only in comparison to D-RaCe (10).

Ersev *et al.* (43) evaluated residual filling following removal of 3 sealers utilized with a matched-taper filling technique having single cone and compared the efficacy of PTUR with a traditional hand system. They used the ImageJ 1.38· image analysis software (National Institutes of Health, Bethesda, MD, USA) for calculation at 3 levels of the root canal. Similar to other studies, irrespective of sealer and technique selected for retreatment, removal of the filling material totally from the canals was not possible. PTUR had similar safety and

effectiveness as manual instruments in terms of reaching until the working length of root canal (43).

Kumar *et al.* (44) compared the effectiveness of PTUR utilized with or without a solvent solution and stainless-steel hand files for the purpose of removing filling. Image Pro Plus software was used to evaluate the images captured at X 12.5 magnification. No matter which technique was utilized, all specimens caused residue to remain walls of the canal. The ProTaper Universal retreatment system files by themselves were determined to be speedier compared to other groups and exhibited better removal of gutta-percha. They commented that PTUR files which possess larger tapers may cause a cleaner canal system compared to stainless steel hand files and their design may be responsible for their better performence. They added that the features of D1, D2 and D3 instruments having progressive taper and lengths may enable them to cut and pull the gutta-percha into flutes of the file and carry it toward the canal entrance. On the other hand, they mentioned that even though the ProTaper system gave better results, it still was not satisfactory to clean gutta-percha material completely and further refining is necessary as the final instrument D3 which reaches working length of the canal does not permit a total cleaning capacity (44).

In a micro computed tomography study performed by Ma *et al.*, oval root canals were used and PTUR with or without a solvent were evaluated in terms of the efficacy of removal of continuous wave technique and cold lateral compaction technique. None of the systems were able to entirely clean all filling from canals. Higher amount of filling remained in root canals filled by using the continuous wave condensation compared to cold lateral compaction following retreatment procedure. The authors explained this finding with the fact that the continuous wave of condensation resulted in a filling possessing a higher dentisty compared to conventional cold lateral condensation. They added that root filling material of continuous wave of condensation which is softened by the application of heat may easily be compacted into irregular portions and in the tubules specifically found in the apical third (45).

Another study by Rödig *et al.* investigated retreatment efficacy of D-RaCe instruments, PTUR or Hedström files in curved root canals using the micro-CT. D-RaCe instruments left significantly lower amount of residual material in comparison to PTUR and hand files. The authors described micro-CT imaging as a nondestructive methodology which provides and accurate quantitative evaluation of remaining material and the dentine removal. The authors determined a large standard deviation for the PTUR in terms of residual filling. They

explained this finding by indicating that ProTaper Universal retreatment instruments generally remained significant amount of filling material (46).

Khalilak *et al*. investigated the efficacy of H-File and ProTaper utilized with or without chloroform solvent for the removal of gutta-percha during retreatment procedure. They evaluated the images taken at x25 under the stereomicroscope using the AutoCad 2007 system. The authors mentioned that longitudinal separation of root buccolingually is a feasible methodology to investigate the efficacy of the retreatment method. They further added that unlike radiographic images, the splitting method and examination of microscopic images provides a three-dimensional visualization of canal. They drew attention to the fact that the chisel used for splitting the root into 2 halves should not touch the walls in order not to compromise the results. Their results revealed that ProTaper Ni-Ti instruments were more efficient and they saved time compared to H-File in root canals having no or slight curvature. The authors added that the mild curvature of the samples might have resulted in more successful performance of the D series instruments (D1, D2, D3) with tapers equal to (9%, 8% and 7% respectively). They concluded that because these instruments contacted canal walls and removed filling residue better compared to H-Files with 2% taper, more favorable results were obtained (47).

Alves *et al.* (48) specifically focused on the cleanliness of the apical third during retreatment in their study in which they compared ProTaper Universal (PT), PTUR, Mtwo (M2) and Mtwo Retreatment (M2r). Stereomicroscopic images taken at X16 magnification were investigated by using a software. Residual material was detected in all sections, no matter which technique was utilized and PT or M2 showed similar effectiveness as PTr/PT or M2r/M2 instruments. No significant difference was observed between the methodologies that were tested. The authors mentioned that the cleavage method permits direct observation of remaining root material by using magnification and it is an accepted methodology in the existing literature. Their study attempted to find an answer to the question of whether retreatment instruments are in fact required for filling removal. Their results revealed that performance of instruments developed for retreatment showed similar results compared to their corresponding Ni-Ti systems (48).

Chandrasekar *et al.* (49) evaluated the performance of PTUR by comparing them with RaCe, K3 and H-files using volumetric analysis by micro-CT. Their results showed that PTUR significantly differed compared to other groups in removal of filling materials and recommended these instruments during retreatment. They used orange extract as a solvent

which they reported was a safe alternative to other solvents. They mentioned that even though the ProTaper retreatment files pull the filling material into the flutes carrying the remnants towards the orifice, the ProTaper retreatment files did not exhibit any statistical difference in cleaning of material compared to RaCe rotary files. They attributed this to the similar designs of negative rake angles and triangular cross-sections in both the files (49).

Gokturk *et al.* compared the performance of 4 systems which were Mtwo R, R-Endo, ProTaper Universal Retreatment, and D-RaCe systems. Hedströem files were also used as hand instruments in their study. Digital images taken at x12.5 magnifications were evaluated using the NED Cad system. Hedström files caused less filling material to remain compared to the rotary retreatment systems but significant difference was identified only in the middle portion of canal. Apical third was found to be the area with the most residual filling in comparison to other portions of canal (50).

Iriboz *et al.* investigated the efficacy of ProTaper and Mtwo retreatment systems for the cleaning of resin-based filling methodologies. Resilon + Epiphany, gutta-percha + Epiphany, gutta-percha + AH Plus and gutta-percha + Kerr Pulp Canal Sealer (PCS) combinations were used for filling. The authors used the scanning electron microscope for the evaluation of the remaining material and debris at the coronal, middle and apical portions of each canal. Their results showd that teeth which were instrumented with Mtwo resulted in significantly more amount of material compared to teeth prepared using ProTaper system. Furthermore, the Resilon + Epiphany and AH Plus + gutta-percha materials were cleaned more readily compared to the Epiphany + gutta-percha and Kerr PCS + gutta-percha fillings. The authors attributed the better performance of PTUR to their design features in which D1, D2 and D3 instrument possess 3 progressive tapers as well as lengths. They commented that these characteristics of instrument may render ProTaper retreatment instruments to engage and cut both the filling material, and also the superficial layer of dentin during the removal of root filling. As stated previously, the authors indicated that the unique flute design and rotary motion of ProTaper retreatment instruments which pull obturation material into flutes and carry it towards the canal entrance, is another factor for more successful performance of the system (51).

Mittal and Jain compared the efficacy of ProTaper and MTwo retreatment systems as well as hand files with or without using a solvent solution. Their samples consisted of mandibular molars with hand files. They calculated volume of filling before and after retreatment procedure using computed tomography (CT). Their results showed that the highest amount of

filling was removed during retreatment procedure conducted with ProTaper retreatment system utilizing a solvent solution and the least amount of material was removed with hand retreatment system utilized in combination with a solvent solution. The authors mentioned that a unique characteristic feature of ProTaper shaping files is the progressive taper which enhances instrument's flexibility, cutting efficacy and reduces the recapitulations required to reconfirm working length, specifically in narrow or more curved canals. They further stated that ProTaper instruments also have a convex triangular cross-section and this feature decreases contact area between file blades and dentin, and facilitates cutting action and enhances safety by lowering torsional load. The balance between the pitch and helical angles of ProTaper optimizes the cutting effect, efficiently allows blades to transfer debris out of the canal systems, and prevents instruments from screwing in canal space (52).

Rios *et al.* compared ProTaper system with 2 reciprocating instruments which were Reciproc and WaveOne. They used mandibular incisors as experimental teeth and after retreatmet procedure, roots were split and the material was observed under a stereomicroscope at x5 magnification and images were evaluated using Image Tool software. The mean residual filling was 4.30%, 2.98%, and 3.14% in Reciproc, WaveOne and ProTaper groups, respectively. No statistically significant difference ($P > .05$) was noted among the tested groups. Reciproc and WaveOne systems were determined to be as successful and efficient as PTUR for filling removal. The authors indicated that although the Reciproc and WaveOne reciprocating systems were not specifically produced for retreatment purposes, the unique features of these instruments and the reciprocating motion may be advantageous to achieve successful removal filling based on their results which suggested that no statistical difference was found when compared with the PTUR, which is a system that is specifically manufactured for retreatment procedures (53).

Another study which compared PTUR with reciprocating motion was by Rödig *et al.* in which retreatment procedure was performed using Reciproc, ProTaper Universal Retreatment or Hedströem files. They determined the ratio of residual material and dentin removal using the micro-CT. No significant difference was noted among 3 retreatment techniques with respect to residual filling material. Errors related with the procedure were encountered with PTUR and Reciproc (54).

Colaco *et al*. evaluated effectiveness removal of gutta-percha using using H-files and xylene (H + X) and H-files and System B (H + SB) (SybronEndo, Orange, CA) and with rotary techniques using the PTUR and D-RaCe Retreatment (D-RR) (FKG Dentaire, La Chaux-de-

Fonds, Switzerland) systems. Following instrumentation of canals filled using GP cones and zinc oxide eugenol containing sealer using lateral compaction method, roots were split longitudinally and images taken at x40 magnification were examined using the Image J 1er soft-ware (National Institutes of Health, Bethesda, MD) to calculate area of GP remnants on the whole root canal and canal wall area. Rotary techniques were found to be more effective compared to than manual methodologies. In general, the D-RaCe Retreatment system was determined to be the most successful method. The manual use of H-files with System B was determined to be the least efficient. All techniques used showed GP residue and it was not possible to display them by radiographs. The authors attributed the differences between D-Race and ProTaper Universal to variations in design of file, number of files, and speed used during the operation. They indicated that the D-RR system utilizes only 2 files at a greater speed compared to 3 files utilized at lower speed in the PTUR. The difference size of tip of last file utilizedin both systems were also indicated as possible reasons that might be responsible for the results (55).

Capar *et al.* evaluated PTUR from a different perspective and evaluated the system when utilized with rotary or reciprocating adaptive motion in retreatment. Root filling was performed using AH Plus and gutta-percha and System B plugger for vertical compaction. Sections were taken from teeth after instrumentation, and the half portions were analyzed at x8 magnification. The ratio of residual material was recorded by transferring images to the computer and calculating the areas. The adaptive motion which is a modified reciprocating motion combining rotation and reciprocation was found to clean higher amount of filling compared to rotational movement. They explained this finding with engagement of the material by the instrument during initial motion and removal of filling by using second motion (56).

De Souza *et al.* also compared PTUR system with Reciproc, which is a reciprocating system. In their study where both systems were utilized in order to remove filling filling was performed by selecting AH Plus and the lateral compaction system, they transferred images of tooth halves at x8 magnification and transferred them to the computer to analyze using the Image Tool software. They found no statistically significant difference with respect to remaining material between groups. Time that was necessary for cleaning of material was statistically shorter in Reciproc. The authors made similar comments with Rios *et al*. and indicated that the unique structural design of instrument in combination with reciprocating motion is important for a successful removal of filling, because there was no difference

between Reciproc and PTUR which is specifically produced for the purpose of retreatment (57).

Jaiswal *et al.* used a modified methodology in which they made teeth transparent prior to transferring images taken under the microscope. They compared the retreatment performance of PTUR with R-Endo, Mtwo and Hedstrom files. Teeth retreated with the H-files caused lower filling material to remain compared to others, statistically significant difference was identified only between H-file and R-Endo (58).

Akbulut *et al.* compared ProTaper Universal retreatment system with Twisted File Adaptive and Reciprocating Systems. Using the CBCT. Lateral compaction was used as the filling method in which gutta-percha was utilized in combination along with AH-Plus. Filling was found to be more successfully cleaned with the Reciproc and PTUR compared to Twisted File Adaptive and hand instruments. Their results were contradictory to the results obtained by Rödig et al who found no superior performance of the ProTaper and Reciproc systems in comparison with hand files. Akbulut *et al.* attributed this difference to the anatomical features of teeth used in both studies (59).

Bernardes *et al.* performed a study in which they compared the efficacy of PTUR with Reciproc and G3-Manual (hand files and Gates Glidden burs) used along with ultrasonic activation. They not only used micro-CT scans for the evaluation of remaining debris but they also separated the roots in halves, took images by SEM and made scoring depending on the area covered by filling residue. Reciproc method showed less remaining root filling compared to the ProTaper and manual methods. The authors also concluded that activation performed by ultrasound significantly facilitated removal of filling and decreased amount of remaining filling in all groups included (60).

In a study by Colombo *et al* (61), ProTaper and WaveOne were compared in terms of gutta-percha removal, when used with or without a solution as a solvent. Images taken at x5 magnification by the operating microscope were investigated by using a software. Their results showed no statistical difference between groups in terms of residual material (61).

In a micro-CT study, Crozeta *et al.* investigated removal of material from canals having an oval configuration with the use of different methods. They included PTUR in combination with ProTaper Universal F2, F3, F4, and F5 files, Reciproc R50 file, and TF Adaptive 50.04 files. They concluded that adaptive motion facilitated filling removal in middle and apical portions in comparison with reciprocation. The authors explained the more successful

removal of filling obtained with TFA with the combined use of the rotation and reciprocating motion in which rotation has a cutting effect and the reciprocating motion facilitates the removal of the material in a coronal direction (62).

In another micro-CT study performed by Crozeta *et al*., PTUR, group W40 (WaveOne 40.08), R40 (Reciproc 40.06), R50 (Reciproc 50.05), W25/W40 (WaveOne 25.08/ 40.08), and R25/R40/R50 (Reciproc 25.08/40.06/ 50.05) were compared in terms of removal of an epoxy resin-based sealer in combination with gutta-percha filled by utilizng Tagger's hybrid technique. ProTaper Universal retreatment instruments showed an equal performance compared to W40, R40, R50, W25/W40, and R25/R40/R50. In WaveOne, use of only one instrument was found to remove the filling more successfully (63).

Koçak *et al.* compared the effectiveness of hand file, a nickel titanium rotary instrument, and 2 instruments with reciprocating motion. Root canals filled using AH Plus with the lateral compaction method were retreated using PTUR, Reciproc, WaveOne and hand instruments. Images taken at x8 magnification under the stereomicroscope were transferred to a computer and ImageJ 1.33 software was used to calculate the area of material and convert it to a percentage. The samples which were prepared with WaveOne displayed significantly lower amount of residual filling. Reciproc showed significantly less residual material compared to PTUR. The group with the highest filling was the one where Gates-Glidden burs and SS manual files were utilized for removal (64).

Pawar et al. (65) used a combination of retreatment systems in their CBCT study performed in oval canals using PTUR and then WaveOne reciprocating file or the SAF. The authors concluded that retreatment involving PTUR followed by SAF was more successful compared to PTUR followed by WaveOne (65).

Another study which evaluated the effectiveness of additional files after retreatment systems was conducted by Yürüker et al. in which filling in root canals was evaluated using PTUR files alone or in combination with with the Self-Adjusting File (SAF; ReDent-Nova, Ra'anana, Israel), Reciproc (VDW, Munich, Germany), or Hedströeom-files (H-file; VDW, Antaeos, Munich, Germany). The complementary utilization of SAF did not result in a significant enhancement in removal of filling when compared with the PTUR alone though a better cleanliness was observed. On the other hand, the additional use of Reciproc or hand H-files significantly improved removal of filling when compared with the PTUR alone (66).

Fariniuk *et al.* performed a comparison of the effectiveness of ProTaper Next, ProTaper Universal and Hedström files in removal of filling material during retreatment. ImageTool 3.0 software was used to analyze the image scaptured following the sectioning of cleared teeth which were decalcified using diaphanization technique by hydrochloric acid. The authors indicated that the PTU and PTR systems caused similar amount of filling in all portions of the canal and and there was no statistical difference between them (67). Due to this result, the authors stated that PTU instruments can also be feasible alternative for both filling removal and repreparation and could simplify the retreatment procedure by decreasing the number of instruments, and be economically more suitable.

Jorgensen *et al.* (68) compared the capacity of WaveOne Reciprocating File System with the PTUR using 2 obturating techniques. They used mesiobuccal roots belonging to lower mandibular teeth and filled the root canals by a warm vertical system or GuttaCore. They concluded that the WaveOne Primary file caused higher amount of fracture and could not remove filling as effectively as PTUR. Root canals filled using GuttaCore more efficiently cleaned and with less file fractures compared to canals filled by continuous wave technique (68).

Although teeth having low curvatures were generally used in studies assessing the effectiveness of a retreatment system, some investigators utilized teeth with severe curvatures, as well. Kaşıkçı- Bilgi *et al.* used the mesio-bucccal and disto-buccal roots of molars whose curvature ranged between 30 and 49 degrees to compare the effectiveness of Hedström files, R-Endo Reciproc and PTUR. Digital periapical radiographs were to evaluate residual material remaining within root canal. Their results showed that no significant differences existed between techniques (69).

Ozyurek *et al*. compared the efficacy of ProTaper Next (PTN; Dentsply Maillefer, Ballaigues, Switzerland), Twisted File Adaptive (TFA; Axis/SybronEndo, Orange, CA), Reciproc (PRC; VDW, Munich, Germany), PTUR systems using the AutoCAD software (Auto-desk, San Rafael, CA). They concluded that the PTN and the PTR resulted in less amount of remaining filling compared to the TFA and RPC. The authors attributed the better results obtained with these 2 methods to the biggest final apical taper (.06) of PTUR and the unique offset design of ProTaper Next. (70).

A micro-CT study by Bago *et al.* evaluated Reciproc Blue, Reciproc and PTUR in terms of the removal of epoxy resin-based sealer and gutta-percha istraight canals with oval shape.

Reciproc system was determined to clean significantly higher amount of filling in comparison with ProTaper Universal and Reciproc Blue. No difference was found between the latter techniques. The authors explained better result obtained with the Reciproc instrument with the h S-shaped cross section of Reciproc which provided a better cleaning compared with PTUR which had a triangular cross-section (71).

De Castro *et al.* evaluated retreatment ability of ProTaper system using different methodologies. They compared the use of this instrumentation system alone and in combination with Orange Oil or Passive Ultrasonic Irrigation. They evaluated the samples by utilizing confocal laser scanning microscopy and evaluated them with the help of a software. Their results demonstrated that PTR used in combination with PUI gave better results (72).

Bioceramic sealers which recently gained more popularity due to their favorable properties have also been assessed in terms of their retreatability using PTUR. Kakoura and Pandelidou evaluated the remaining filling material when 4 types of root fillings were used. They filled the root canals using GP/AH26, GP/TotalFill BC Sealer, and GP/BioRoot RCS. The samples were examined under SEM, to determine the remaining material following instrumentation using PTUR (Dentsply Maillefer, Ballaigues, Switzerland) and further instrumention until size 50/.04. Their results revealed no significant difference in terms of the residual material left in the root canal (73).

Patil *et al.* (74) compared D-Race, ProTaper, MTwo retreatmet files and manual Hedström files in cleaning of material using the Software Image J on photos taken by the stereomicroscope at X8 magnification. ProTaper retreatment files and D-RaCe files revealed more successful results in terms of root filling removal compared to other instrument systems (74).

Raj *et al.* (75) used a similar methodology for the comparison of D-Race, PTUR and Hedström files in the removal of gutta-percha. They evaluated the systems at 3 levels of root canal and their results demonstrated that PTUR retreatment files showed better performance compared to the other methods. Performance of PTUR was found to be better at middle third compared with other techniques (75).

ProTaper retreatment system was investigated in terms of its performance in removing 3 different types of fillings which were Thermafil, GuttaCore or vertically compacted gutta-percha and AH Plus. Removal mof material and dentine were evaluated by using micro-CT.

Residual material and dentine removal were determined to be similar in all techniques that were included (76).

In a micro-CT evaluation performed by Rubino *et al*., PTUR and Mani NRT-GPR were compared. The results showed that PTUR system was more effective and removed significantly more dentine in curved mesial canals of lower molar teeth (77).

Another micro-CT study was conducted by Wulandari *et al.* in which rotary and reciprocating systems were compared. The authors concluded that the reciprocal motion (R25- Reciproc Blue system) instrument removed higher amount of material from root canal, specifically in apical 1/3rd. The authors explained this with the larger helical angle of Reciproc Blue compared to ProTaper Universal retreatment system. Furthermore, they attributed the finding to the fact that PTURS performs and in and our motion whereas Reciproc Blue employs both in and out and brushing motion which causes more successful preparation of canal walls (78).

In a micro-CT study, root canals filled with Gutta-core carrier system in combination with AH-Plus sealer were retreated using ProTaper Retreatment instruments, Reciproc Blue and a technique using Gates-Glidden drills and Hedsrom files. The teeth in PTR group exhibited statistically lower residual carrier-based root filling compared to the H-GG group. On the other hand, no significant differences were observed between the amount of remaining carrier-based materials of the RCB50 and PTR groups and between the RCB50 and H-GG study groups. They added that PTUR has a greater internal core and area, and a convex triangular section, variable taper, and a helical pitch that showed continuous change. This feature causes efficient cutting and coronal withdrawal of gutta-percha material (79).

In another study in which images of split portions of root canals surfaces were evaluated in terms of the quality of retreatment, canals filled using GuttaCore Pink, Thermafil and warm vertical compaction methodology were retreated by PTUR in combination with Protaper Universal. No significant difference was found between groups in. The authors indicated that according to the manufacturer, GuttaCore Pink has a rigid central core, which includes crosslinked gutta-percha, it is not influenced by heat applied by oven and is more easily removed compared to systems which utilize plastic or metal carriers. Their results confirmed this finding because GuttaCore Pink could be dislodged from canal within a shorter period than Thermafil (80).

Keshav *et al.* retreated canals of premolars filled by Resilon using Hedstrom files and PTUR using orange oil as solvent. Lesser percentage of filling was observed with the PTUR compared to hand files. The authors stated that Orange oil was used as a solvent solution in their study due to its biocompatible properties and lower amount of cytotoxicity compared to other types of solvent solutions. They also attributed the better result obtained with PTUR with the characteristics of the system. The indicated that the system pulls material out of the root canal through flutes (81).

2.2.2. Wave-One Gold System

WaveOne GOLD (Dentsply Sirona, Ballaigues, Switzerland) is a reciprocating single file system which is manufactured utilizing an innovative thermal process resulting in a super-elastic file. Treatment performed by heat changes transformation temperatures where transformation occurs (austenitic start and austenitic finish), which is indicated to have a positive influence on the characteristics of the files (82).

Instruments of the system have sizes 20, .07 taper (small), 25, .07 taper (primary), 35, .06 taper (medium) and 45, .05 taper (large), and they possess a parallelogram-shaped cross sectional design having a round shaped tip. They exert a rotational cutting action to the left, thus require special device to be used (83). The cross-section of Wave One Gold differs from its predecessor WaveOne which has a convex triangular cross-sectional structure as well as larger size and taper (84). The parallelograms of their cross section are ordered spatially in a discontinuous manner. This provides variation in the point of contact between every instrument and walls of the canal. This action was described to reduce taper lock risk (85). This property also provides successful debris removal and prevents apical blockage (86).

WaveOne GOLD files are designed with a reverse cutting helix, engage and cut dentine in a counterclockwise (CCW) direction with 150 degrees and then, disengages in a clockwise (CW) direction with 30 degrees. The overall movement cycle is 120 degrees and following 3 cycles, the file makes reverse rotation of 360 degrees (82). According to the manufacturer, WaveOne GOLD files should be utilized with brushing action to decrease resistance and provide an efficient instrumentation in canals with irregular anatomical properties. Brushing motion is suggested to eliminate coronal irregularities, create space laterally, and enhance the inward advancement of the instrument. The brushing action is also stated to reduce the contact between the file and dentine, which eliminates the possibility of complications such as taper lock, and permits the instrument to operate easily (82).

2.2.2.1 Studies Evaluating The Retreatment Capacity Of Wave One Gold Technique

Although instruments using a reciprocating motion were initially manufactured to be used for root canal preparation, the flexibility and fatigue resistance of these instruments allowed them to be feasible alternatives in retreatment, as well. Thus, studies were conducted which evaluated the retreatment capacity of these files, one of which is Wave One Gold.

Ekici et al. (87) compared cleaning of various materials by using Wave One Gold Reciproc file. The authors performed retreatment on premolar teeth filled using MTA Fillapex, EndoREZ and AH 26. Following sectioning the teeth longitudinally, they evaluated filling material using a digital camera. Their results showed that none of the sealers could be totally removed. MTA‐based sealer was found to be removed speedier than resin‐based ones (87).

Azim *et al.* (88) evaluated the retreatment ability of 3 systems using single files:

WaveOneGold (WOG) Primary, Hyflex EDM "one file" (EDM; Coltene/ Whaledent, Alstatten, Switzerland), and XP Shaper (XP; FKG, La Chaux de Fonds, Switzerland) were compared using mandibular anterior teeth. Cone-beam computed scans were taken before and after the teeth were retreated. XP was determined as the most effective method in the removal of gutta-percha from canals when used at a higher speed (3000 rpm) followed by EDM and WOG. They explained their finding with the result of another study which suggested that features of WOG may not be able to provide sufficient space for removed debris to be carried which adversely affected its cutting ability (89). They added that although the cross-section of EDM instruments showed similarity to WOG from D0 to D3, it was more successful in removal of gutta-percha in comparison with WOG. They explained this finding with the suggestion that full rotation may be a more preferable and appropriate cutting motion compared to reciprocating motion when retreatment is concerned (88).

In a micro-CT study, mesiobuccal roots of lower molar teeth were assigned in 3 groups. These were: WOG—WaveOneGold Primary and Medium; PTG—ProTaper Retreatment and ProTaper Next; RCG—D-RaCe and RaCe. There was no significant difference between groups at any moment; however, during shaping, WOG was determined to be faster than PTG and RCG. The authors commented that despite attempts to facilitate enlargement of root canal with shaping following removal step, no significant reduction in terms of remaining material was determined in apical third in all groups. They suggested the utilization of supplementary files such as XP-Endo Finisher as well as passive ultrasonic irrigation to obtain better results (90).

Sarıyılmaz *et al.* examined the effect of novel reciprocating techniques in gutta-percha removal from canals filled using the warm vertical compaction methodology. Reciproc Blue, Reciproc, WOG and hand instrumentation were systems used in the study. Teeth were split and each root half was examined at ×10 magnification under stereomicroscope. Analysis of the the images was performed using Image J software. They concluded that the success of Reciproc Blue, WOG and Reciproc in root canal filling removal were similar and more successful than hand instrumentation. They commented that the offset cross-sectional design and lowered taper might be responsible for successful filling removal of WaveOne Gold by facilitating penetration and coronal extrusion of the filling material (91).

Borges *et al.* not only evaluated the efficacy of different reciprocating systems but they also investigated the effectiveness of complementary systems using the micro- CT and scanning electron microscope. The reciprocating systems used were Reciproc Blue (RB): 25/0.08 and 40/0.06; ProDesign R (PDR): 25/0.06 and 35/0.05; and WaveOne Gold (WOG): 25/0.07 and 35/0.06. On the other hand, the complementary systems were XP-Endo Shaper (30/0.01); passive ultrasonic irrigation (PUI); 60° oscillatory instrumentation with #30 H-file. Results indicated that the reciprocating systems were similarly effective in removal of material whereas additional instrumentation using XP-Shaper facilitated material removal (92).

Canali *et al.* compared the efficiency retreatment between Wave One Gold and Wave One by using Micro-CT and confocal microscopy. They determined that WG showed a similar performance compared to WO. The time necessary was shorter for WO 25 than WG 25. They added that Wave One Gold could serve as an alternative method for retreatment procedures because there was no difference compared to WaveOne (84).

Bago *et al.* ompared some rotary and reciprocating systems which included: ProTaperUniversal Retreatment system + ProTaper Gold (PTG) instrumentation system up to PTG F2; Reciproc Blue system up to the instrument RB25; Reciproc system up to the instrument R25 and Wave One Gold (WOG) system up to the instrument WOG25. Their results demonstrated that the four systems were equally effective in removal of material and additional shaping using larger files provided a better removal of filling materials (93).

A study on the efficacy of WOG and MTwo retreatment files used for removal of carrier-based gutta-percha materials was conducted by Maruşter *et al.* Retreatment with 2 systems was carried out without any solvent and a scoring was given after photographing the images of the retreated samples. Their results demonstrated that none of the files could remove all

GP, however WOG system was found to be more effective. The authors also supported the use of single file techniques by indicating that single-file rotary systems can be utilized with high level of predictability, including retreatment due to shorter time it takes to complete the procedure. They added that WaveOne files were produced to provide superior hygiene and significantly reduced contamination because of single use of file (94).

A systematic review comparing the retreatment efficacy of rotating and reciprocating files showed that neither system could totally clean previous material. The authors underlined the necessity of conducting further studies comparing these 2 systems (95).

Chen *et al*. evaluated the retreatment of canals having curvature filled by gutta-percha (GP) and iRoot SP by 3 systems. Micro-computed tomographic analysis was selected to compare the retreatment potential of PTUR + ProTaper Next system up to PTN X2, Waveone Gold (WOG) system (WOG25) and Reciproc Blue (RB) system (RB25). They concluded that all 3 instruments exhibited similar retreatment ability in curved root canals filled with gutta-percha and iRoot SP. They added that Reciproc Blue may be more effective and safer in curved cases specifically in the apical portion due to its structural characteristics such as S-shaped design having sharp cutting edges and larger chip space as well as the larger taper size at the tip (96).

2.2.3 Xp-Endo System

XP-Endo is a new expandable, newer generation system which includes XPES and Finisher (FKG Dentaire SA, La Chaux‑de‑Fonds, Switzerland)**.** The innovative system is produced by heating the Ni-Ti alloy during production and by heat treatment and hardening, the flexibility of the instrument is increased. A unique feature of the system is that it provides a three-dimensional instrumentation which also engages the irregularities of the root canal. XPES hasa rotary Ni‑Ti snake‑shaped instrument. This file has an initial taper of 0.01 in the M phase when cool (97)**.**

XP Endo Finisher

FKG manufactured the XP Endo Finisher® (XPEF) in 2015 for shaping the canal to facilitate the effect of irrigating solutions as well as removal of smear layer. The instrument is produced from an alloy named MaxWire (Martensite‑Austenite Electropolish -FleX, FKG Dentaire). The file is straight in M phase when cooled, and it converts into A phase in body temperature. In the body temperature, it will acquire a spoon shape having a length of 10 mm from the tip and a depth of 1.5 mm due to molecular memory. The file is recommended to be

utilized at 800 rpm and 1.0 Newton Torque using irrigants after canal preparation to size #25 or larger. The diameter of the instrument is ISO #0.25 and it has 0 taper (97).

XP Endo Shaper

XPES file was introduced by FKG in 2016. Similar t XP-Endo Finisher, this instrument is also manufactured using MaxWire alloy; it has a 4% taper and an ISO #30 apex. The insturment has a unique design, that impresses its shape within the canal, however it has a waves throughout its body. With such a structure, the instrument maximally engages the root canal walls when expanded. This is called Adaptive Core Technology. The tip of XPES has a booster tip and has 6 cutting blades to provide superior guidace. The tip has a minimum diameter of #0.15 and a maximum diameter of #0.30. When used at body temperature, the instrument converts to the austenite shape and the high flexibility allows the instrument to cover taper up to 8% and canal diameter up to #0.90. The instrument has a taper of 1%. The file has M phase below 35°C and converts to austenitic phase at above 35°C along with taper of 0.02–0.08. The tip size of the instrument is #30–#90. It functions with a minimum torque of 1 Nw (97).

XP Endo Finisher‑R

This file was introduced in 2017 and is dedicated to retreatment. The XPEF‑R has stronger core compared to XPEF and its diameter is ISO #0.30 (97).

The XP-endo Finisher R is manufactured to provide an ideal cleaning during retreatment procedure. The tip size is 30, has no taper and uses an innovative alloy technology which has the ability to expand under body temperature, converting into a ‘spoon’ shape. When utilized mounted on a motor with rotary motion, the instrument is subjected to compression and its tip is projected and causes abrasion of canal walls. The instrument both displaces the remaining root filling following traditional methods but it also has the potential to agitate the root canal irrigant. XP-endo Finisher R has similar characteristics with XP-endo Finisher.

The major differences are the larger tip (size 30 for XP-endo Finisher R and size 25 for XP-endo Finisher) and the semiactive tip (98).

A study reported that the quality of cleaning and removing gutta‑percha is excellent (99).

2.2.3.1 Studies Evaluating The Retreatment Capacity Of Xp-Endo Technique

Alves *et al.* compared the efficacy of a reciprocating and a rotary system followed by a complementary instrumentation using XP-Endo Finisher system. They both compared the effectiveness of Reciproc with Mtwo which are instruments having similar cross-section and the effects of utilizing 2 sizes of Reciproc (R25 and R40) on filling removal. Furthermore, they evaluated the effect of XP-Endo-Finisher as an adjunctive instrument. The authors who used the micro-CT technique concluded that MTwo was more effective than Reciproc and XP-Endo Finisher exerted a significantly favorable effect on filling material removal. The authors commented that using XP-Endo Finisher gave promising results because the residual material's volume was highly decreased after the instrument was used as an adjunct. They attributed this result to the fact that the instrument's expansion at body temperature as well as the helical motion may have caused it to engage and remove the material. They added that although PUI is another supplementary strategy, there are some studies with conflicting results (100).

Ozyurek and Demiryurek (101) compared the effect of 3 activation systems on the removal of filling which were XP-endo Finisher (XP), EndoActivator (EA) and IrriSafe (IS). The amount of material in the XP group was found to be lower compared to the other groups. The lower amount of material in the XP group was attributed to the fact that when the file converts from martensitic to austenitic phase at a temperature above 35°C, the file can expand until 100 times its diameter and touch all the walls (101).

Karamifar *et al.* compared the effect of hand instruments, RaCe and RaCe plus XP-endo finisher instruments in removal of gutta-percha during retreatment using Image J software. Their results demonstrated that XP-endo finisher file provided cleaner canal walls and was more successful in carrying gutta-percha from the coronal toward the apical. The efficacy of XP-endo finisher was attributed to its metallurgical properties as well as elliptical movement within the root canal. The authors commented that this type of movement facilitated the instrument's access to inaccessible parts of canal (102).

In a micro-CT study by Silva *et al.*, the efficacy of removal from oval-shaped canals following usage of additional files (XP-endo Finisher and XP-endo Finisher R) was evaluated using micro-CT. Both XP-endo files were found to be similarly efficient in removal. The authors indicated that they specifically selected oval canals because the circular anatomy caused further difficulties in terms of retreatment. They added that XP-endo Finisher R was

different in terms of its core diameter and the angulation of tip compared to the XP-endo Finisher and this property made this file more aggressive and effective in root filling removal. Despite this, no difference was found between the 2 files. The authors commented that future studies could be planned which investigated the performance of XP-endo used with or without solvent (99).

In a micro-CT study by Aksel *et al.,* PTUR followed by complementary instrumentation with XP-Endo Finisher was evaluated in terms of removing filling. AH Plus, NeoMTA Plus and EndoSequence BC were used as sealers along with the single cone technique. Micro-CT analysis showed that supplementary shaping with XP Endo Finisher provided improvement in removal of materials (103).

Campello *et al.* evaluated success of eucalyptol in facilitating material removal from canals combined by isthmuses, and additional cleaning efficacyof XP-endo Finisher R. Retreatment was performed using MTwo instruments. Their results indicated that eucalyptol was not effective in the removal of material from molar mesial canals having Vertucci's type II configuration and isthmuses. On the other hand, XP-endo Finisher R had a significant effect in the removal of material from canals and isthmuses. Evaluation of remaining material was conducted using the micro-CT. The authors suggested that because some material may be compacted in isthmuses during retreatment, supplementary approaches may be helpful (104).

Another study was conducted by de Deus *et al.* (2019) who performed retreatment in canals with oval configuration using Reciproc R25 instruments. Supplementary steps were completed by XP-endo Finisher R or PUI and the removal of the filling was evaluated by micro-CT. Although no technique was found to be successful total removal of filling from oval canals, XP-endo Finisher R removed significantly more filling compared to PUI. The authors indicated that the function of XP-endo Finisher R instruments appears to be better in removing filling than activation of irrigants using PUI which provides cavitation and acoustic streaming (98).

Machado *et al*. (105) evaluated preparation using Self-Adjusting File (SAF), TRUShape and XP-endo Shaper systems, and an additional final step with XP-endo Finisher R in lower molars.

The results of the miro-Ct examination showed that all systems were similarly effective in removing material from the apical 5 mm. The additional final step with XP-endo Finisher R facilitated the removal of material. The authors summarized benefits offered by XP-endo

Finisher R such as expansion which allowed reaching 100-fold in comparison to a conventional instrument having same dimensions. They suggested that this feature might cause it to engage more root canal walls and facilitate cleaning. XP-endo Shaper yielded better results than TRUShape in terms of total filling removal (105).

Kapasi *et al.* (106) compared efficacy of hand files, PTUR and XP-endo files using CBCT. XPS + XPF-R was determined to remove gutta-percha more efficiently. They indicated that XPF is less effective compared to its newer version which is XPF-R due to differences in core diameter and tip angulation. This configuration gave XPF-R stiffness and more aggressiveness. Furthermore, XPF-R did not sacrifice sound dentin during instrumentation which was considered as an additional advantage. The authors attributed this to the instrument's flexibility, zero tapers, and NiTi MaxWire technology. The instrument was found to be able to move towards every corner and walls of canal system and removed debris by respecting the original path of root canal (106**).**

In a radiological evaluation study using split teeth, complementary cleaning using XP-Endo-Shaper following D-Race rotary and S1 reciprocating instruments, consistent with the results of previous studies (107).

Considering that most studies evaluated removal of root filling in short-term, Liu *et al.* (108) investigated the efficacy of XP-Endo instrument in the retreatment of teeth aged as long as 54 months using micro-CT. The authors concluded that even though the combined use of XPS and XPFR facilitated removal of bulk of aged material from lower molar teeth, retreatment in the apical portion of teeth filled using vertical condensation remained to be a challenge. They explained this by stating that warm vertical compaction compacted the material deeply into irregularities such as isthmus, fin and oval-shaped canals (108).

A study evaluating the removal of Thermafil and GuttaCoreRemoving Thermafil and GuttaCore by XP-Endo retreatment system using micro-CT concluded that The XP-endo Finisher system removed both GuttaCore and Thermafil gutta-percha carrier-based materials. GuttaCore required less time for removal. The authors explained the longer period required for the removal of Thermafil with the challenge of removing plastic carrier portion.

They also stated that variations in tip of XP-endo Finisher R allowed it to be more rigid and facilitated its effectiveness in removing materials (109).

In another micro-CT study, the efficacy of XP-Endo Finisher R and R1-Clearsonic inserted in material from oval canals following instrumentation with Reciproc R50.was evaluated. The results showed that neither instrumentswas efficient in totally removing material from the apical, however more favorable results were achieved using XP-Endo Finisher R in the entire length of the canal. The authors also drew attention to the fact that supplementary cleaning performed by the two supplementary instruments was less evident in the apical portion. They attributed this to the challenging anatomy of the apical region and emphasized that other protocols should be improved to enhance removal of filling in this area (110).

A recent meta-analysis on XP-Endo systems in retreatment concluded that supplementary utilization of XP-Endo Finisher and XP-Endo Finisher R is advantageous in additional cleaning of filling materials. XP-Endo Finisher R file was determined to be much better in removal of materials compared to other irrigant activation methodologies (111).

3. MATERIALS AND METHODS

3.1 Selection of The Sample Teeth

This study was approved by the Yeditepe University Clinical Research Ethics Committee with the decision number Kaek no:2023/1801.

Ninety extracted single rooted human teeth were used in this study. Inclusion criteria used during the selection were: single canals with Vertucci 1 root canal classification, root canals with curvatures less than 10° according to Schneider's method, no cracks or fractures as observed under the operating microscope (Zeiss Opmi Pro, Oberkochen, Germany), fully developed apices and no calcifications within the root canal system. *(Fig 1a) (*Selected experimental teeth*)* The teeth were measured at 5- and 10-mm distance from the apical using a *digital caliper* and those with similar dimensions were included. *(Fig 1 b)* (Measurement of the experimental teeth using a digital caliper) Residual soft tissue as well as calculus on the teeth were removed using ultrasonic devices and teeth were preserved in isotonic sodium chloride solution until use.

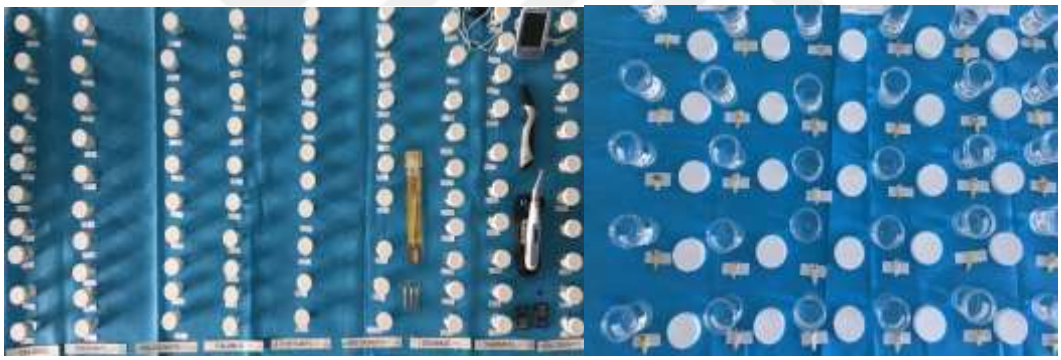

Figure 1 a Selected experimental teeth

Figure 1 b Measurement of the experimental teeth using a digital caliper

3.2 Preparation Of The Sample Teeth

Ninety teeth meeting the above mentioned conditions were separated from their crowns under water cooling by using a diamond separator (Horico. RINGLEB & CO. GMBH & CIE,Germany) and their root lengths were adjusted to 16 mm. *(Fig 2 a)* (Separated tooth using a diamond separator).

Figure 2 a Separated tooth using a diamond separator

3.3 Biomechanical Preparation Of The Sample Teeth

Root canal preparation of specimens was performed using Hyflex EDM Nickel-Titanium rotary instruments (Coltene/Whaledent, Altstätten Switzerland) *(Figure 3 a*) (Root canal preparation of teeth using Hyflex rotary instruments) using the following protocol:

A 25/12 Orifice Opener was used for access opening. Then, a Glide Path was formed using no. 10 K-files (Dentsply Maillefer, North America) and EDM Glide-Path file 10/0.05. Shaping was completed using 0.25 Hyflex One File until working length which was 16 mm. During shaping, instruments were mounted on a Dual Move Motor (MicroMega Besançon Cedex, France) *(Figure 3 b) (*Dual Movement motor used for shaping the root canals) Irrigation was performed using 2 ml. of 5 % NaOCl (Wizard, Chemical Directory, Turkey) until 2 mm. short of the working length using 30-gauge side-perforated irrigation needles (KerrHawe SA, Switzerland) after each instrument and activation of the irrigation solution was performed using ultrasonic instruments for 20 seconds. *(Fig 3 c).* (Activation of the

irrigant during shaping using ultrasonics) Final irrigation was performed using 2 ml. of sterile saline Drying of the root canals was performed using paper points. (Diadent, Diadent International Group, Korea). *(Fig 3 d)* (Drying of root canals following irrigation) .

Figure 3 a Root canal preparation of teeth using Hyflex rotary instruments

Figure 3b Dual Movement motor used for shaping the root canals

Figure 3c Activation of the irrigant during shaping using ultrasonics

Figure 3d Drying of root canals following irrigation

3.4 Creation Of The Groups

Initially, the teeth were divided into 3 groups of 30 according to filling method used:

Group 1: Calamus Dual 3D Systems + AH Plus *(Fig 4 a).* (Photograph of Calamus Dual 3D System)

Group 2: Thermafil Obturators + AH Plus *(Fig 4 b).*

Group3 : Lateral Condansation +AH Plus *(Fig 4 c*).

Figure 4 a Photograph of the Calamus Dual 3D System

Figure 4 b Photograph of the Thermafil Obturation System

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Figure 4c Photograph of the lateral condensation system

Group1: Calamus Dual 3D Obturation System

Calamus Dual 3D Obturation System (Dentsply Tulsa Specialties, Tulsa, OK) consists of 2 parts which are: “Flow” and “Downpack”. The downpack is used in the apical 1/3 portion for vertical condensation. It consists of tips of different sizes that can be heated. Following the filling of the apical third portion, gutta-percha in the cartridge placed in Flow cap was heated and the remaining middle and coronal portions of the root canal were filled. Following shaping, irrigation and drying of the root canals, a 0.06 Taper No. 30 master cone was inserted and its adaptation was confirmed. AH Plus was placed within the root canals using gutta-percha cones. Care was taken during this procedure so that a thin layer of sealer remained on canal walls. Later, master cone was placed until the working length. A plastic stopper was mounted on the tip of plugger in the downpack part of the Calamus Dual 3D Obturation System so that 15 mm. of the plugger remained to be inserted in the root canal. The activator which provided the heating of the plugger was was pressed for 15 seconds so that the heat increased until 200 ° C. The plugger at 200 ° C was placed within the root canal so that 4 mm. of gutta-percha stayed in the apical and kept for 3 seconds. Later, the heat current was switched off. The plugger which cooled off was kept in the root canal for 10 seconds by applying an apical pressure; thus shrinkage of gutta-percha was prevented. Later, the plugger was activated again for 1 seconds and removed out of root canal. 12 mm. portion of the gutta-percha was removed using plugger. The remaining gutta-percha in root canal was vertically condensed by a small hand plugger (Dentsply Mailefer, Ballaigues, Switzerland).

Backfilling was performed in the remaining portion using the Flow portion of the Calamus Dual 3D Obturation System. The 20 Gauge cartridge was placed in the flow portion and the canulla was bent. Heat was increased until 160 ° C and flow to 60. The activator was pressed to allow heating of the gutta-percha and the cannula was placed in root canal. The cannula was removed after placement of 2-4 mm. gutta-percha. The gutta-percha was vertically condensed using a hand plugger. (Dentsply Mailefer, Ballaigues, Switzerland). This method was repeated for filling of remaining part of the root canal and once the filling was completed, it was controlled by radiography. The access cavities of the samples were sealed using (Coltosol F (Coltene/Whaledent AG, Switzerland) temporary filling. The 30 teeth filled with this method were preserved in an incubator at 37 ° C and 100% humidity for 2 weeks for the sealer to set.

Group 2: Thermafil Obturators

Following preparation, the final shape of canals was confirmed by a verifier. After this confirmation, canal walls were sealed with a thin layer of AH Plus. No. 30 and .06 taper Thermafil (Tulsa Dental prod, Tulsa, OK, USA) was heated in the ThermaPrep oven (Tulsa Dental prod, Tulsa, OK, USA) and slowly inserted until the working length. After a waiting period for the carrier to cool down, the carrier was severed at root canal access level. Following radiographic evaluation of the root filling, the 30 teeth filled with this method were preserved in an incubator at 37 ° C and 100% humidity for 2 weeks for the sealer to set.

Group 3: Lateral Condansation +AH Plus Root Canal Sealer

A no. 30 gutta-percha cone with (Diadent, Diadent Groups, Korea) with 0.02 taper was used as the master cone. After the root canal walls were sealed using AH Plus sealer, master cone dipped in the sealer was inserted in the root canal. A no. 25 Finger spreader was used for condensation. No. 20 gutta-percha cones with 0.02 taper were used as accessory cones. The procedure was completed until the spreader no longer penetrated more than 3 mm. The cones were cut at root canal access. following radiographic evaluation of the root filling, the 30 teeth filled with this method were stored in an incubator at 37 ° C and 100% humidity for 2 weeks for the sealer to set.

3.5 Retreatment

Each group was divided into 3 subgroups, consisting of 10 teeth and 3 different retreatment procedures were conducted as follows:

Group 1: Calamus Dual Core System

A. Protaper Universal System D Series (n:10)

B. Wave One Gold System (Assortment Reciprocating Files And Glide Path) (n:10)

C.XP-endo Retreatment System (D1R& Shaper&Finisher (n:10)

Group 2: Thermafil Obturation System

A. Protaper Universal System D Series (n:10)

B. Wave One Gold System (Assortment Reciprocating Files and Glide Path) (n:10)

C. XP-Endo Retreatment System (D1R& Shaper&Finisher R) (n:10)

Group 3: Lateral Condensation System

A. Protaper Universal System D Series (n:10)

B. Wave One Gold System (Assortment Reciprocating Files and Glide Path) (n:10)

C.FKG swiss endo XP-endo Retreatment System (D1R& Shaper&Finisher R) (n:10)

Retreatment using Protaper Universal System D Series:(PTUR)

The coronal 1/3rd portion of filling was removed using D1 instrument of the system, the middle 1/3rd was removed by using D2 instrument, and the apical 1/3rd was removed by instrument D3. Between all instruments, samples were irrigated using 2 mL of 5 % NaOCl solution. Irrigation in all samples was performed using a total of 10 mL NaOCl solution. As the final irrigation protocol; 5mL 17% EDTA was used for the removal of smear layer; later 2mL of 5% and NaOCl and finally 2mL saline were used to avoid detrimental effect of solutions. (Fig5a)

Figure 5a Irrigating Solutions used in the study

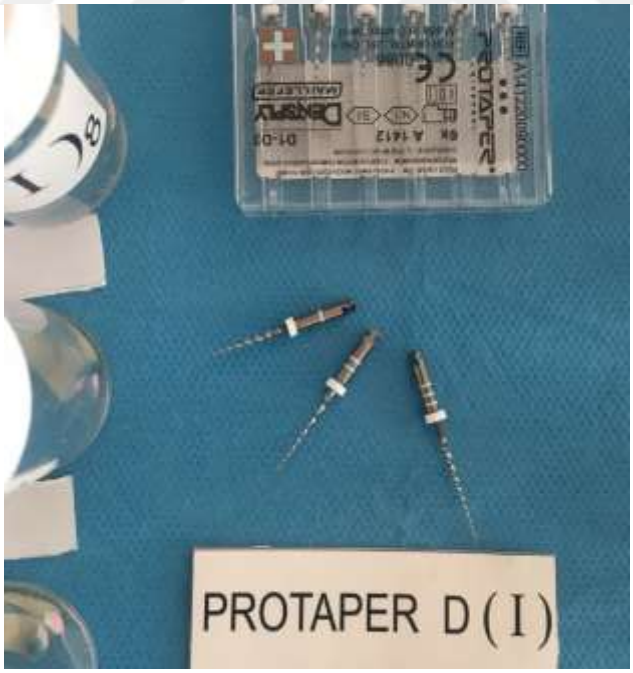


Figure 5 b ProTaper Universal Retreatment System (PTUR)

Retreatment using Wave One Gold System (Assortment Reciprocating Files and Glide Path)

WaveOne Gold Primary instrument was used for the removal of root filling. The instrument was used with a slow in-and-out pecking motion having amplitude of 3 mm and using a brushing motion on canal walls. The procedure was continued until the instrument reached the canal working length. *(Fig 5 c)* Wave One Gold Retreatment System. A similar irrigation protocol was followed as PTUR group.

Figure 5 c Wave One Gold Retreatment System

Retreatment using XP-Endo Retreatment System

DR1 instrument was placed into filling material and a 3-4 mm starting point was formed for the XP-endo Shaper tip. XP-Endo Shaper tip was inserted into prepared area in the filling. Pecking motion was used till the XP-endo Shaper´s tip engaged the gutta percha. Then, XP-endo Shaper was advanced until the working length using light pressure. Gutta percha was removed using XP-endo Shaper by gentle strokes until the working length. After irrigation using NaOCl, XP-endo Finisher R (ISO 30) was placed in the root canal and allowed to contact all the root canal surfaces with slow longitudinal movements. Filling left in the root canals was removed using copious NaOCl irrigation and suction. A similar irrigation strategy was followed as in other groups.

In all techniques, Endoultra ultrasonic instruments were applied for 20 seconds for facilitating the effect of the irrigation solution following irrigating with each solution. (Fig 5 d XP Endo Retreatment System)

After the completion of the retreatment procedures and final irrigation, all canals were dried by paper points. (Diadent, Diadent Groups, Korea).

Figure 5 d XP Endo Retreatment System

3.6 Evaluation Of The Residual Material

Grooves were prepared on teeth buccolingually using a diamond disc and sections were taken longitudinally by a chisel. Both root halves were examined under the operating microscope (Carl Zeiss, Oberkochen, Germany) at X 15 and images were transferred to the image analysis software (Autocad 2018, Microsoft, Redmond, Washington, USA) to measure the areas of residual filling material and root canal walls. (Fig 6 a AutoCad Software)

The borders of the filling material residue were marked using the software as well as the total canal area and recorded in millimeters. (Fig 6 b Calculation of the remaining material in the AutoCad system)

The percentage of remaining material in the root canal walls (A) was calculated by the following formula: A = (area of the remnant · 100)/area of root canal.

Statistical analyses were performed using SPSS software version 25. Descriptive analyses were written using means, standard deviations for continuous data. The variables were analyzed using Kolmogorov-Smirnov test to identify the type of distribution. Homogeneity of the variances was analyzed by Leneve's test. Since distribution of variables is normal and variances are homogeneous, ANOVA test was utilized to compare means of more than 2 groups. Tukey HSD test was used to investigate significance of pairwise for multiple comparisons. A 5% type-I error level was used to identify a statistical significance.

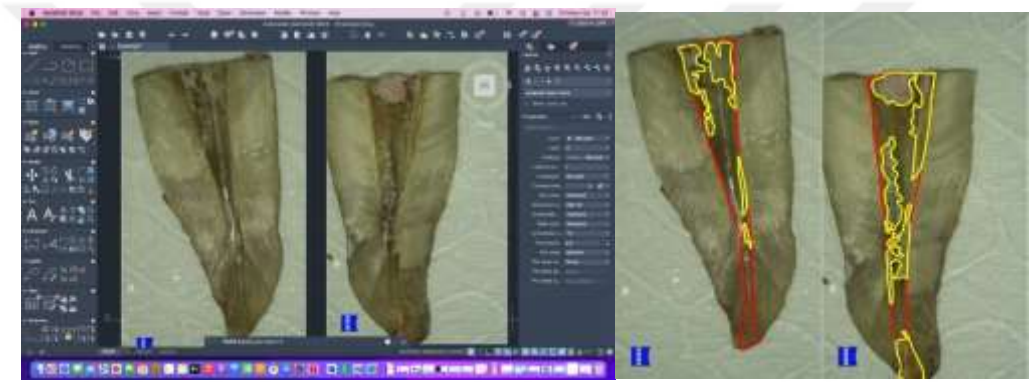


Figure 6 b Calculation of the remaining material in the AutoCad system

4. RESULTS

In the present study, ProTaper Universal Retreatment System, WaveOne Gold System and Xp-Endo System were compared in terms of their efficacy in the removal of filling material in root canals filled using the Calamus, Thermafil and Cold Lateral Compaction techniques. Images obtained using the dental operating microscope taken at X15 magnification were transferred to the computer and AutoCad Image analysis software was utilized to calculate area of residual filling and its ratio to the overall root canal.

Power Analysis

The number of samples used was calculated using the G*Power 3.1.9.2 program. A previously conducted study was taken as a reference and based on the differences in the measurements of this study, the high impact value was determined as 0.55, power as 95% and Type I tolerance as 5%. Therefore, it was considered suitable to include 90 teeth and 10 teeth in each group in the present study.

4.1. Design of the Groups

Group 1	Calamus + ProTaper Universal retreatment
Group 2	Calamus+ WaveOne Gold
Group 3	Calamus + XP-Endo
Group 4	Thermafil+ ProTaper Universal retreatment
Group 5	Thermafil+ WaveOne Gold
Group 6	Thermafil+ XP-Endo
Group 7	Lateral condensation + ProTaper Universal retreatment
Group 8	Lateral condensation + WaveOne Gold
Group 9	Lateral condensation + XP-Endo

4.2 Calamus Group

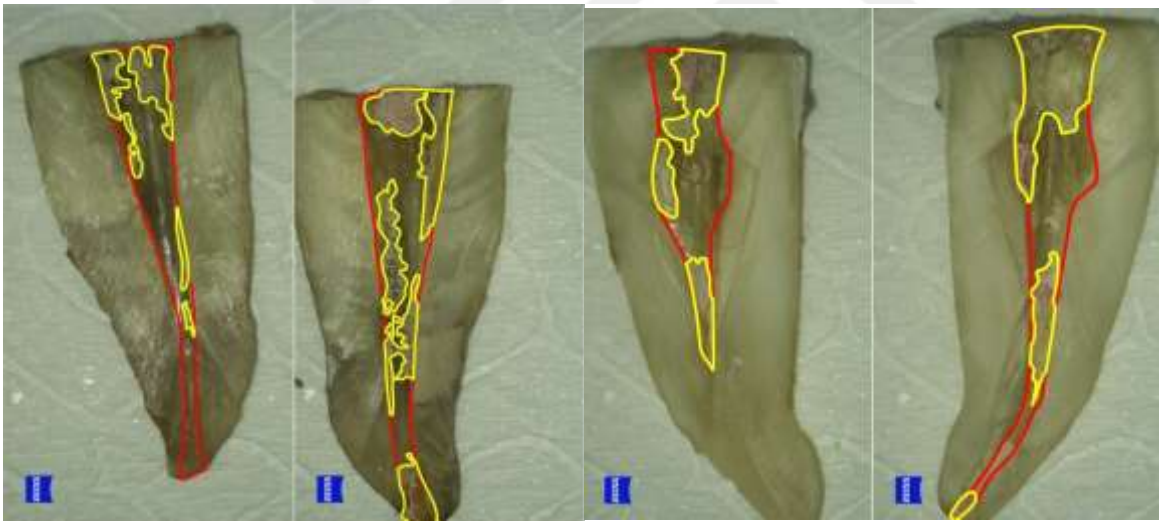
The percentage of material remaining in the Calamus group when 3 retreatment techniques were used is shown in Table 1. Figure 7 a shows the filling material in all samples of Calamus + PTUR Group. Figure 7 b shows the filling material in all samples of the Calamus+

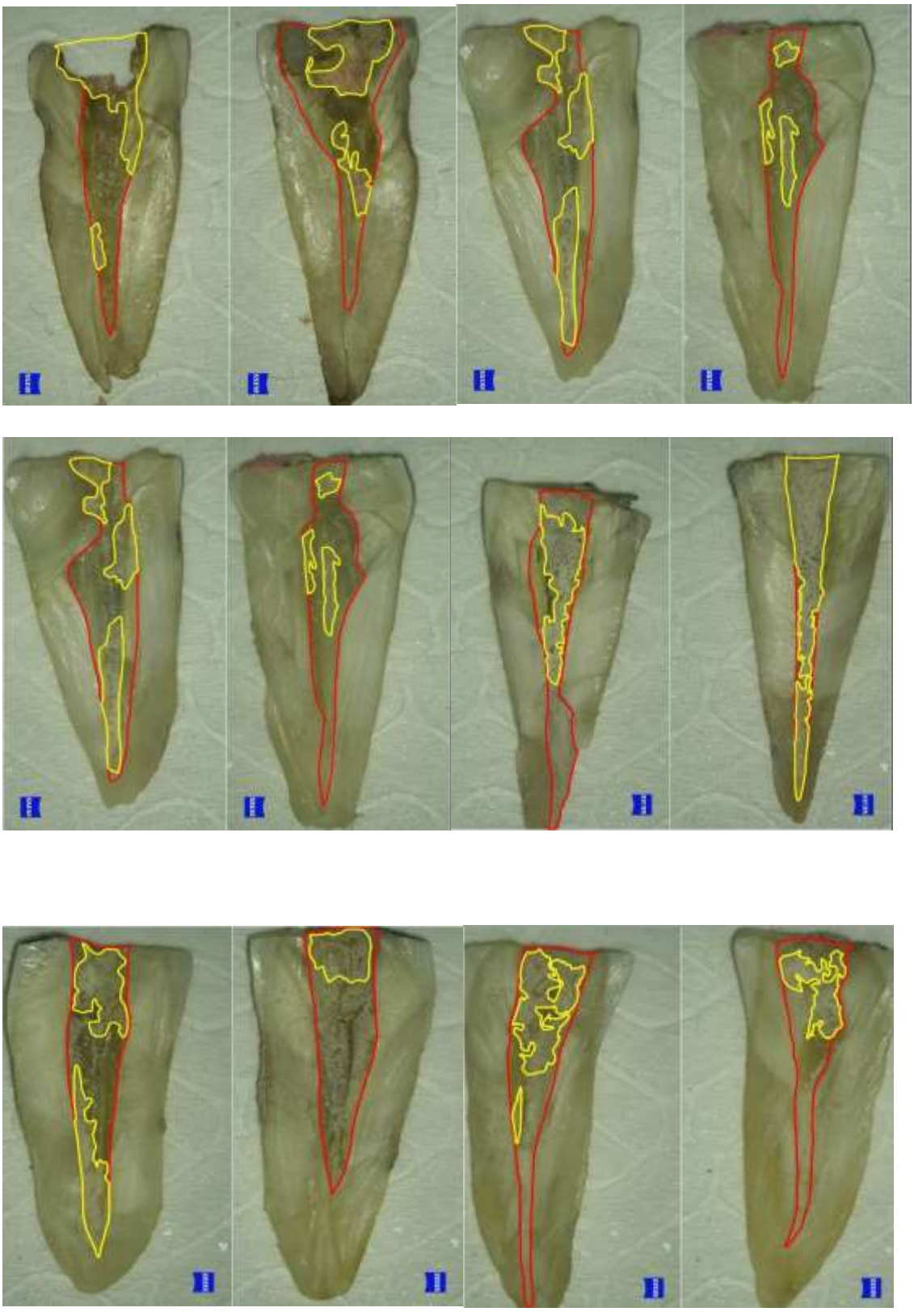
WaveOne Group. Figure 7c shows the filling material in all samples of the Calamus + XP Endo group.

CALAMUS

Table 1. The percentage of filling material remaining in the Calamus group

					95% Confidence Interval for Mean				
	N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum	P value
PTRU	10	43,04268	12,430766	3,930953	34,15025	51,93512	27,206	65,758	0,258
WOG	10	40,80607	19,871799	6,284014	26,59065	55,02150	4,575	70,874	
XP	10	30,50557	19,802666	6,262153	16,33959	44,67154	4,948	66,846	
Total	30	38,11811	17,973443	3,281487	31,40671	44,82950	4,575	70,874	





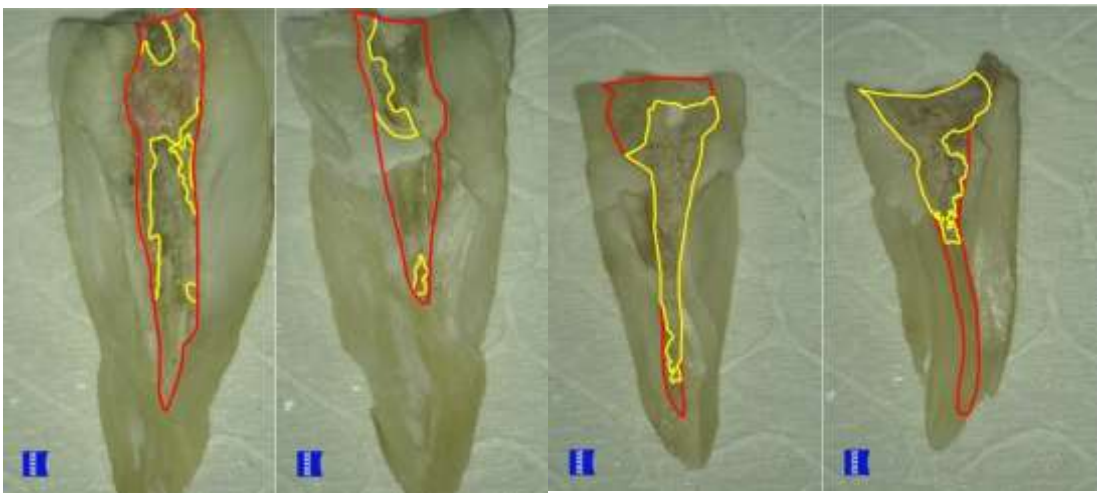
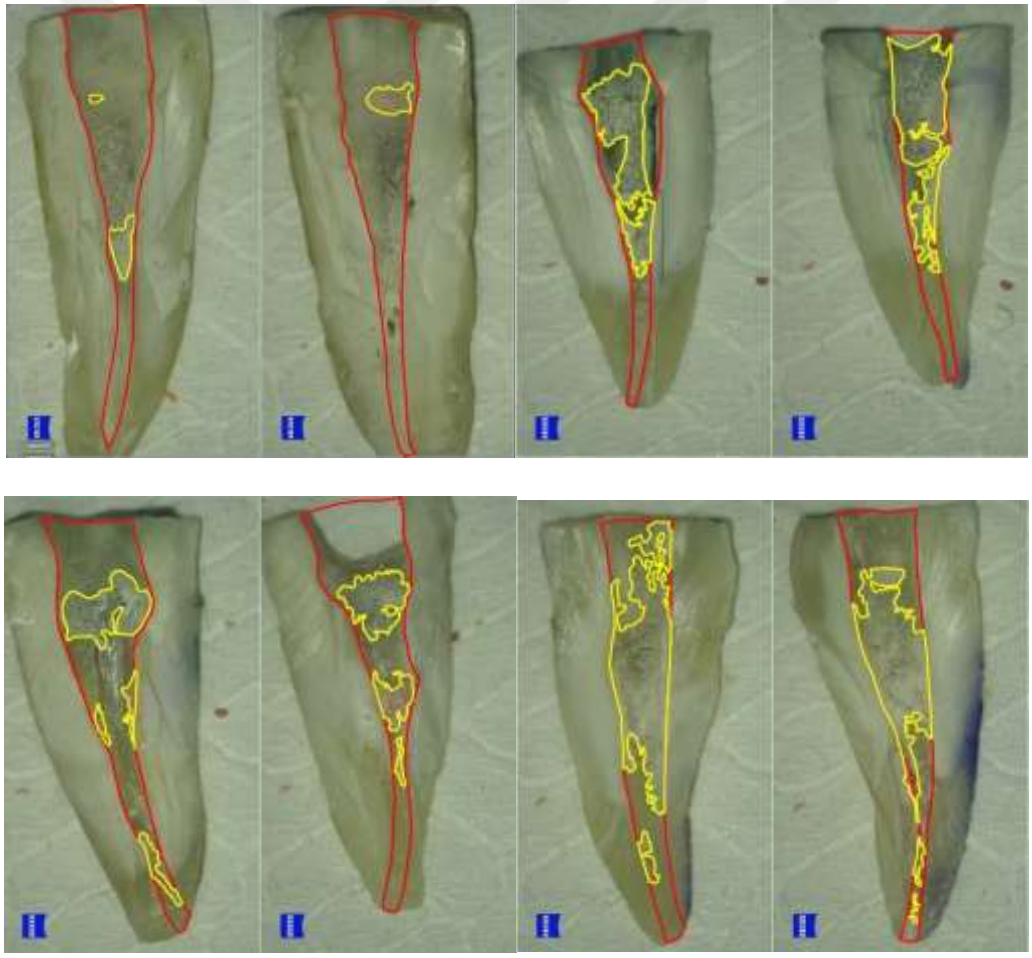


Figure 7 a the remaining filling material in all samples of the Calamus + PTUR Group



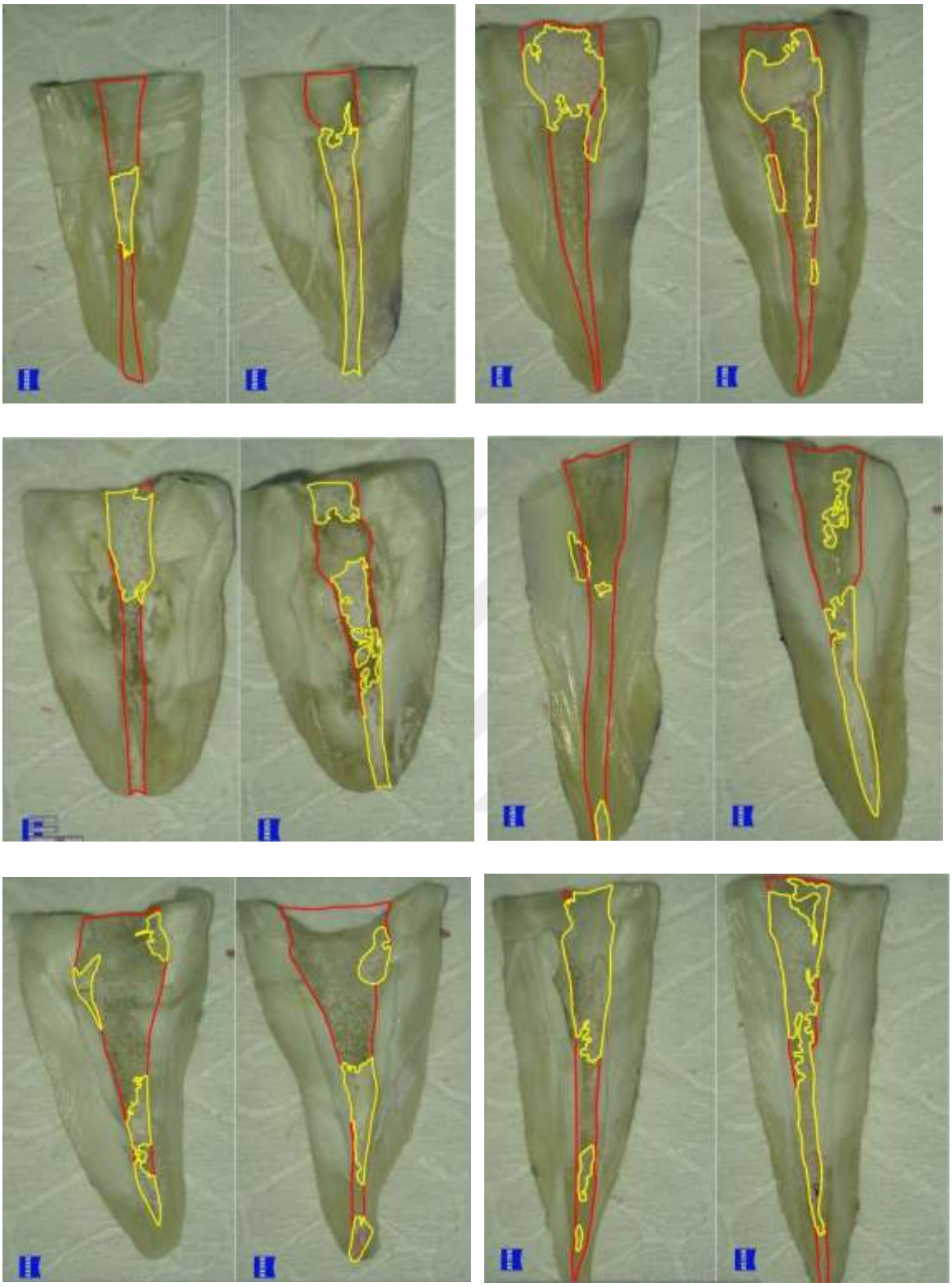
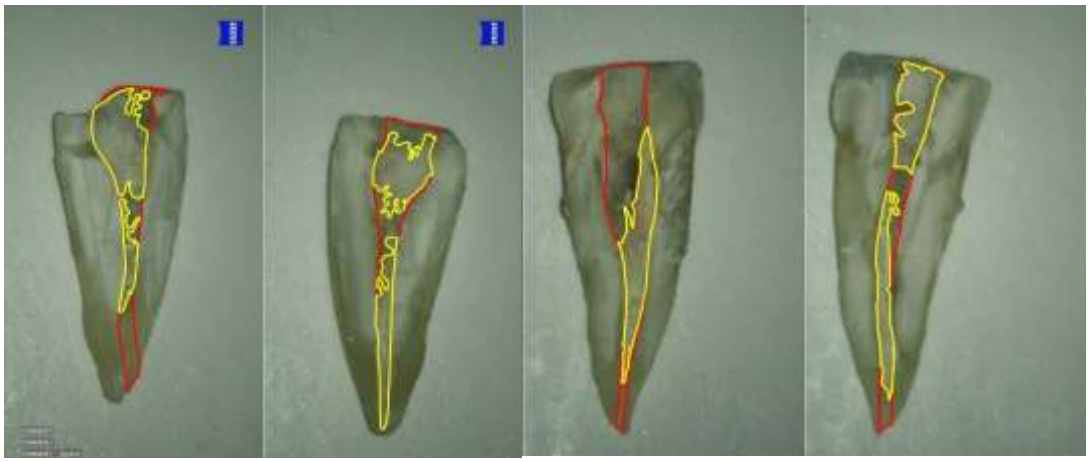
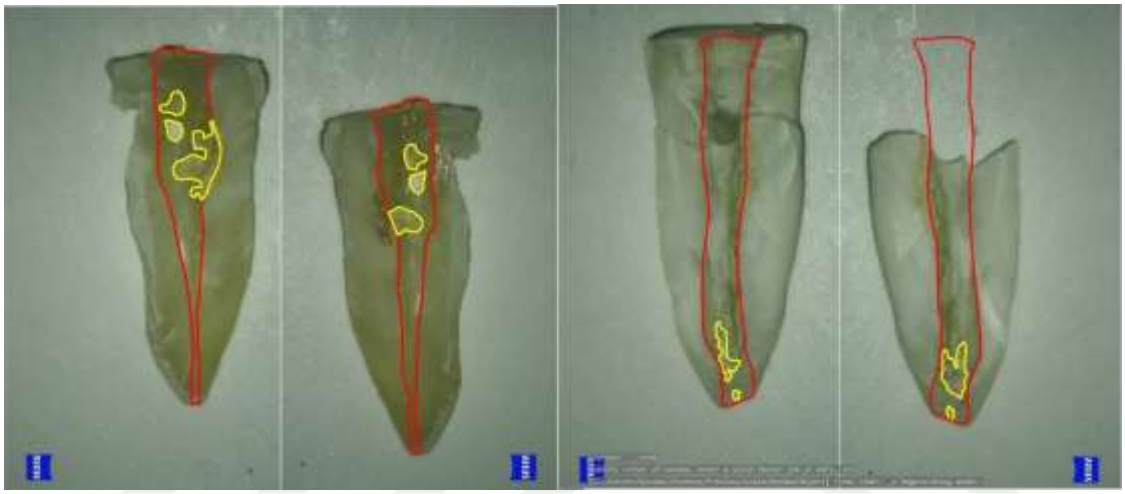
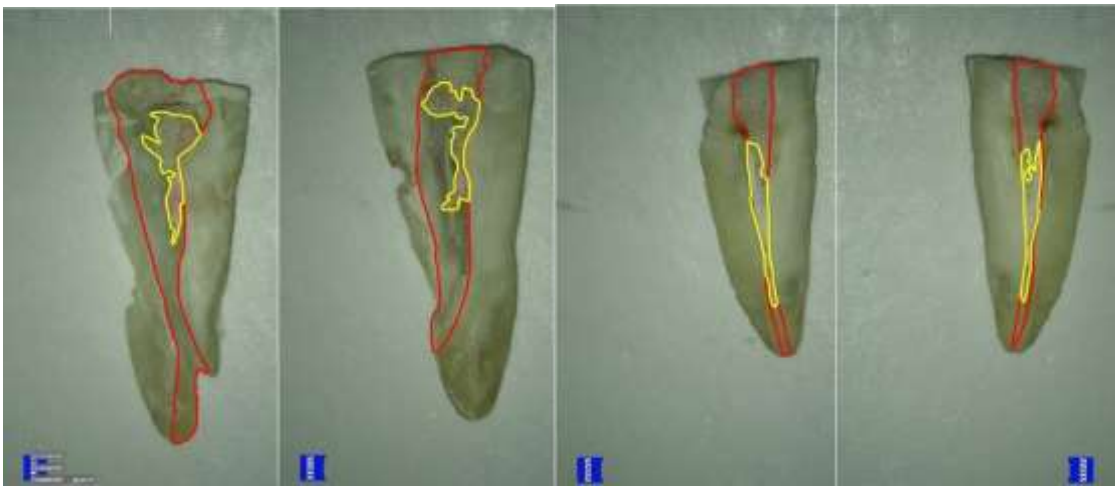


Figure 7 b the remaining filling material in all samples of the Calamus+ WaveOne Group







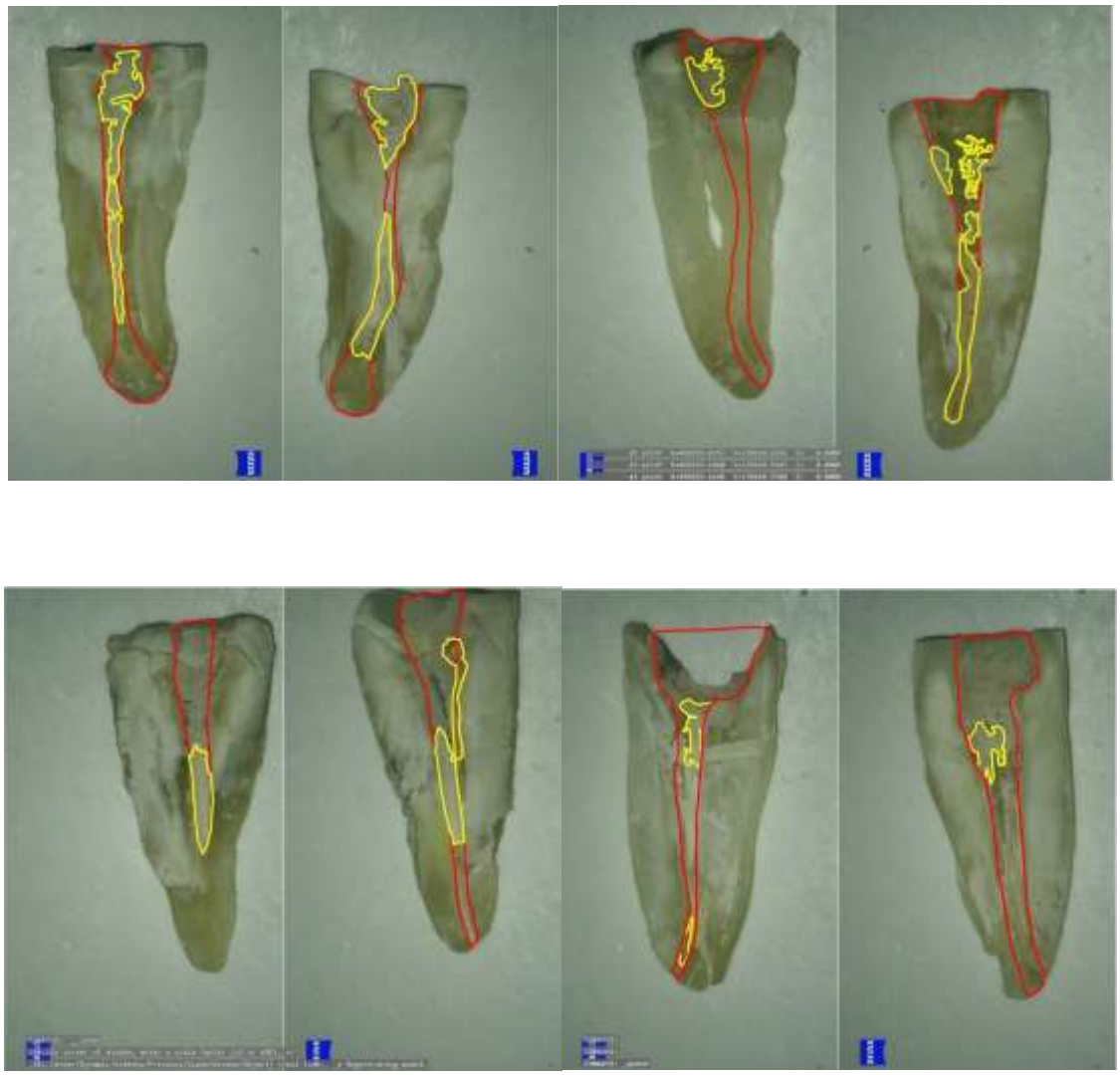


Figure 7c the remaining filling material in all samples of the Calamus + XP Endo Group

When the area of remaining filling was compared in the Calamus group, no statistically significant difference was determined between 3 techniques. $p>0.05$.

4.3. Thermafil Group

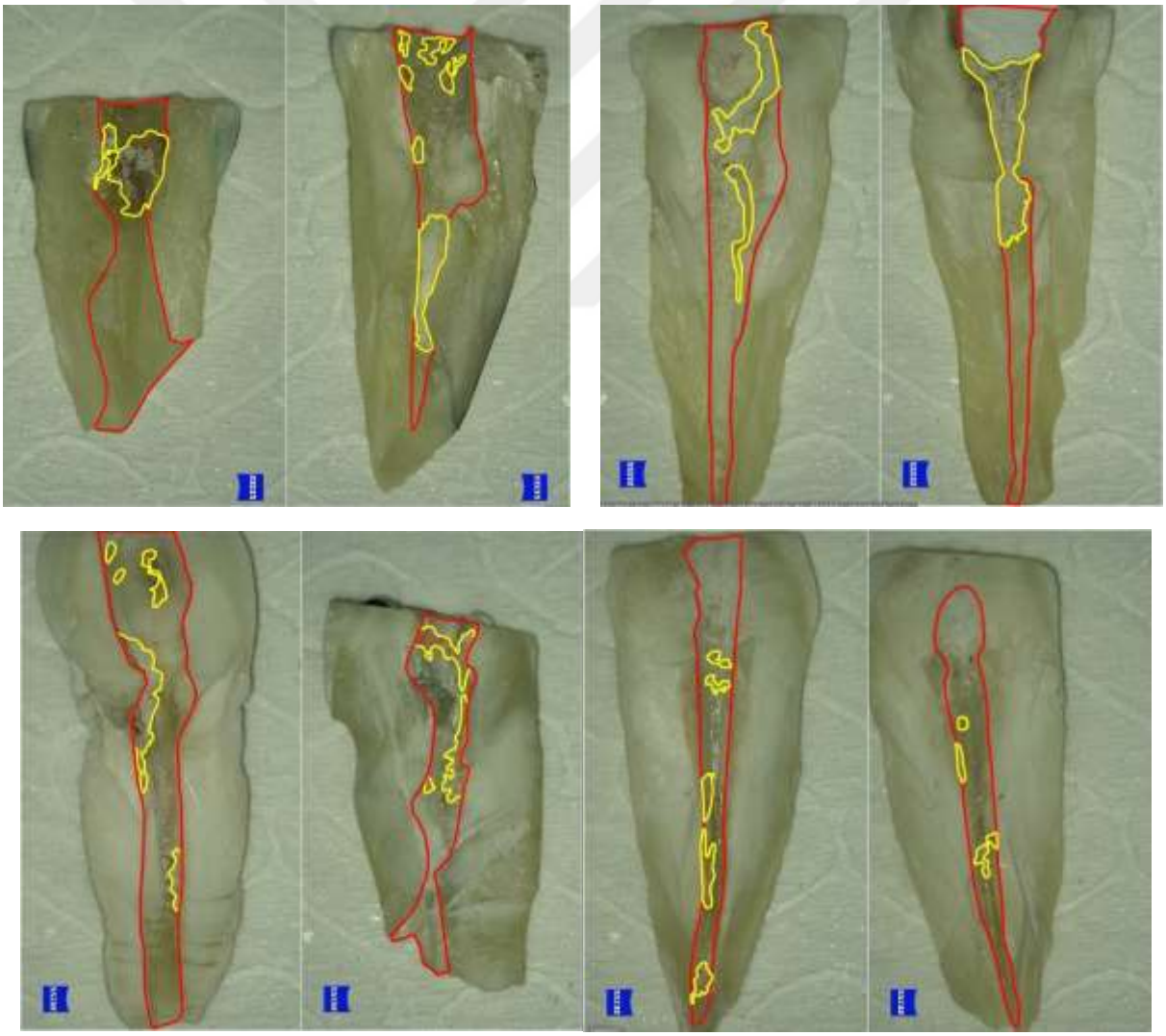
The percentage of material remaining in Thermafil group when 3 retreatment techniques were used is shown in Table 2.Figure 8 a shows the filling material in all samples of Thermafil +PTUR Group Figure 8 b shows the filling material in all samples of the Thermafil+Wave One Group. Figure 8 c shows the filling material in all samples of the Thermafil +Xp Endo Group.

THERMAFIL

Table 2 The percentage of the filling material remaining in the Thermafil group

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum	P value
					Lower Bound	Upper Bound			
PTRU	10	21,74791	9,717784	3,073033	14,79622	28,69959	8,313	42,623	0,315
WOG	10	29,73958	17,296596	5,469664	17,36634	42,11282	6,051	68,927	
XP	10	29,29129	10,415826	3,293773	21,84026	36,74233	14,052	45,693	
Total	30	26,92626	13,027965	2,378570	22,06154	31,79098	6,051	68,927	

ANOVA



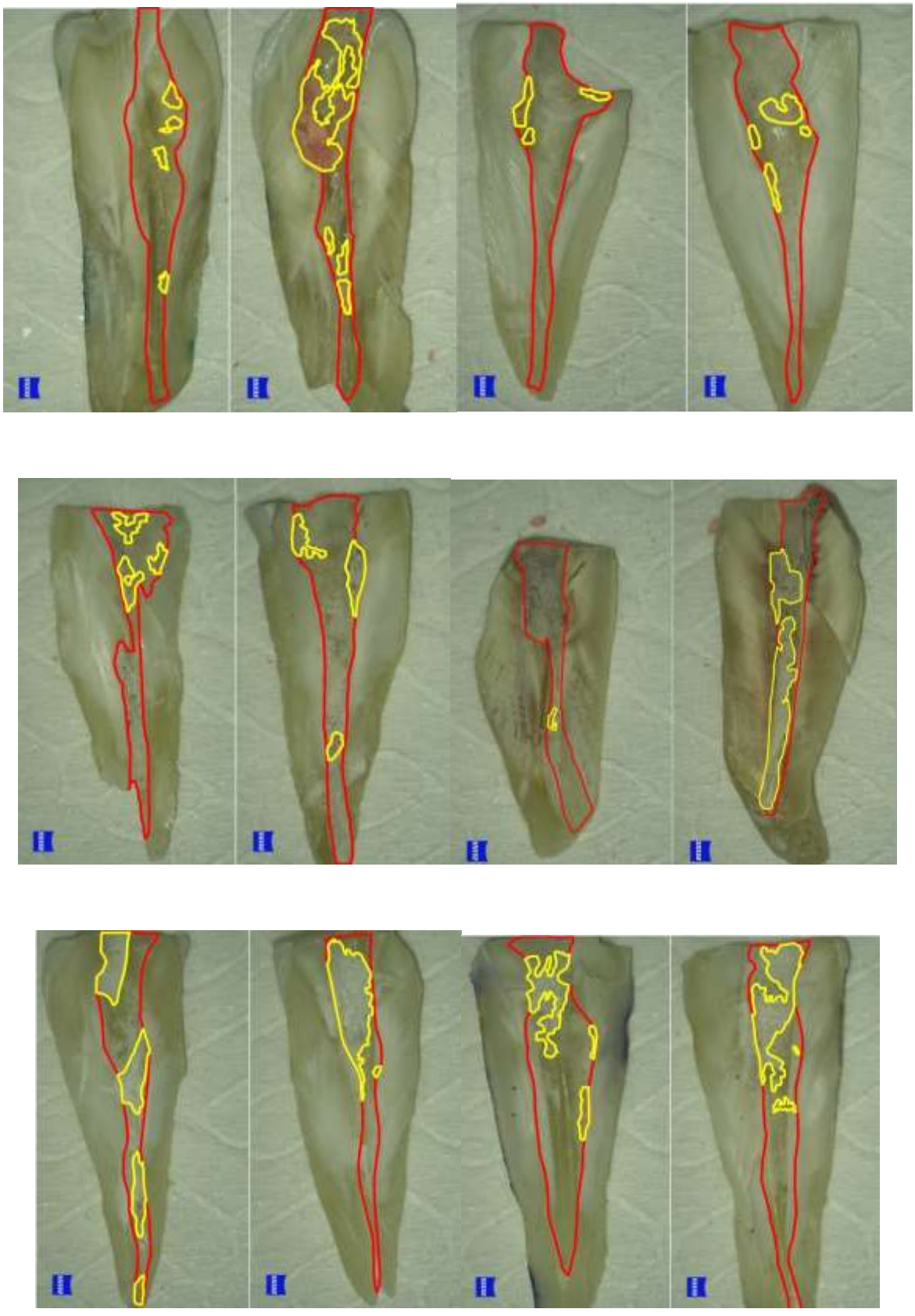
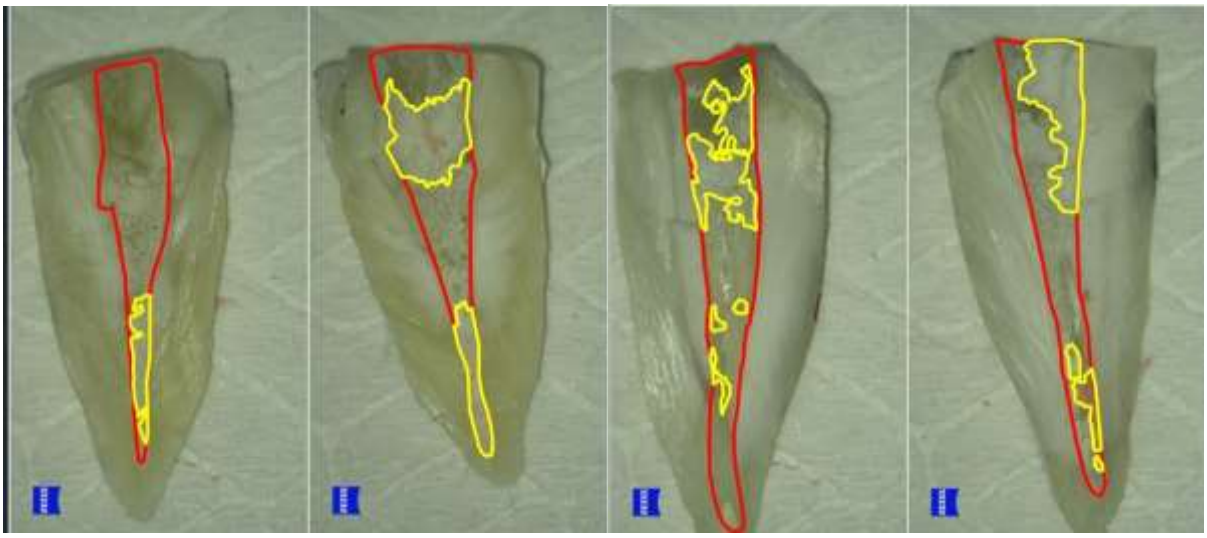
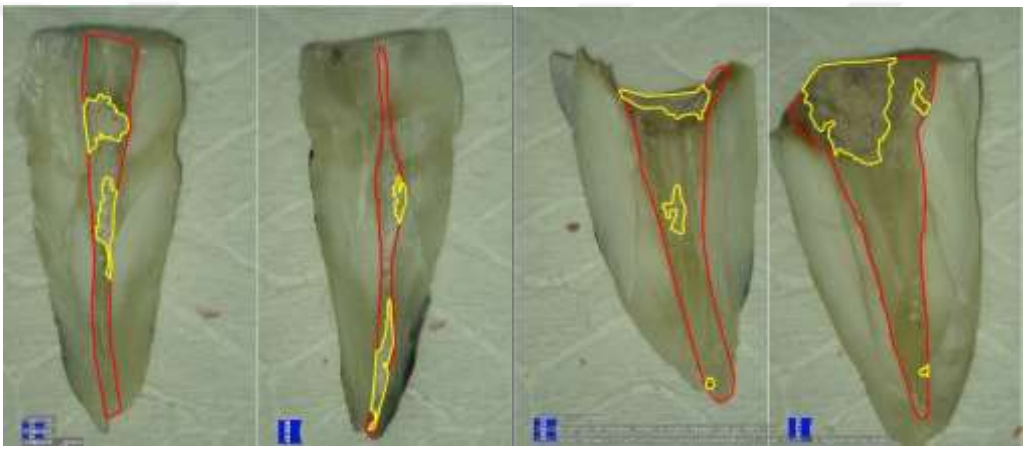
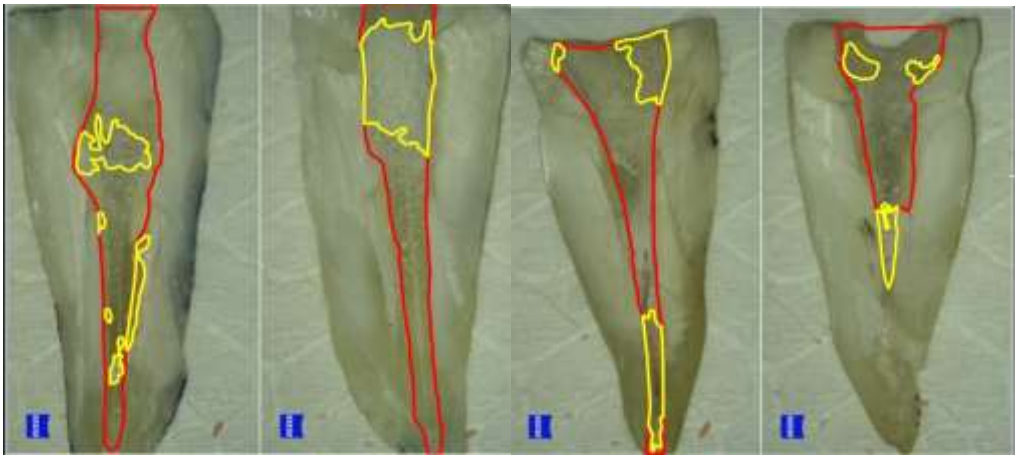
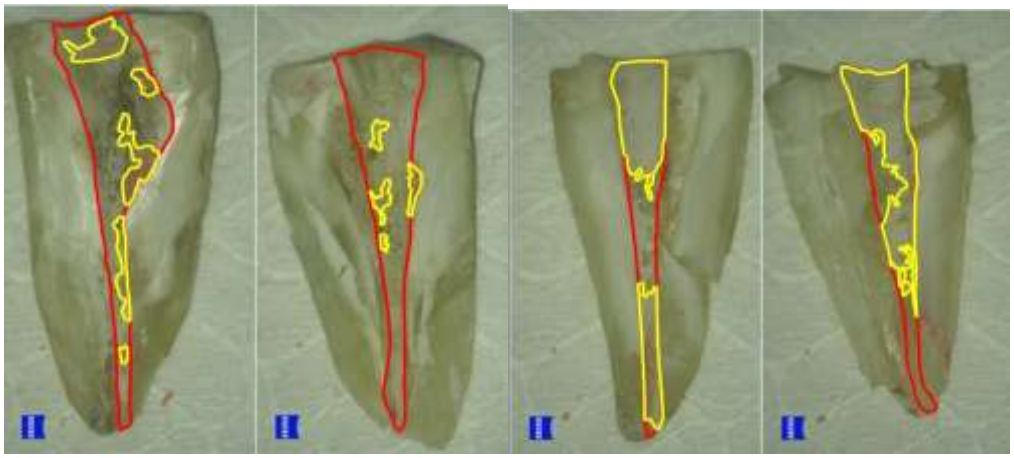


Figure 8 a the remaining filling material in all samples of Thermafil+PTUR Group









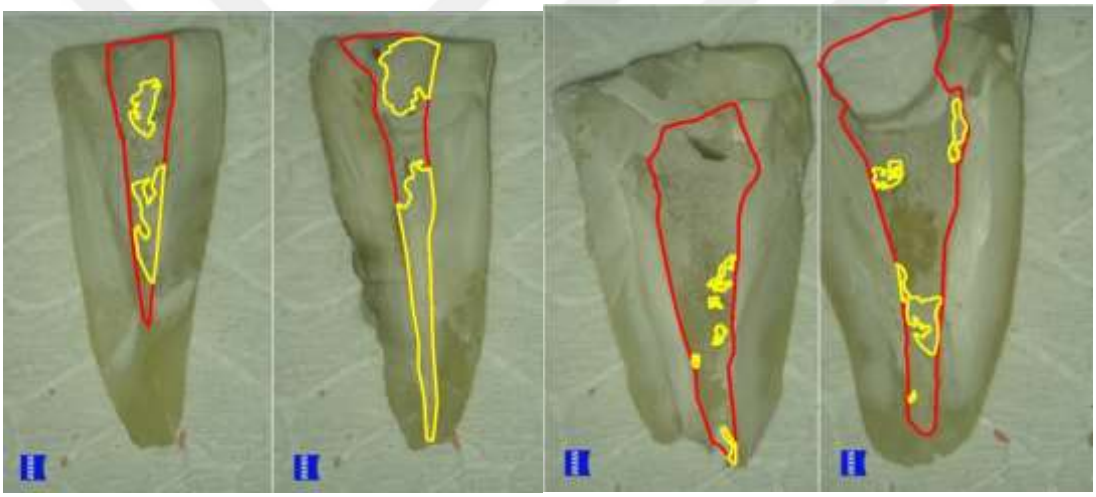
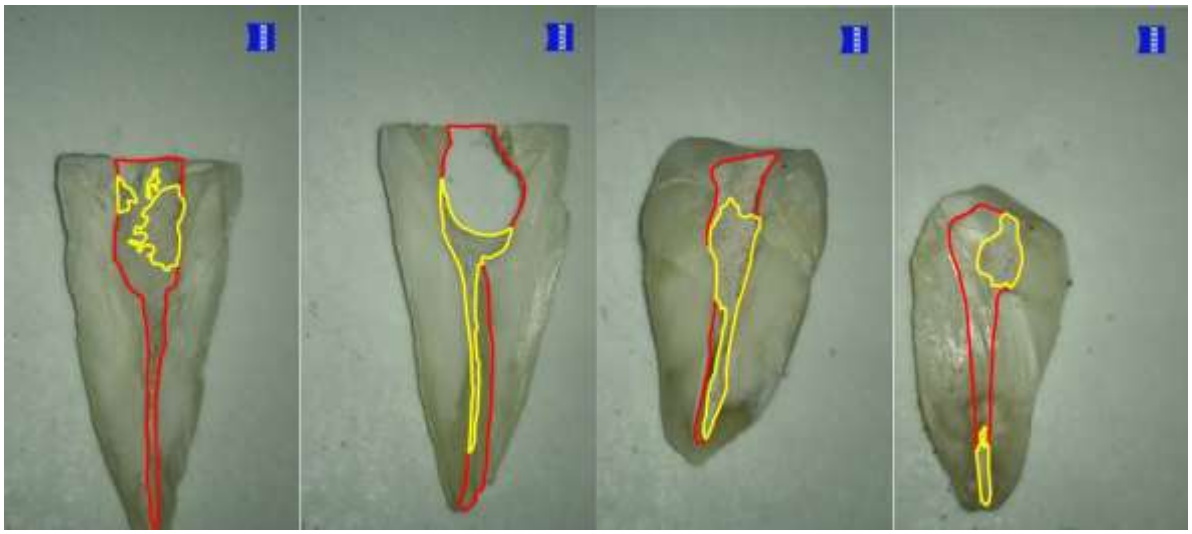
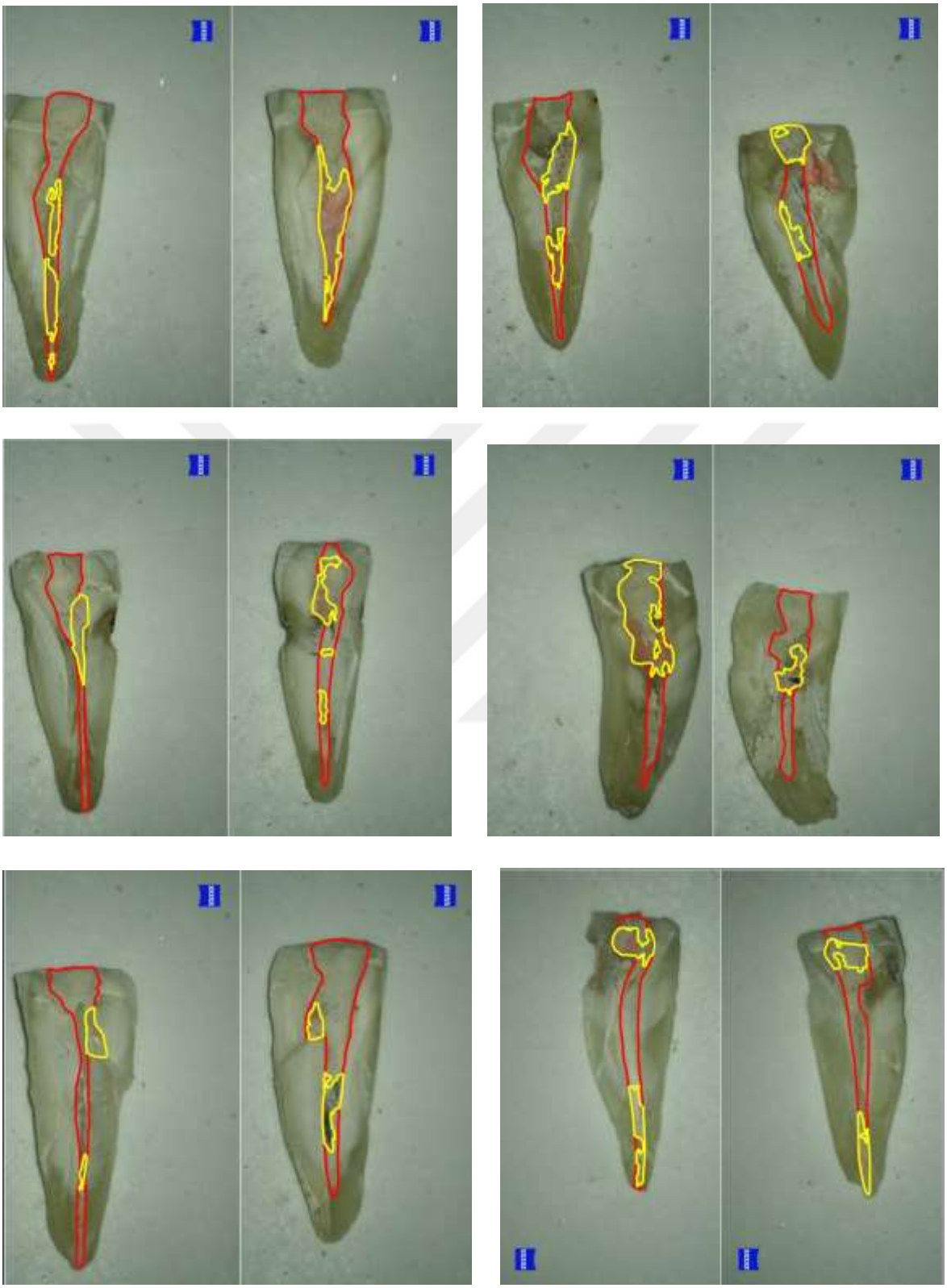


Figure 8 b the remaining filling material in all samples of Thermafil+Wave One Group





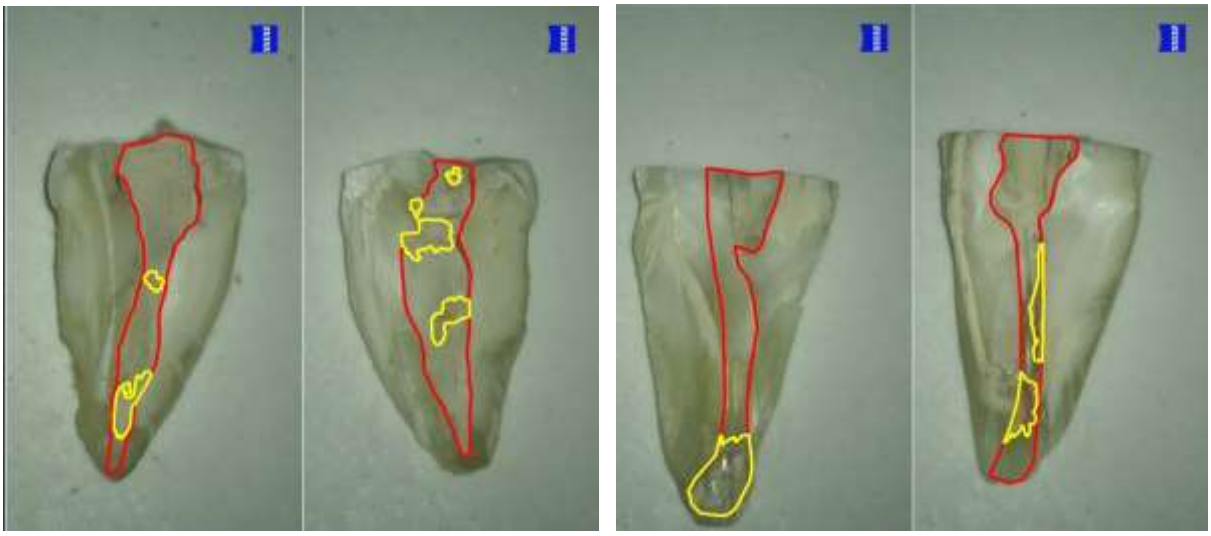


Figure 8 c the remaining filling material in all samples of Thermafil+XP-Endo Group

When the area of filling material was compared in Thermafil group, no statistically significant difference was determined between 3 retreatment techniques. p>0.05.

4.4 Lateral condensation group

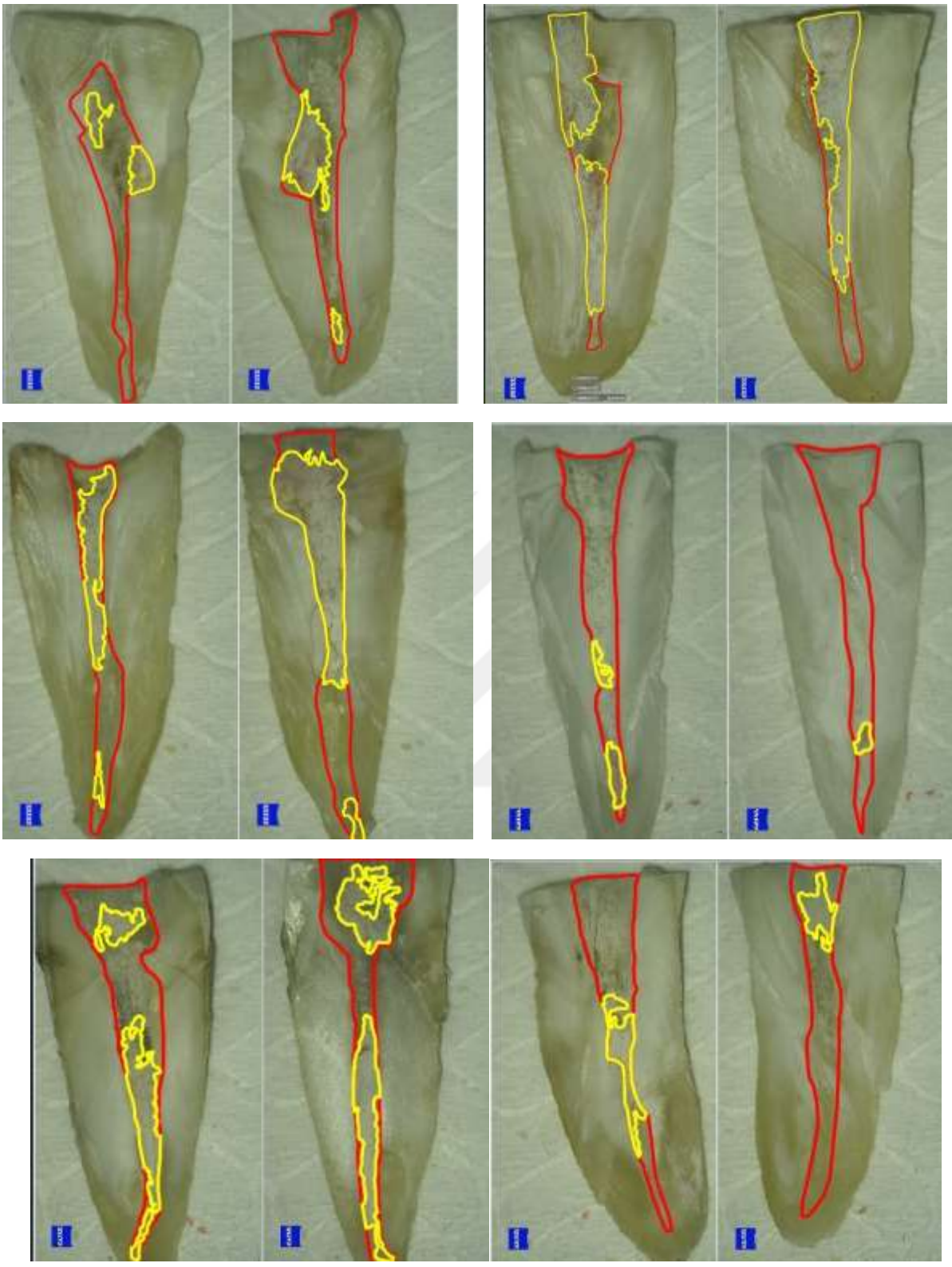
The percentage of filling material remaining in lateral condensation group when 3 retreatment techniques were used is shown in Table 3. Figure 9 a shows the filling material in all samples of Lateral Condansation+PTUR Group Figure 9 b shows the filling material in all samples of the Lateral Condansation +Wave One Group. Figure 9 c shows the filling material in all samples of the Lateral Condansation +Xp Endo Group.

LATERAL CONDENSATION

Table 3 The percentage of the filling material remaining in the lateral condensation group

					95% Confidence Interval for Mean				
	N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum	P value
PTUR	10	39,24469	14,523217	4,592645	28,85541	49,63397	21,090	71,160	0,008*
WOG	10	21,40119	10,168026	3,215412	14,12742	28,67495	6,774	41,161	
XP	10	28,74788	10,206539	3,227591	21,44656	36,04919	13,274	43,195	
Total	30	29,79792	13,613971	2,485560	24,71438	34,88146	6,774	71,160	

ANOVA *p<0.05 statistically significan



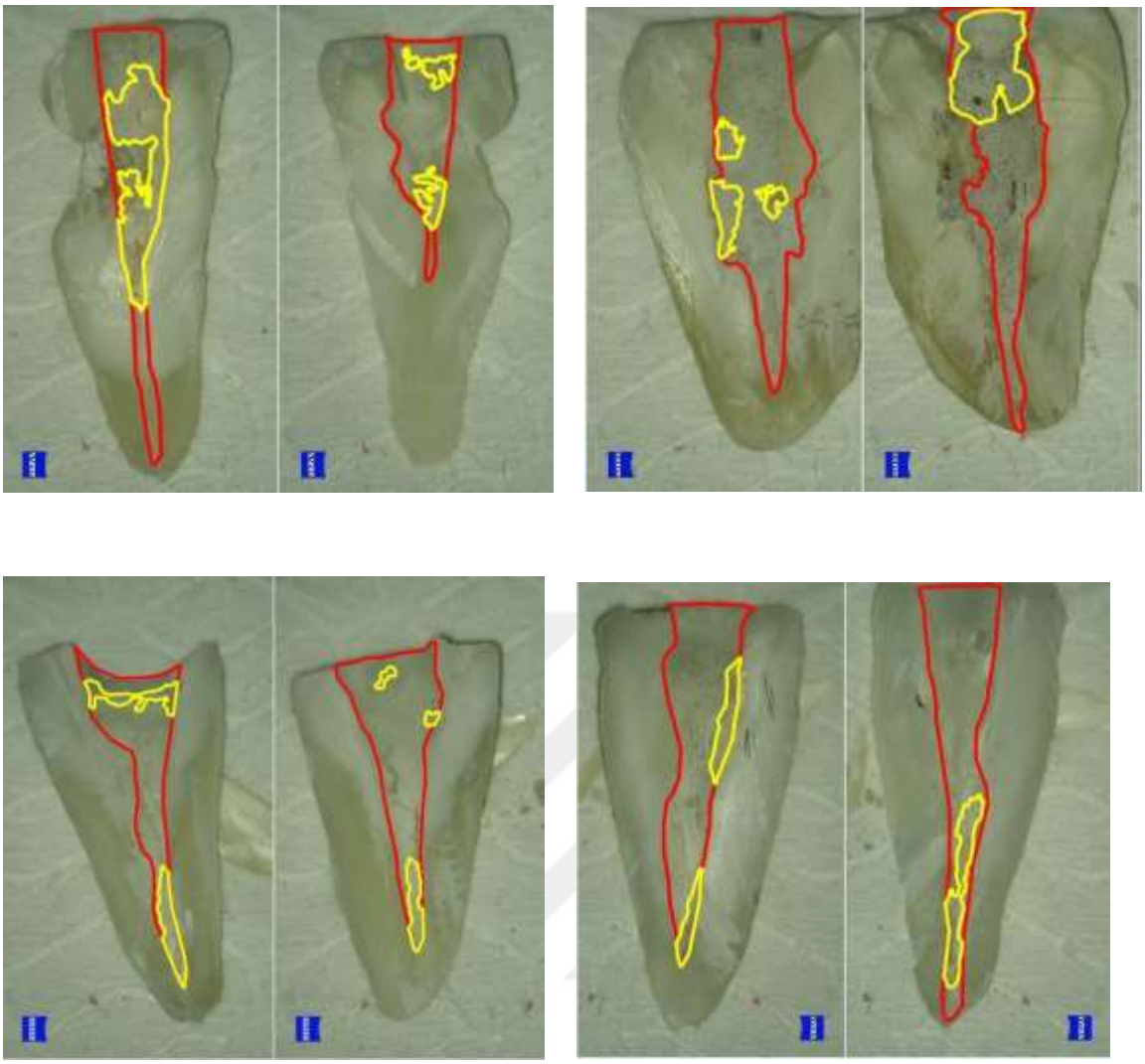
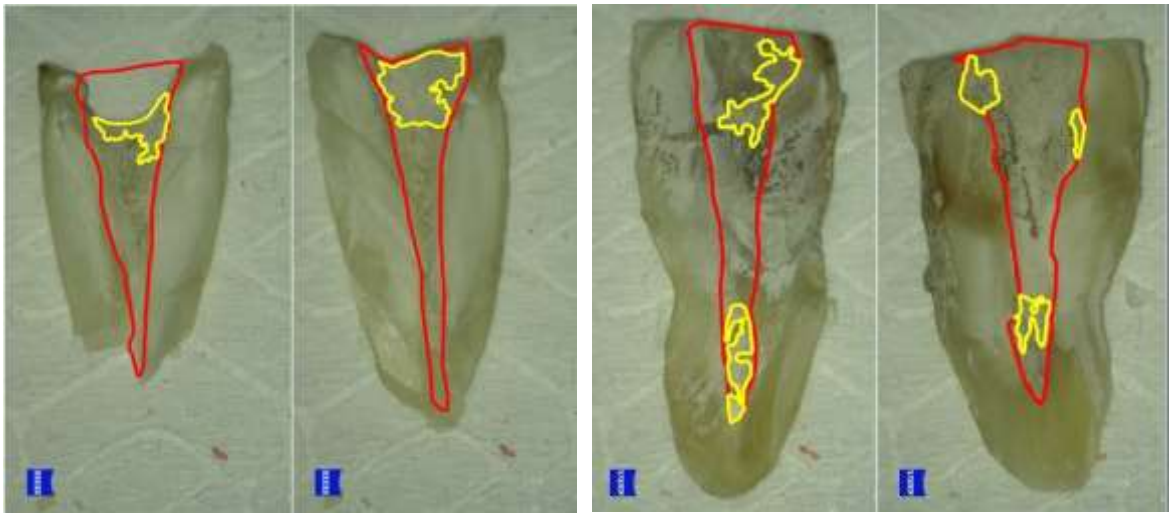
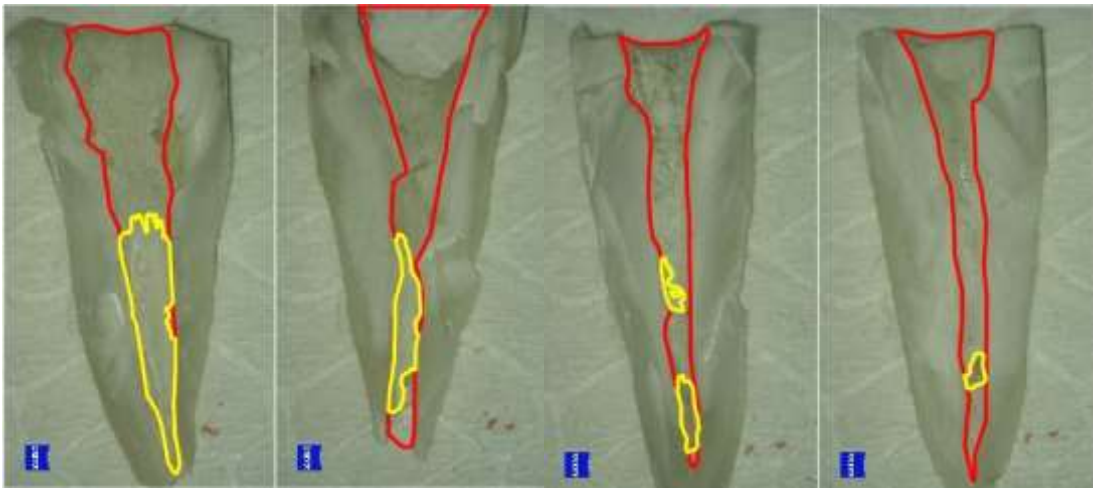
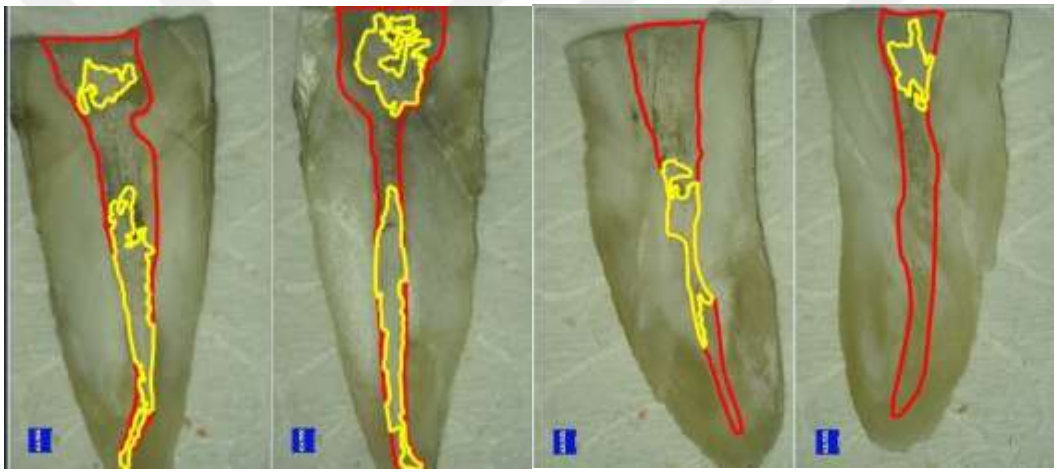
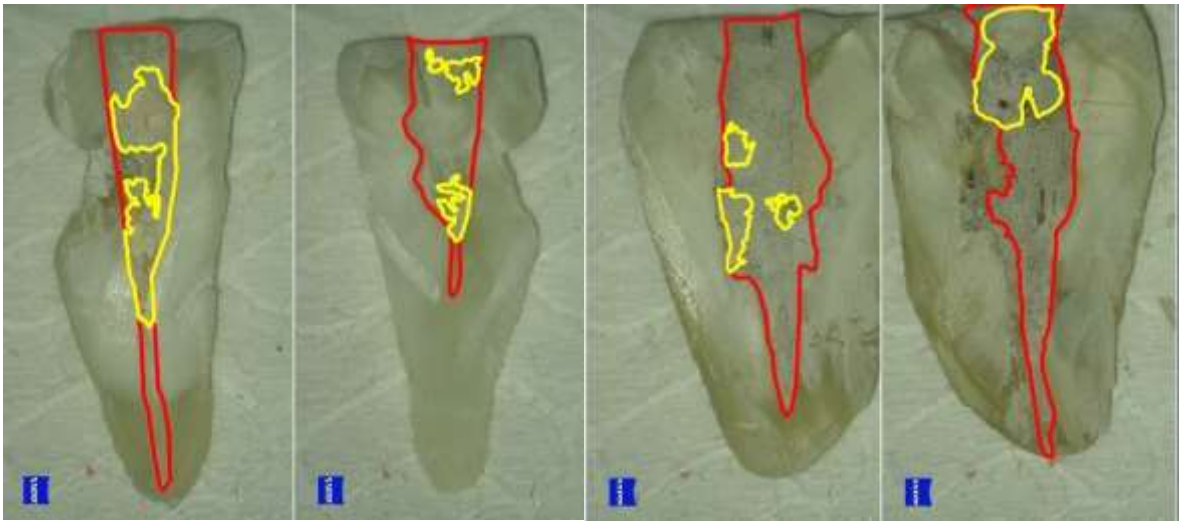


Figure 9 a the remaining filling material in all samples of Lateral Condensation +PTUR Group









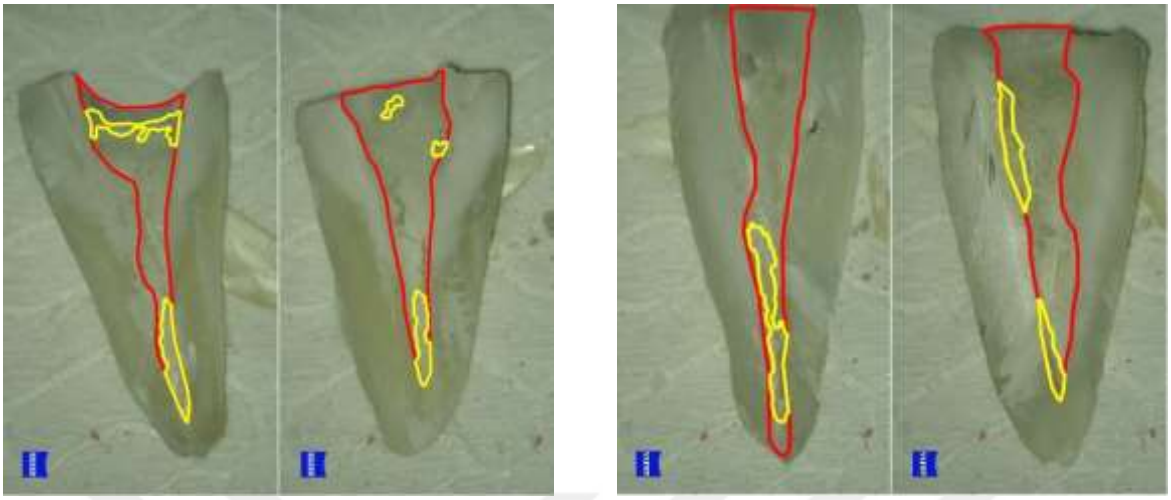
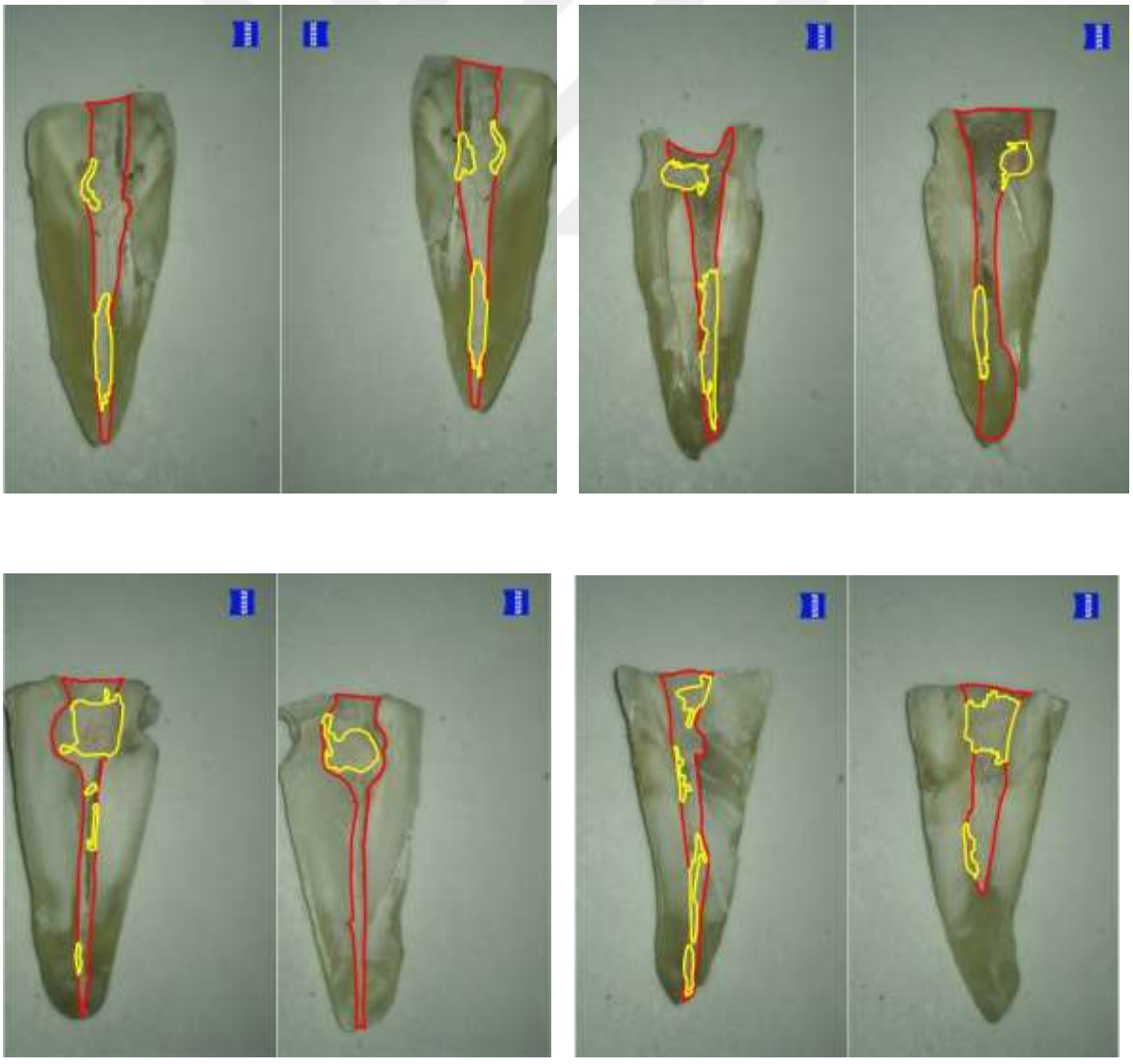


Figure 9 b the remaining filling material in all samples of Lateral Condensation+Wave -One Group



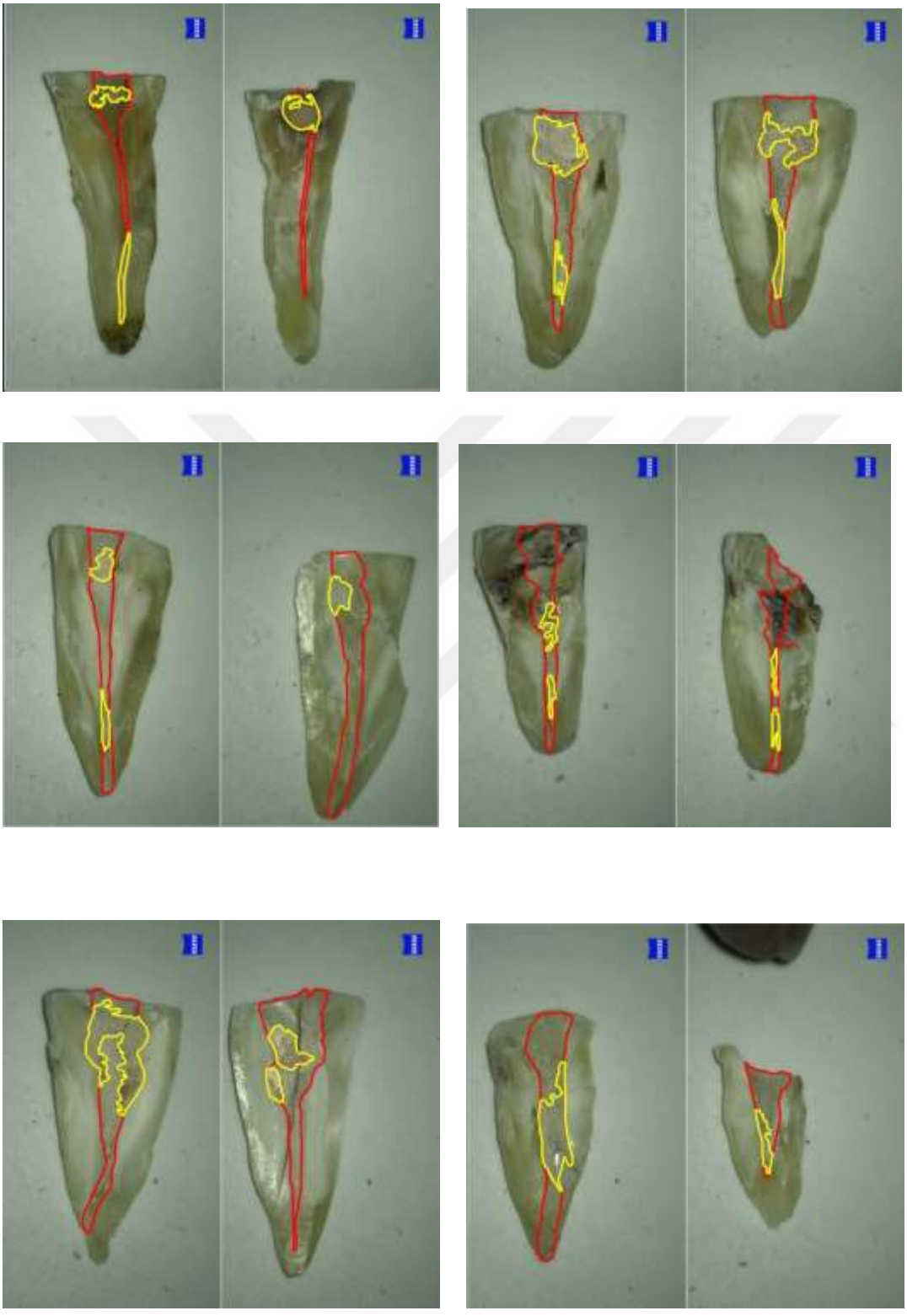


Figure 9 c the remaining filling material in all samples of Lateral Condensation + XP-Endo Group

A statistically significant difference was determined in mean values of groups. ($p<0.05$.) Tukey test was used to identify groups with a statistical difference.

Table 4 Multiple Comparisons in the lateral condensation group

Multiple Comparisons

Tukey HSD

		Mean Difference			95% Confidence Interval	
(I) subgroup	(J) subgroup	(I-J)	Std. Error	P value	Lower Bound	Upper Bound
1,0	2,0	17,843504*	5,281957	,006*	4,74733	30,93968
	3,0	10,496812	5,281957	,135	-2,59937	23,59299
2,0	1,0	-17,843504*	5,281957	,006*	-30,93968	-4,74733
	3,0	-7,346692	5,281957	,360	-20,44287	5,74949
3,0	1,0	-10,496812	5,281957	,135	-23,59299	2,59937
	2,0	7,346692	5,281957	,360	-5,74949	20,44287

A statistically significant difference was determined between Protaper Universal retreatment system and WaveOne Gold system in Calamus group. ($p<0.05$). The percentage of the filling remaining with PTUR was significantly higher compared to WOG:

4.5 Comparison of filling techniques in terms of remaining filling material is shown in **Table 5**

COMPARISON OF CALAMUS, THERMAFIL AND LATERAL CONDENSATION TECHNIQUES IN TERMS OF REMAINING FILLING MATERIAL

Table 5 Comparison of the filling techniques in terms of remaining filling material

					95% Confidence Interval for Mean				
	N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum	P value
CALAMUS	30	38.11811	17.973443	3.281487	31.40671	44.82950	4.575	70.874	0.014*
THERMAFIL	30	26.92626	13.027965	2.378570	22.06154	31.79098	6.051	68.927	

LATERAL CONDENSATION	30	29.79792	13.613971	2.485560	24.71438	34.88146	6.774	71.160
Total	90	31.61410	15.612068	1.645656	28.34421	34.88398	4.575	71.160

ANOVA *p<0.05 statistically significant

There was a statistically significant difference between the groups. (p<0.05.) Tukey test was used for multiple comparisons and to identify the groups with a statistical difference.

Table 6 Multiple Comparisons between the filling techniques

Multiple Comparisons

Dependent Variable: oran

Tukey HSD

		Mean Difference			95% Confidence Interval	
(I) grup	(J) grup	(I-J)	Std. Error	P value	Lower Bound	Upper Bound
A	B	11.191847*	3.881903	.014*	1.93553	20.44817
	C	8.320191	3.881903	.087	-.93613	17.57651
B	A	-11.191847*	3.881903	.014*	-20.44817	-1.93553
	C	-2.871656	3.881903	.741	-12.12797	6.38466
C	A	-8.320191	3.881903	.087	-17.57651	.93613
	B	2.871656	3.881903	.741	-6.38466	12.12797

Multiple comparison showed that there was significant difference between Calamus and thermafil groups (p<0.05). The residual filling material in the Calamus group was significantly higher compared to Thermafil group.

4.6 Inter-group comparison

Table 7 shows the inter-group comparison of groups in the study.

Table 7 Inter-group Comparisons

					95% Confidence Interval for Mean				
	N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum	P value
Cal+PTUR	10	43,04268	12,430766	3,930953	34,15025	51,93512	27,206	65,758	0,006*
Cal+WOG	10	40,80607	19,871799	6,284014	26,59065	55,02150	4,575	70,874	

Cal+XP	10	30,50557	19,802666	6,262153	16,33959	44,67154	4,948	66,846
The+PTUR	10	21,74791	9,717784	3,073033	14,79622	28,69959	8,313	42,623
The+WOG	10	29,73958	17,296596	5,469664	17,36634	42,11282	6,051	68,927
The+XP	10	29,29129	10,415826	3,293773	21,84026	36,74233	14,052	45,693
Lat+PTUR	10	39,24469	14,523217	4,592645	28,85541	49,63397	21,090	71,160
Lat+WOG	10	21,40119	10,168026	3,215412	14,12742	28,67495	6,774	41,161
Lat+ XP	10	28,74788	10,206539	3,227591	21,44656	36,04919	13,274	43,195
Total	90	31,61410	15,612068	1,645656	28,34421	34,88398	4,575	71,160

ANOVA *p<0.05 statistically significant

A statistically significant difference was determined with the comparison of all groups. Tukey test was used to identify groups with a statistical difference and multiple comparison. (p<0.05)

Table 8 shows the multiple comparisons between the groups in the study.

Table 8 Multiple comparisons between all subroups

Multiple Comparisons

Tukey HSD

		Mean Difference			95% Confidence Interval	
(I) group	(J) group	(I-J)	Std. Error	P value	Lower Bound	Upper Bound
Cal+PTUR	Cal+WOG	2,236610	6,432800	1,000	-18,26605	22,73927
	Cal+XP	12,537117	6,432800	,583	-7,96555	33,03978
	The+PTUR	21,294777*	6,432800	,036*	,79211	41,79744
	The+WOG	13,303102	6,432800	,502	-7,19956	33,80577
	Lat+PTUR	13,751390	6,432800	,456	-6,75127	34,25405
	Lat+PTUR	3,797995	6,432800	1,000	-16,70467	24,30066
	Lat+WOG	21,641499*	6,432800	,031*	1,13884	42,14416
	Lat+XP	14,294807	6,432800	,402	-6,20786	34,79747
Cal+WOG	Cal+PTUR	-2,236610	6,432800	1,000	-22,73927	18,26605
	Cal+XP	10,300507	6,432800	,801	-10,20216	30,80317
	The+PTUR	19,058166	6,432800	,089	-1,44450	39,56083
	The+WOG	11,066492	6,432800	,732	-9,43617	31,56915
	Lat+PTUR	11,514780	6,432800	,688	-8,98788	32,01744
	Lat+PTUR	1,561385	6,432800	1,000	-18,94128	22,06405
	Lat+WOG	19,404888	6,432800	,078	-1,09777	39,90755
	Lat+ XP	12,058197	6,432800	,633	-8,44447	32,56086

Cal+XP	Cal+PTUR	-12,537117	6,432800	,583	-33,03978	7,96555
	Cal+WOG	-10,300507	6,432800	,801	-30,80317	10,20216
	The+PTUR	8,757660	6,432800	,909	-11,74500	29,26032
	The+WOG	,765985	6,432800	1,000	-19,73668	21,26865
	Lat+PTUR	1,214273	6,432800	1,000	-19,28839	21,71694
	Lat+PTUR	-8,739122	6,432800	,910	-29,24178	11,76354
	Lat+WOG	9,104382	6,432800	,889	-11,39828	29,60704
	Lat+XP	1,757690	6,432800	1,000	-18,74497	22,26035
The+PTUR	Cal+PTUR	-21,294777*	6,432800	,036*	-41,79744	-,79211
	Cal+WOG	-19,058166	6,432800	,089	-39,56083	1,44450
	Cal+XP	-8,757660	6,432800	,909	-29,26032	11,74500
	The-WOG	-7,991674	6,432800	,944	-28,49434	12,51099
	Lat+PTUR	-7,543387	6,432800	,960	-28,04605	12,95928
	Lat+PTUR	-17,496782	6,432800	,157	-37,99944	3,00588
	Lat+WOG	,346722	6,432800	1,000	-20,15594	20,84938
	Lat+XP	-6,999970	6,432800	,974	-27,50263	13,50269
The+WOG	Lat+PTUR	-13,303102	6,432800	,502	-33,80577	7,19956
	Lat+WOG	-11,066492	6,432800	,732	-31,56915	9,43617
	Lat+XP	-,765985	6,432800	1,000	-21,26865	19,73668
	The+PTUR	7,991674	6,432800	,944	-12,51099	28,49434
	Lat+PTUR	,448288	6,432800	1,000	-20,05437	20,95095
	Lat+PTUR	-9,505107	6,432800	,863	-30,00777	10,99756
	Lat+WOG	8,338396	6,432800	,930	-12,16427	28,84106
	Lat+XP	,991705	6,432800	1,000	-19,51096	21,49437
Lat+PTUR	Cal+PTUR	-13,751390	6,432800	,456	-34,25405	6,75127
	Cal+WOG	-11,514780	6,432800	,688	-32,01744	8,98788
	Cal+XP	-1,214273	6,432800	1,000	-21,71694	19,28839
	The+PTUR	7,543387	6,432800	,960	-12,95928	28,04605
	The+WOG	-,448288	6,432800	1,000	-20,95095	20,05437
	Lat+PTUR	-9,953395	6,432800	,830	-30,45606	10,54927
	Lat+WOG	7,890108	6,432800	,948	-12,61255	28,39277
	Lat+ XP	,543417	6,432800	1,000	-19,95925	21,04608
Lat+PTUR	Cal+PTUR	-3,797995	6,432800	1,000	-24,30066	16,70467
	Cal+WOG	-1,561385	6,432800	1,000	-22,06405	18,94128
	Cal+XP	8,739122	6,432800	,910	-11,76354	29,24178
	The+PTUR	17,496782	6,432800	,157	-3,00588	37,99944
	The+WOG	9,505107	6,432800	,863	-10,99756	30,00777
	Lat+PTUR	9,953395	6,432800	,830	-10,54927	30,45606
	Lat+WOG	17,843504	6,432800	,140	-2,65916	38,34617
	Lat+XP	10,496812	6,432800	,785	-10,00585	30,99947
Lat+WOG	Cal+PTUR	-21,641499*	6,432800	,031*	-42,14416	-1,13884

	Cal+WOG	-19,404888	6,432800	,078	-39,90755	1,09777
	Cal+XP	-9,104382	6,432800	,889	-29,60704	11,39828
	The+PTUR	-,346722	6,432800	1,000	-20,84938	20,15594
	The+WOG	-8,338396	6,432800	,930	-28,84106	12,16427
	Lat+PTUR	-7,890108	6,432800	,948	-28,39277	12,61255
	Lat+PTUR	-17,843504	6,432800	,140	-38,34617	2,65916
	Lat+XP	-7,346692	6,432800	,966	-27,84935	13,15597
Lat-XP	Cal+PTUR	-14,294807	6,432800	,402	-34,79747	6,20786
	Cal+WOG	-12,058197	6,432800	,633	-32,56086	8,44447
	Cal+XP	-1,757690	6,432800	1,000	-22,26035	18,74497
	The+PTUR	6,999970	6,432800	,974	-13,50269	27,50263
	The+WOG	-,991705	6,432800	1,000	-21,49437	19,51096
	Lat+PTUR	-,543417	6,432800	1,000	-21,04608	19,95925
	Lat+PTUR	-10,496812	6,432800	,785	-30,99947	10,00585
	Lat+WOG	7,346692	6,432800	,966	-13,15597	27,84935

According to multiple comparisons, statistically significant difference was determined between Calamus + PTUR and Thermafil+ PTUR as well as Calamus + PTUR Group and Lateral Condensation + WaveOne Gold Group. ($p<0.05$). Retreatment using PTUR in teeth filled with Calamus resulted in significantly higher filling material compared to retreatment using ProTaper Universal retreatment system in teeth filled with Thermafil and retreatment using WaveOne Gold in teeth filled with lateral condensation. The mean residual filling material in Calamus + PTUR was higher compared to other groups.

Figure 10 graphically represents the comparison of all groups used in the study.

A1. Calamus+PTUR

A2. Calamus+ WOG

A3. Calamus+ XP-Endo

B1. Thermafil+ PTUR

B2. Thermafil+ WOG

B3. Thermafil+ XP-Endo

C1. Lateral condensation+ PTUR

C2. Lateral condensation+ WOG

C3. Lateral condensation+ XP-Endo

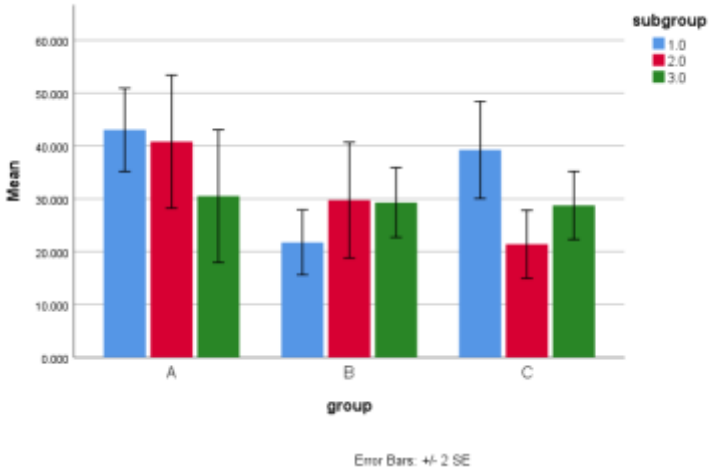


Figure 10 Graphical representation of all the groups in the study

5. DISCUSSION

The main purpose of non-surgical endodontic retreatment is to provide a thorough entry into the canal system by completely removing previously performed filling material, followed by cleaning, shaping and filling. In spite of all efforts, significant amount of material may still remain in root canal following retreatment (77). Various methodologies were suggested for removal of material from root canals. Automated NiTi instruments have been proposed to allow safer and speedier removal of material compared to manual methods**.** Some of the NiTi systems are especially manufactured for retreatment purposes and they have special characteristics such as cross-section, cutting angle, and presence/absence of an active tip that may influence removal of gutta-percha and dentin (112,113). Three retreatment systems have been selected in this study for comparison in terms of retreatment. ProTaper Universal retreatment technique is a widely used technique and many studies have been conducted in which different retreatment methodologies have been compared with this frequently selected method. WaveOne Gold is specifically produced for root canal shaping procedures; on the other hand, it has also been used as a tool for retreatment, so it was included as one of the experimental systems. XP-Endo is a recently introduced innovative system and appears to hold promise in terms of retreatment due to its unique physical characteristics; therefore, it was also included in the present investigation.

Different techniques were proposed to examine quality of removal of filling after retreatment. Some methodologies were used for quantifying residual material in canals following endodontic retreatment. These include radiographs, clearing, scanning electron microscopy, longitudinal cleavage of roots for microscopic or photographic evaluation, and micro-CT. All these methodologies have their own advantages as well as drawbacks. Some authors have used non-destructive methods such as radiographic examination (114,115) or clearing of teeth (116)**.**

Radiographic analysis has been criticized because it gives a 2‑dimensional image and is less effeicient compared to other methodologies (117,118). Ozyurek et al. also stated that radiographs provide only 2-dimensional images of 3-dimensional structure and may be susceptible to factors such as magnification and distortion (70). Similar comments were made by other authors who stated that radiographs are less precise in identifying remaining debris and may not be able to display all remnants, specifically small ones. Furthermore,

radiographs may not be able to detect gutta-percha with similar radiopacity to dentin (55,119,120)

Alves *et al.* Also stated that using radiographs and clearing, areas of remaining filling may be overlapped and this is a commonly encountered issue (48). Clearing techniques with digitized images have also been reported as time consuming and chemicals used during the process may affect the remaining filling materials within the root canals (121**).**

Micro-CT was suggested as a successful method for investigating the effectiveness of different methodologies. In this method, X-rays are used to create images with high-resolution and the method provides three-dimensional evaluation of remaining filling following procedure (60,122,123). Micro-CT software does not section the specimens into equal thirds and the entire volume of the filling material is reported (50). Limitations of micro-computed tomography have been reported as accessibility, financial restrictions and the necessity of advanced technical knowledge (91).

Vertical splitting method was used in the present study because it is an easy method and there is a constant distance between the object and device. This causes a standardization. The methodology was shown to be more reliable compared to radiographs in evaluating filling material during retreatment (102). The amount of remaining material was initially evaluated by taking longitudinal sections of roots. Meticulous care was exercised not to cause displacement of gutta-percha. For this purpose, grooves were prepared and then cleavage was performed. Similar comments were made by other authors (40,53). Although there is the risk of residual material being lost by splitting the roots longitudinally, no such complication was experienced by careful splitting as described above.

Although some studies have utilized solvents during retreatment, no solvent was preferred in the present investigation, because previous investigations determined that solvents resulted in filling residue on the root canal walls as well as dentine tubules (123-125).

The use of a solvent has also been regarded as a controversial issue. Even though a solvent such as chloroform can facilitate penetration of the instrument, it may result in the formation of a thin layer of filling adhered to dentinal walls which may be very hard to remove (40,126). Furthermore, the use of solvent solutions should be performed carefully due to risk of extrusion towards periapical area (61).

In the present investigation, single rooted teeth having similar configurations were selected to provide a standardization. Although extreme care was taken with respect to the selection of the experimental specimens, minor variations are always likely with respect to configurations. Furthermore, different results may be obtained in case multi-rooted teeth or teeth with severe curvatures used. This may be considered as a limitation of the study. Despite this, all procedures were conducted by the same operator; thus standardization was achieved in that respect.

In the present investigation, retreatment was accepted to be finished when no observable remaining material was left on retreatment instruments. On the other hand, even though it was ensured that no visible remaining material could be seen on retreatment instruments, visual observation of the split halves showed that there was remaining filling. This confirms the that the absence of material remnants on instruments is not a reliable observation to demonstrate that all materials have been removed from the root canal. Similar comments were made by Ekici et al. who used a similar approach (87).

In this study, an operating microscope was utilized to observe the remaining material at x15 magnification, which provided very clear images with high resolution. The favorable properties of the dental operating microscope have been indicated by other authors who used a similar methodology (120). The authors commented that the microscope with its enhanced illumination and magnification facilitated the identification of remaining material that may contain necrotic tissuesor bacteria which are significant factors responsible for post-treatment disease. Carr *et al.* indicated that there is improved illumination in the operating microscope because the light is parallel to the sight line and will provide two to three times lighter compared to one given by a surgical headlamp (127). Schirrmeister *et al*. also drew attention to that fact that utilization of an operating microscope during treatment is a very significant methodology to identify root canals, which are unable to be detected (120). Due to all abovementioned properties operating microscope proved to be a feasible and advantageous approach to evaluate of remaining material following endodontic retreatment.

The AutoCAD software provided the exact area covered by material in root canal system. This methodology provided a more accurate and objective evaluation of material remaining in canals after instrumentation. Similar comments were made by other authors who used the same methodology (42).

In the present study, ultrasonic passive irrigation (PUI) was applied between irrigating solutions to facilitate the effect of the instruments. Other studies have also demonstrated that clinical use of ultrasonics improves the removal capacity of material in retreatment. In this study, all groups received ultrasonic activation following each irrigation, therefore the ultrasonic activation was not a parameter to be compared, but rather used as a complementary procedure (90, 104, 128).

When the area of remaining filling was compared in Calamus group, no significant difference was determined between 3 retreatment methods. It was generally observed in this group that relatively higher residual filling percentages were observed compared to other filling techniques. Some authors indicated that this is an expected result because warm vertical compaction technique is a methodology which pushes and compacts the material deep into root canal irregularities (108). This may also be one of the challenges experienced in the present study when continuous wave condensation method is utilized. Statistical evaluation also showed that the mean material in the Calamus group was significantly higher than the Thermafil group. Other authors have also commented that continuous wave of condensation causes filling with greater density compared to conventional cold lateral condensation. They indicated that root filling material of continuous wave of condensation which is softened by the application of heat may easily be pushed into irregularities and dentinal tubules which are especially observed in the apical portion (45). Rubino *et al.* performed obturation using continuous wave of condensation technique (77). Other authors also explained the persistence of remaining filling with the utilization of the continuous wave of condensation technique. They also indicated that heat applied gutta-percha can be easily pushed compacted into areas which cannot be reached by instruments which may explain the higher percentage of remaining material compared to cold obturation techniques (45,129,130).

When the results of the Thermafil group were evaluated, no significant difference was determined between 3 retreatment methodologies, similar to the Calamus group. Wilcox and Juhlin indicated that in Thermafil retreatment procedure, ability to remove carrier of the system rather than gutta-percha is a more important factor that determines success. They suggested that removal of carriers was not checked or no attempt was made to distinguish carriers from other material remaining in the root canal (131). Beasley *et al.* evaluated the time for the removal of GuttaCore and 2 other filling materials in canals with moderate curvature using PTUR and ProTaper file systems (132). They concluded that carrier-based systems may be more challenging to remove compared to gutta-percha. In a study by

Maruşter *et al*., MTwo Retreatment and WaveOne Gold were evaluated in terms of the removal of 2 carrier-based gutta-percha (GP) fillings, which were GuttaCore and GuttaFusion. Their results showed that WOG was more successful in removal of GP compared to MTwo. The authors explained this finding with the advantages of WaveOne Gold files in comparison to the previous WaveOne (Dentsply Maillefer) instruments. They commented that the capacity of the previous system in cleaning gutta-percha from canals could have been facilitated by the use of the NiTi Gold-alloy. They also drew attention to the enhanced shape memory of WOG which could prevent complications such as strips and ledges during retreatment procedures. Similar to other authors, they indicated that the parallelogram-shaped cross-sectional features allowed more effective removal of material, and the partially active tip is a useful feature. In our study, no significant difference was noted between WOG and other methods when Thermafil was used. This finding can be attributed to the different systems against which WOG is compared in the present investigation as well as the utilization of resin blocks in their study whereas human teeth were selected in ours (94).

In the lateral condensation group, a statistically significant difference was identified between PTUR and Wave-One Gold system (WOG). WOG resulted in significantly less amount of residual material in comparison with PTUR in the lateral condensation group. A search of literature shows that there are relatively lower studies conducted using WaveOne Gold in non-surgical endodontic retreatment. No significant difference was noted between WOG and XP-Endo. Azim *et al.* (88) evaluated efficacy of 3 single-file systems: WaveOne Gold Primary, Hyflex EDM "one file" and XP Shaper for retreatment in mandibular anterior teeth. The XP-Shaper exhibited a more successful cleaning in comparison with Hyflex EDM and WaveOne Gold in their study. This differs from results obtained in the present investigation. On the other hand, their results showed that WOG left 25% of material inside canal, which is similar to our results where 21.4 % of material remained within root canal in lateral condensation group with WOG. The difference between the results of 2 studies may be attributed to the utilization of warm vertical compaction in their study as well as the calculation of remaining filling using Micro-CT (88).

Delai *et al*. (90) compared WOG Primary and Medium; PTUR and ProTaper Next; RCG and D-RaCe and RaCe using the micro-CT. The authors used lateral condensation method for filling. Their results showed that no system could totally clean the material and no significant difference was noted among tested systems. In the present investigation, WaveOne Gold appeared to be more successful compared to PTUR, inconsistent wih their findings. This

difference might be because of the utilization of CBCT in their study as well as the inclusion of teeth having curved canals rather than straight ones. Keskin *et al.* who compared WOG with Reciproc and Reciproc Blue determined no difference between the 3 techniques. On the other hand, the authors mentioned the parallelogram-shaped cross-sectional configuration of the instrument which has been indicated to provide sufficient space for cutting, loading and transfer of debris and canal content towards the coronal. Furthermore, they indicated that the offset cross-sectional design and reduction in taper might result in successful filling removal because it increases penetration into filling material and its coronal extrusion (91). The better results obtained with WOG in the present investigation might be explained with the aforementioned favorable features of WOG (90).

Bago *et al.* (93) compared filling material residue in retreatment of canals with severe curvature in which PTUR and WOG were also included. The difference in their study design was as follows: After retreatment, supplementary apical enlargement was conducted in each group with a one size larger instrument. The volume of material was calculated using micro-CT at 4 stages which were after canal filling, basic retreatment with size 25 files, after supplementary enlargement with larger instruments and after final irrigation. Their results demonstrated that no significant differences existed among the systems. They concluded that the systems were equally effective in removal of fillings from canals with curvature. They added that supplementary apical enlargement utilizing larger files facilitated the removal of remnants after basic retreatment (93). Their results differed from ours, both due to differences in the study design, utilization of micro-CT and curved teeth. Furthermore, this study measured the amount of remnants at the end of retreatment protocol and no additional instrumentation technique was used but instrumentation was conducted in line with the protocol recommended by the manufacturers. All these factors might account for the different result obtained in the present study in the lateral condensation group where WaveOne Gold yielded superior results compared to PTUR.

Chen *et al.* (96) performed retreatment in curved root canals filled using a gutta-percha (GP) and iRoot SP which is a novel bioceramic based sealer. They used 3 different systems which also included PTUR and WOG. Their results showed that all tested Ni-Ti instruments displayed a similar performance. In the technique using I-Root-SP, the filling procedure is performed by placing tip of syringe within root canal and injecting sealer in accordance with manufacturer's instructions. Later, the gutta-percha is adjusted until working length and severed at the orifice. It is also a cold gutta-percha filling technique similar to ours, however,

while our results showed a significantly better result using WOG, their results demonstrated no significant differences among the systems tested. The difference between the results can be explained by usage of lateral condensation in our investigation, as well as the utilization of canals having curvature and micro-CT in their study.

The results of our study showed that, a significant difference existed between Calamus + PTUR and Thermafil+ PTUR as well as Calamus +PTUR and Lateral Condensation + WOG. ($p<0.05$). Retreatment using PTUR in teeth filled with Calamus resulted in significantly higher amount of material in comparison with retreatment using PTUR in teeth filled with Thermafil and retreatment using WOG in teeth filled with lateral condensation. The mean residual material in the Calamus + PTUR was higher in comparison with other groups. No other significant differences were determined among other systems tested.

PTUR has been widely investigated in terms of its capacity in retreatment. So *et al*. (39) evaluated the efficacy of PTUR and hand files for removal of material. Furthermore, they evaluated the effect of the sealer on the presence of filling residue in canals which received reinstrumentation. The authors found no significant difference among 3 root canal portions within each group. All groups presented filling residue in the 3 canal portions after reinstrumentation. They commented that the producer of the PTUR does not recommend use of the system in root canals filled by using resin-based sealers which show strong adhesion to walls of canal, and attributed more filling debris in EndoFill/ProTaper and AH Plus/ProTaper due to this factor (39). The usage of AH Plus, a resin-based sealer may be one reason why PTUR in the lateral condensation group gave higher results compared to lateral condensation+ WaveOne group. The cold lateral condensation technique can be considered as a technique which is more dependent to sealer compared to warm vertical condensation and carrier-based systems and may require rmore sealer for compaction of gutta-percha cones. This may be one of the reasons why lateral condensation + ProTaper resulted in more remaining material.

Another study by DaSilva *et al*. compared PTUR, D-RaCe, and Mtwo Retreatment in terms of retreatment capacity. The authors used these 3 systems in 3 groups and they used additional files in the 3 other groups along with the aforementioned systems. There were no statistically significant differences between groups when supplementary instruments were utilized. The ratio of remaining material was found to be the lowest in the PTUR group and showed a statistically significant difference only in comparison with D-RaCe system (10). In the present investigation, PTUR was used in accordance with the manufacturer’s suggestions and no other additional instrument was used to facilitate cleaning. The difference between results of

the 2 studies can be attributed to the supplementary files utilized in the investigation performed by da Silva *et al.*

Kumar *et al*. compared the efficacy of PTUR with or without using solvent solutions and stainless-steel hand files. They concluded that PTUR files, by themselves, were speedier than other groups and displayed better gutta-percha removal. They suggested that the features of D1, D2 and D3 instruments having progressive taper and lengths may cause instruments to cut and pull gutta-percha into flutes of the file and and carry it toward the access. On the other hand, they mentioned that even though the ProTaper system gave better results, it still was not satisfactory to clean gutta-percha completely and further refining of canal may be necessary as the final instrument D3 which reaches working length does not permit a total cleaning capacity (44). In our investigation, D3 was used until the working length; however different results may be obtained if supplementary files are used after ProTaper to facilitate the cleaning action.

Another study by Rödig *et al.* which investigated the retreatment efficacy of D-RaCe instruments, PTUR or Hedström files in curved root canals using the micro-CT determined that D-RaCe instruments left significantly less amount of filling material compared to PTUR and hand files. The authors indicated that a large standard deviation for the ProTaper Universal Retreatment group in terms of residual root canal filling was noted. They explained this finding by stating that PTUR generally remained significant amount of filling material (46). The standard deviation related with PTUR in the present study did not markedly exceed the deviations of other sealers, contrary to their findings. This may be due to the utilization of curved canals and micro-CT in their investigation.

Alves *et al.* (48) attempted to find an answer to the question of whether instruments produced for retreatment are in fact necessary for removal of filling. Their results revealed that the performance of instruments developed for retreatment showed similar results compared to the corresponding Ni-Ti systems. They compared ProTaper Universal (PT), PTUR, Mtwo (M2) and Mtwo Retreatment (M2r) in their investigation. And their results demonstrated that no significant difference existed among methods. In the present investigation, WaveOne Gold demonstrated significantly better results compared to PTUR in the lateral condensation group, when in reality, it was not an instrument specifically produced for non-surgical retreatment. Therefore, the results of the 2 studies may show a similarity in that respect and may reveal that even though some instruments are not especially manufactured for retreatment purposes, they may exhibit successful results, as well.

A similar comment was made by de Azavedo Rios *et al*. who compared the efficacy of ProTaper system with Reciproc and WaveOne. No significant difference was observed among groups in which continuous wave of condensation was used. The Reciproc and WaveOne systems were as effective as PTUR for filling removal. The authors indicated that although Reciproc and WaveOne systems were not specifically manufactured for the purpose of non-surgical retreatment, their unique features and the impact of reciprocating motion can be advantageous for successful removal of the filling (53). Their study showed similarity to the study design of the present investigation as the remaining filling was evaluated in the total canal surfaces rather than in 3 different portions of root canal.

Colombo *et al.* also compared ProTaper and WaveOne in terms of gutta-percha removal, with or without utilizing a solvent solution (61). The authors also used dental operating microscope and evaluated residual filling in total, similar to our investigation**.** Their results showed no significant difference between groups in terms of the amount of remaining material. The difference between the results of the 2 studies may be attributed to the use of WaveOne in their study whereas WOG with improved characteristics were utilized in the present investigation.

XP Endo system is a recently introduced methodology which was investigated in terms of retreatment ability in various studies. In the present investigation, XP Endo system was not found to be superior to other techniques in any of the filling methodologies. Silva *et al.* evaluated the efficacy of filling removal from oval-shaped canals following the utilization of supplementary files (XP-endo Finisher and XP-endo Finisher R) using micro-CT. XP-endo was found to be equally effective in removal of remaining material from the canals (99). In their investigation, the authors performed retreatment using Reciproc R25 and R40 instruments followed by XP-Endo finisher and XP-Endo Finisher R, as supplementary files. In the present investigation, retreatment procedure was entirely performed using XP-Endo system rather than using them as supplementary files following the use of another system. This might be a reason for the different results obtained between the 2 investigations as well as the utilization of micro-CT in the study by Silva *et al.* Silva *et al.* also indicated that a complementary technique to increase the area occupied by instruments and solutions would be practical, especially when retreatment is concerned, because additional difficulties are associated with retreatment cases such as persistent infection, removal of infected filling material and treatment of disrupted canal anatomy(99). Thus, different results may be

obtained in case XP-Endo-R used as a supplementary file following the usage of another retreatment technique. This warrants further research to be conducted on the topic.

A similar result with Silva *et al*. was also reported by Aksel *et al.* who compared removal of fillings using PTUR followed by a supplementary shaping using XP-Endo Finisher. Micro-CT evaluation revealed that additional preparation with an XP-Endo Finisher file, after using the PTUR and F3 ProTaper instruments, facilitated the removal of materials from root canals. Their study differed from ours in terms of the usage of mesio-buccal canals as well as micro-CT. Furthermore, they used XP-Endo finisher rather than XP-Endo-R. The difference between our results with theirs can also be attributed to the use of XP-Endo as a supplementary system rather than the main retreatment system (103) .

Other studies which used XP-Endo-R as a supplementary instrument also revealed favorable results and significant improvement in the removal of residual material (98,104,105,110). Tavares *et al.* (110) concluded that additional cleaning enhanced by the two supplementary instruments (XP-Endo Finisher R or R1-Clearsonic ultrasonic) was less visible in the apical part. Therefore, even though they recommended both supplementary procedures with the purpose of facilitating material removal, they cannot be considered adequate to completely clean the apical portion of oval canals. They concluded that this shows again that apical portion is the most difficult and challenging part for cleaning during retreatment procedures and drew attention to the necessity of developing systems with better capacity. Our study is not directly comparable to the aforementioned studies as XP-Endo was not used as a supplementary system or evaluation of cleanliness was not specifically directed towards 3 different portions of the canal but a total evaluation of the filling was conducted. Nevertheless, the results show the possibility of better results in case XP-Endo is chosen as a supplementary system. Further research on this issue is necessary to highlight the topic.

Retreatment is a procedure which encompasses access to root canal system, successful cleaning of previous root filling material and a thorough cleaning and disfinfection anda final obturation with the goal of establishing healthy periapical tissues and heal infection. This requires meticulous care and the usage of efficient instruments for the achievement of a successful results. Manufacturers continue to produce different systems with innovative metallurgical and physical properties to facilitate the retreatment procedure and each product is assessed by investigations to demonstrate their degree of success. The present study, as well as other previous investigations show that no available system is yet adequate enough to

thoroughly remove the filling materials and debris is likely to remain in every instrumented canal. Even though the present study, as in all *in vitro* studies has certain limitations, it is obvious that further steps should be taken to obtain an ideal cleaning within root canal system during retreatment, which is a prerequisite for achieving success. Further studies are necessary which not only assess innovative systems but also hybrid techniques which incorporate the combined usage of instruments to draw more reliable conclusions.

6.CONCLUSION

Within the limitations of the present study, the following conclusions can be drawn:

1. Residual filling material and debris were observed in all the evaluated groups. No system was able to entirely remove the canal filling from root canal system.
2. When the area of remaining material was compared in the Calamus group, no statistically significant was determined between the Protaper Universal Retreatment, WaveOne Gold and XP-Endo systems.
3. When the area of remaining material was compared in the Thermafil group, no statistically significant was determined between the the Protaper Universal Retreatment System, WaveOne Gold system and XP-Endo system.
4. When the area of remaining material was compared in lateral condensation group, a statistically significant difference was determined between Protaper Universal retreatment and WaveOne Gold systems. The area of residual filling in the Protaper system was significantly higher compared to WaveOne Gold.
5. When the amount of residual filling was compared between filling methodologies, there was a significant difference between Calamus and Thermafil groups. The area of residual filling in Calamus group was significantly higher compare to the Thermafil group.
6. When all the groups were compared with each other using multiple comparisons, a statistically significant difference was determined between Calamus + ProTaper Universal retreatment Group and Thermafil+ ProTaper Universal retreatment Group as well as Calamus + ProTaper Universal retreatment Group and Lateral Condensation + WaveOne Gold Group. Retreatment using ProTaper Universal retreatment system in teeth filled with Calamus resulted in significantly more amount of remaining filling material compared to retreatment using ProTaper Universal retreatment system in teeth filled with Thermafil and retreatment using WaveOne Gold in teeth filled with lateral condensation.
7. Further studies are warranted which evaluate retreatment in teeth with different configurations, using different innovative methodologies as well as combined hybrid techniques in order to reach more valid conclusions.

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9. APPENDICES

8.2.Ethical Approval

T.C. YEDİTEPE ÜNİVERSİTESİ

Sayı: 37068608-6100-15-2597 02.Kasım.2023
Konu: Klinik Araştırmalar
Etik Kurul Başvurusu hk.

Sorumlu Araştırmacı Dt. Yağmur Çelik
(Yeditepe Üniversitesi Diş Hekimliği Fakültesi Endodonti AD., ISTANBUL)

Klinik Araştırma başvurunuz ve ek belgeleriniz Yeditepe Üniversitesi Klinik Araştırmaları Etik Kurulu (KAEK) tarafından incelendi. Etik Kurulumuz tarafından, başvurunuzun ve ek bilgilerinizin değerlendirilmesinin ardından, **01 Kasım 2023** tarihli toplantısında **"Kanal Tedavisi Tekrarı İçin Geliştirilen Güncel Döner Alet Sistemlerinin Etkinliğinin Auto-CAD Yöntemi İle Karşılaştırılmalı Olarak İncelenmesi"** başlıklı klinik araştırma protokolünüz ve başvurunuz uygun bulunmuştur.

Onay bilgileri:

Referans No : *2023/1801*
Onay Süresi : *Kasım 2023 -Kasım 2024*
Yetkili Personel : *Prof. Dr. Jale Tanalp*

Yeditepe Üniversitesi Klinik Araştırmalarda Etik Kurulu Sağlık Bakanlığı, TİTCK Başkanlığın onayı ile oluşturulmuştur. Söz konusu projeniz, "İlaç ve Biyolojik Ürünlerin Klinik Araştırmaları Hakkında Yönetmeliği, Tıbbi Cihaz Yönetmeliği ve uluslararası etik ilkeler çerçevesinde değerlendirilmiş ve onaylanmıştır. Bu araştırma projenizle ilişkili raporların, onay tarihinden itibaren her 12 ayda bir sunulması ve klinik araştırma belgelerinin 14 (ondört) yıl süreyle saklanması gerekmektedir. Proje ile ilgili raporların bir yılın sonunda sunulmaması, projenin devam etmediğinin onayı olarak değerlendirlecektir. Bilginize sunulur.

Saygılarımla,

Prof. Dr. Turgay Çelik

Klinik Araştırmaları Etik Kurul Başkanı

10. CURRICULUM

Name	YAGMUR	**Surname**	CELİK

VITAE Personal

Information

Educational Background

Degree	**Field of study**	**Graduated Institution**	**Graduation Year**
PhD	Endodontics	Yeditepe University Institute of Health Sciences	
Postgraduate			
Undergraduate		Yeditepe University Faculty of Dentistry	2013
High School	-		2005