ACTA
STOMATOLOGICA
CROATICA
www.ascro.hr

Acta stomatol Croat. 2024;58(2):136-144.
DOI: 10.15644/asc58/2/3

ORIGINAL SCIENTIFIC PAPER
IZVORNI ZNANSTVENI RAD

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Micro-Computed Tomography Analysis of Resin and Calcium Silicate Based Sealers Removal in Mandibular Molars Curved Canals

Mikro-CT analiza uklanjanja smola i cementa na bazi kalcijeva silikata u zakrivljenim kanalima kutnjaka donje čeljusti

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Abstract

Objective: The removal of the root canal sealer is an important factor in nonsurgical retreatment. The aim of this study was to compare the removal of AH Plus, Well Root ST, and AH Plus Bioceramic Sealer using Protaper Universal retreatment files. **Methods:** The curved mesio-buccal canals of extracted mandibular molars were prepared with the Protaper Gold file system (up to F2). Specimens were randomly divided into 3 groups and filled with the single cone technique using AH Plus, Well-Root ST, and AH Plus Bioceramic Sealer, respectively. After two weeks, the root canal filling of all specimens was removed using Protaper Universal retreatment files. All specimens were scanned using micro-CT. The remaining volume of the root canal filling was recorded in total and the coronal, middle, and apical third of each specimen. **Results:** Well-Root ST and AH Plus Bioceramic Sealer groups had a higher percentage of total remaining filling material than the AH Plus group ($P<0.05$). **Conclusion:** This study has shown that the volume of remaining root canal filling was significantly higher in the samples filled with calcium silicate-based sealers.

Received: December 8, 2023
Accepted: March 13, 2024

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MeSH Terms: Root Canal Filling Materials; Retreatment; Synthetic Resins; Silicate Cement
Author Keywords: Micro-CT; Root canal sealers

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Introduction

The chemomechanical preparation and three-dimensional filling of the root canal system are critical components of endodontic treatment success (1). Inadequate cleaning, shaping, and filling can lead to the failure of primary root canal treatment (2). Nonsurgical retreatment is the first treatment option to overcome this failure (3). Root canal filling consists of gutta-percha, a core material placed using cold or warm

Uvod

Kemomehanička obrada i trodimenzionalno punjenje sustava korijenskih kanala kritične su komponente uspjeha endodontskog liječenja (1). Neodgovarajuće čišćenje, oblikovanje i punjenje mogu završiti neuspješnim primarnim liječenjem korijenskog kanala (2). Nekirurška revizija prva je terapijska opcija za prevladavanje tog neuspjeha (3). Punjenje korijenskog kanala sastoji se od gutaperke, jezgrenog materi-

techniques, and cement that seals the interface between the core and dentinal walls (4). The nonsurgical retreatment procedure removes existing canal filling materials. In particular, the root canal sealer is an important factor that affects the removal of canal filling (5).

Nowadays, there are various root canal sealers in terms of content in dental marketing. AH Plus (Dentsply De Trey Gmbh, Konstanz, Germany) epoxy resin-containing sealer is widely used in endodontics. AH Plus exhibits physicochemical properties such as high radiopacity, low solubility, suitable flow, and superior bond strength with dentinal walls (6). Recently, calcium silicate-based sealers, which are called bioceramic sealers, have become very popular and tricalcium silicate or calcium phosphate based root canal sealers are called bioceramic sealers (7). Calcium silicate-based sealers exhibit Ca^{+2} release ability, bioactivity, and biocompatibility (8). These materials contribute to a better prognosis of endodontic treatment with their bioactivity in the periapical area (9). Therefore, Well-Root ST (Vericom, Gangwon-Do, Korea) is based on tricalcium silicate, which contains zirconium oxide, calcium silicate, filler, and thickening agents in its composition. This sealer is an injectable bioceramic paste that has been pre-mixed and designed for root canal treatment. (10). It has hydrophilic characteristics and needs the presence of humidity for hardening (11). It has been reported that the setting time of Well-Root ST is 25 minutes; however, the setting time in root canals can be more than 2.5 h (10). AH Plus Bioceramic Sealer (Dentsply Sirona, Dental Specialties, Tulsa) was introduced as a new bioceramic sealer. This product is premixed and injected into the canal with special 24-gauge tips designed for single use only. Its chemical structure includes zirconium dioxide, tricalcium silicate, dimethyl sulfoxide, lithium carbonate, and thickening agents (12). Moreover, despite AH Plus having been assessed in previous studies (13, 14) there is no study on the removal of Well-Root ST and AH Plus Bioceramic Sealer in the literature.

The effectiveness of the PTU retreatment file system in removing filling material has been demonstrated in previous studies, therefore it is used as the standard in this study (15, 16). Microcomputed tomography (micro-CT) is an analysis method that allows the 3D qualitative, and quantitative evaluation of the location and volume of root canals and endodontic materials (17). Physical and mechanical properties of the filling material as well as the properties of the surface of dentin, such as the existence of the smear layer, affect the interaction between the material and dentin surface (18). The aim of this study was to compare the removal of AH Plus, Well-Root ST, and AH Plus Bioceramic Sealer using Protaper Universal retreatment files with micro-CT analysis.

Materials and methods

The selection of specimens

This study was conducted with the approval of the Ethical Committee of Ankara University Faculty of Dentistry

jala koji se postavlja tehnikom hladne ili tople kondenzacije i cementa koji brtvi sučelje između jezgre i stijenki dentina (4). Nekirurškim postupkom revizije uklanjaju se postojeći materijali za punjenje kanala. Konkretno, cement za brtvljenje korijenskih kanala važan je čimbenik koji utječe na mogućnost uklanjanja punjenja iz kanala (5).

Danas postoje različita sredstva za brtvljenje korijenskih kanala, a razlikuju se po sastavu. AH Plus (Dentsply De Trey Gmbh, Konstanz, Njemačka) brtvilo je koje sadržava epoksidnu smolu i naširoko se koristi u endodonciji. Njegova su fizikalno-kemijska svojstva sljedeća: visoka rendgenska vidljivost, niska topljivost, odgovarajuća tečnost i dobra vezna čvrstoća sa stijenkama dentina (6). Cementi na bazi kalcijeva silikata, koji se nazivaju biokeramička brtvila, postali su vrlo popularni posljednjih godina, a cementi na bazi trikalcijeva silikata ili kalcijeva fosfata nazivaju se biokeramička brtvila (7). Cementi na bazi kalcijeva silikata otpuštaju Ca^{+2} te pokazuju svojstva bioaktivnosti i biokompatibilnosti (8). Ti materijali svojom bioaktivnošću u periapikalnom području pridonose boljoj prognozi endodontskog liječenja (9). Stoga se Well-Root ST (Vericom, Gangwon-Do, Korea) temelji na trikalcijevu silikatu koji u svojem sastavu ima cirkonijev oksid, kalcijev silikat, punilo i zgušnjivače. To brtvilo je biokeramička pasta za ubrizgavanje koja je prethodno izmiješana i predviđena za liječenje korijenskog kanala. (10). Ima hidrofilna svojstva i potrebna joj je vlaga za stvrdnjavanje (11). Zabilježeno je da je vrijeme stvrdnjavanja Well-Root ST-a 25 minuta, ali u korijenskim kanalima može biti i više od 2,5 sata (10). AH Plus Bioceramic Sealer (Dentsply Sirona, Dental Specialties, Tulsa) predstavljen je kao novi biokeramički materijal za brtvljenje. Taj se proizvod najprije miješa i zatim ubrizgava u kanal s posebnim nastavcima veličine 24 G koji su namijenjeni samo za jednokratnu upotrebu. Njegova kemijska struktura uključuje cirkonijev dioksid, trikalcijev silikat, dimetil sulfoksid, litijev karbonat i sredstva za zgušnjavanje (12). Štoviše, unatoč tomu što je AH Plus procijenjen u dosadašnjim istraživanjima (13, 14), u literaturi nema istraživanja o mogućnosti uklanjanja cemenata Well-Root ST i AH Plus Bioceramic Sealer.

Učinkovitost PTU sustava instrumenata za reviziju u uklanjanju materijala za punjenje dokazana je u dosadašnjim istraživanjima i zato je korištena kao standard u ovom istraživanju (15, 16). Mikrokompjutorizirana tomografija (mikro-CT) metoda je analize koja omogućuje 3D kvalitativnu i kvantitativnu procjenu položaja i volumena korijenskih kanala te endodontskih materijala (17). Fizikalne i mehaničke značajke materijala za punjenje te karakteristike površine dentina, kao što je postojanje sloja onečišćenja, utječu na interakciju materijala s površinom dentina (18). Svrha ovog istraživanja bila je usporediti mogućnost uklanjanja cemenata AH Plus, Well-Root ST i AH Plus Bioceramic Sealer korištenjem Protaper Universal instrumenata za reviziju s pomoću mikro-CT analize.

Materijali i metode

Prikupljanje uzoraka

Za ovo istraživanje dobiveno je odobrenje Etičkog odbora Stomatološkog fakulteta Sveučilišta u Ankari (br. 18/01).

(no:18/01). The authors confirm that all procedures were followed in compliance with applicable guidelines and regulations. First and second mandibular molar human teeth were collected that had been extracted for various reasons such as periodontal and periapical diseases. The roots of specimens had no caries and closed apex. Soft tissues and residual debris were removed carefully using a periodontal scaler and curette, and teeth were stored in distilled water at room temperature until the experimental procedure. Initial micro-CT scanning (Bruker microCT Systems, Kontich, Belgium) was performed to examine the root canal morphology of the teeth.

A total of 35 samples were scanned using the parameters tube voltage 90 kVp, beam current 100 µA, 1 mm Cu filter, and 22.0 µm pixel size. The samples were scanned 360° with rotation at 0.2 steps. The mean time of scanning was around 33 min. NRecon (ver. 1.7.4, Bruker microCT Systems, Kontich, Belgium) software was used for the reconstruction of the images. NRecon was used to obtain 1024x1024 pixels with 16-bit gray-level axial 2-dimensional images. CTAn (v. 1.20.3 Bruker microCT Systems, Kontich, Belgium) software was used for image analysis.

Because of scanning, the 31 roots were determined without pulp stone, internal or external resorption, or fracture. Root canal curvature was determined according to the Schindler method (19) and 30° curved roots that exhibit coronal to apical mesiobuccal (MB) canal structure were included in the study. The sample size calculation was carried out by performing the G*Power analysis (Franz Faul, Universität Kiel, Kiel, Germany) and the number of samples for each group was determined as n= 9. Eventually, experimental procedures were performed with 27 samples which met the criteria.

Specimen Preparation

The crowns of the specimens were separated perpendicular to the long axis under water cooling at a standard position approximately 13 mm from the apex, and then the distal root was removed. To determine the working length, a #15 K file progressed until the tip came out of the apical foramen. All MB canals were prepared up to #F2 (0.25 / .08v) using the Protaper Gold rotary file system (Dentsply Maillefer, Ballaigues, Switzerland). The root canal preparation was performed using an X-Smart Plus (Dentsply Maillefer, Ballaigues, Switzerland) endodontic motor. The canals were irrigated with 5.25% sodium hypochlorite during preparation, followed by 17% EDTA solution and distilled water for 1 min. After cleaning and shaping, the canals were dried with paper points. The specimens were randomly divided into 3 groups. The single cone technique was performed for root canal filling (F2 gutta-percha cone, Dentsply Sirona, Tulsa Dental Specialties, USA). The two individual components of AH Plus were mixed according to the manufacturer's instructions and the gutta-percha cones were covered with sealer and inserted into the canal. Well Root ST and AH Plus Bioceramic Sealer, premixed and available in the syringe, were injected into the canal through special cannulas, and then gutta-percha cones were placed. After the filling procedure, the gutta-percha cones were cut at the the canal orifice and condensed with a plugger.

Autori potvrđuju da su svi postupci provedeni u skladu s valjanim smjernicama i propisima. Prikupljeni su ljudski prvi i drugi kutnjaci donje čeljusti koji su bili izvađeni iz raznih razloga kao što su parodontne i periapikalne bolesti. Korijeni uzoraka bili su bez karijesa i apeks im je bio zatvoren. Meko tkivo i zaostali debris pažljivo su uklonjeni parodontološkim strugačima i kiretama, a zubi su pohranjeni u destiliranoj vodi na sobnoj temperaturi do eksperimentalnog postupka. Početno mikro-CT skeniranje (Bruker microCT Systems, Kontich, Belgija) učinjeno je da bi se ispitala morfologija korijenskoga kanala zuba.

Ukupno je skenirano 35 uzoraka uz sljedeće parametare: napon cijevi 90 kVp, struja snopa 100 µA, 1 mm Cu filtar i veličina piksela 22,0 µm. Uzorci su skenirani 360° uz rotaciju od 0,2 koraka. Prosječno vrijeme skeniranja bilo je oko 33 minute. Za rekonstrukciju slika korišten je softver NRecon (ver. 1.7.4, Bruker microCT Systems, Kontich, Belgija). NRecon je korišten za dobivanje 1024 x 1024 piksela sa 16-bitnim aksijalnim dvodimenzionalnim slikama s razinom sive boje. Za analizu slike korišten je softver CTAn (v. 1.20.3 Bruker microCT Systems, Kontich, Belgija).

Skeniranjem je određen 31 korijen bez pulpnog kamenca, unutarnje ili vanjske resorpcije ili frakture. Zakrivljenost korijenskog kanala određena je Schindlerovom metodom (19), a za istraživanje su odabrani korjenovi zakrivljeni pod kutom od 30° koji pokazuju strukturu koronalnoga do apikalnoga meziobukalnog (MB) kanala. Izračun veličine uzorka proveden je G*Power analizom (Franz Faul, Universität Kiel, Njemačka), a broj uzoraka za svaku skupinu određen je kao n = 9. U konačnici, eksperimentalni postupci provedeni su s 27 uzoraka koji su ispunjavali kriterije.

Priprema uzoraka

Krune uzoraka odvojene su okomito na aksijalnu os uz hlađenje vodom približno 13 mm od apeksa, a zatim je uklonjen distalni korijen. Kako bi se odredila radna duljina, instrument K #15 guran je do vrha dok nije izašao iz apikalnog foramena. Svi MB kanali instrumentirani su do #F2 (0,25 / .08v) korištenjem Protaper Gold rotacijskog sustava datoteka (Dentsply Maillefer, Ballaigues, Švicarska). Preparacija korijenskog kanala obavljena je endodontskim motorom X-Smart Plus (Dentsply Maillefer, Ballaigues, Švicarska). Kanali su irigirani 5,25-postotnim natrijevim hipokloritom tijekom instrumentacije, zatim jednu minutu 17-postotnom otopinom EDTA-e i destiliranom vodom. Nakon čišćenja i oblikovanja osušeni su papirnatim štapićima. Uzorci su nasumično podijeljeni u tri skupine. Za punjenje korijenskog kanala primijenjena je tehnika jedne gutaperke (F2 gutaperka konus, Dentsply Sirona, Tulsa Dental Specialties, SAD). Dvije pojedinačne komponente AH Plusa pomiješane su u skladu s uputama proizvođača, a štapići gutaperke umočeni su u cement za brtvljenje i umetnuti u kanal. Well Root ST i AH Plus Bioceramic Sealer, koji se isporučuju u štrcaljki, ubrizgani su u kanal kroz posebne kanile, a zatim su postavljeni štapići gutaperke. Poslike postupka punjenja štapići gutaperke izrezani su na otvoru kanala i kondenzirani nabijačem.

The quality of the root canal filling was checked with micro-CT scanning. Segmentation of the material, dentin, and canal void was carried out using CTAn with the help of global thresholding. The calculations of the remaining materials and the conal void were analyzed after ROI selection. CTVox (v. 3.3.0 Bruker microCT Systems, Kontich, Belgium) was used for 3D visualization. CTVol (v. 2.3.2.0 Bruker microCT Systems, Kontich, Belgium) was used for 3D visualization of the models created using CTAn software. DataViewer (v. 1.5.6.2 Bruker microCT Systems, Kontich, Belgium) was used for the 2D visualization. The access cavity of all samples was closed using temporary filling material (Cavit, 3 M ESPE, St Paul, MN), and the samples were stored in a humid chamber at 37 °C for 2 weeks.

Removal of filling materials

Protaper Universal Retreatment Files and an X-Smart Plus endomotor were used to remove the canal filling. The instruments were used with a pecking motion, and the canals were irrigated with 5.25% sodium hypochlorite during preparation. Protaper Gold F3 file was used for the final apical preparation. Then, 17% EDTA and distilled water were used for the final rinse, respectively. After each instrumentation, residues on the file were gently cleaned. The canals were prepared until the file reached the working length. The patency was checked with a #15 no K file. No solvent was applied during the removal of the canal filling. All procedures were performed by a single endodontist.

Final micro-CT scanning

The remaining volume of canal filling for each specimen was measured as the total, coronal, middle, and apical parts of the canals. The region of interest (ROI) for mesiobuccal canals was 13 mm from the apex of the mesial root, and was determined by integration of the ROI in all slices using CTAn software. The accuracy of the segmentation was verified by making comparisons between the original and segmented scans. 3D models were created with volumetric analysis. (Figure 1) After the re-instrumentation procedure, the remaining obturation material and dentin volumes were measured in cubic millimeters for the total canal and its coronal, middle, and apical thirds (Figure 2). The isthmus area was excluded from the analysis as it cannot be reached to remove filling in this area using only re-instrumentation. The percentage of the remaining total filling material was calculated using the following formula:

$$\%\ \text{remaining filling material after retreatment} = \frac{\text{Volume of remaning filling after retreatment}}{\text{Volume of prepared root canal}} \times 100$$

Statistical analysis

IBM SPSS Statistics 26.0 was used to carry out the statistical analyses (IBM SPSS Inc., Chicago, USA). The Shapiro-Wilk test was used to determine whether the data distribution was normal. Since all data are not normally distributed, statistical analysis was performed with a non-parametric test by using the Kruskal-Wallis for the remaining canal filling volume comparisons.

Kvaliteta punjenja korijenskog kanala provjerena je mikro-CT snimkom. Segmentacija materijala, dentina i šupljine kanala provedena je s pomoću CTAn-a s pomoću globalnoga praga. Izračuni preostalog materijala i konalne šupljine analizirani su nakon odabira ROI-a. Za 3D vizualizaciju korišten je CTVox (v. 3.3.0 Bruker microCT Systems, Kontich, Belgija). CTVol (v. 2.3.2.0 Bruker microCT Systems, Kontich, Belgija) korišten je za 3D vizualizaciju modela kreiranih s pomoću softvera CTAn. Za 2D vizualizaciju korišten je DataViewer (v. 1.5.6.2 Bruker microCT Systems, Kontich, Belgija). Pristupni kavitet svih uzoraka zatvoren je privremenim materijalom za ispune (Cavit, 3 M ESPE, St Paul, MN), a uzorci su pohranjeni dva tjedna u vlažnom mediju na 37 °C.

Uklanjanje materijala za punjenje

Za uklanjanje materijala za punjenje iz kanala upotrijebljeni su instrumenti Protaper Universal Retreatment Files i endomotor X-Smart Plus. Korišteni su kljucajućim pokretima, a kanali su tijekom pripreme irigirani 5,25-postotnim natrijevim hipokloritom. Za završnu apikalnu preparaciju korišten je instrument Protaper Gold F3. Zatim je posljednje ispiranje obavljeno 17-postotnom EDTA-om i destiliranom vodom. Nakon svake instrumentacije ostatci na instrumentima nježno su očišćeni. Kanali su obrađivani dok instrument nije dosegnuo radnu duljinu. Prohodnost je provjerena instrumentom K #15. Tijekom uklanjanja materijala za punjene kanala nije upotrijebljeno otapalo. Sve zahvate obavljao je jedan endodont.

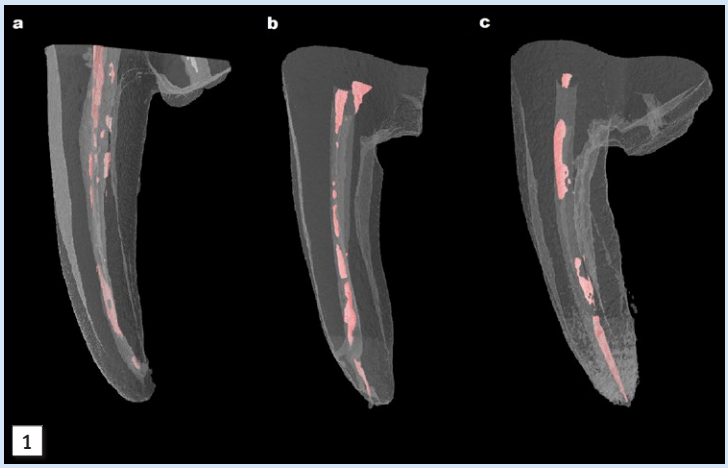
Završno mikro-CT skeniranje

Preostali volumen materijala za punjenje kanala za svaki uzorak mjeren je kao ukupni, te za koronarni, srednji i apikalni dio kanala. Područje interesa (ROI) za meziobukalne kanale bilo je 13 mm od vrha mezijalnog korijena i određeno je integracijom ROI-ja u svim rezovima s pomoću softvera CTAn. Točnost segmentacije provjerena je usporedbom između izvornih i segmentiranih skenova. Trodimenzionalni (3D) modeli izrađeni su volumetrijskom analizom (slika 1.). Poslije postupka reinstrumentacije, preostali volumen materijala za punjenje i dentina izmjereni su u prostornim milimetrima za cijeli kanal i njegovu koronarnu, srednju i apikalnu trećinu (slika 2.). Područje istmusa isključeno je iz analize jer se ne može dosegnuti da bi se uklonilo punjenje u tom području samo reinstrumentacijom. Postotak preostaloga ukupnog materijala za punjenje izračunat je s pomoću sljedeće jednadžbe:

$$\%\ \text{preostali materijal za punjenje nakon reinstrumentacije} = \frac{\text{Volumen preostalog punjenja nakon reinstrumentacije}}{\text{Volumen prepariranog korijenskog kanala}} \times 100$$

Statistička analiza

Za statističku analizu korišten je IBM SPSS Statistics 26.0 (IBM SPSS Inc., Chicago, SAD). Shapiro-Wilkov test upotrijebljen je da se utvrdi je li distribucija podataka normalna. Budući da svi podatci nisu bili normalno raspodijeljeni, statistička analiza provedena je neparametrijskim Kruskal-Wallisovim testom za usporedbu preostalog volumena materijala za punjenje kanala.



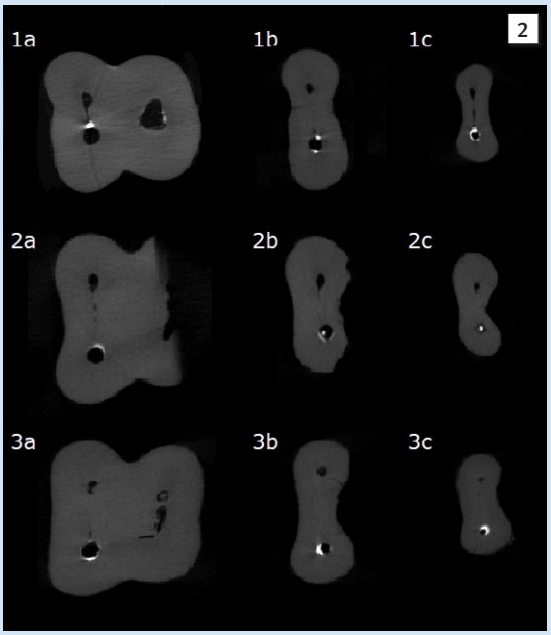


Figure 1 Representative micro-CT images show that the remaining filling materials in the canals after retreatment: a; AH Plus, b; Well-Root ST, c; AH Plus Bioceramic Sealer
Slika 1. Reprezentativne mikro-CT slike pokazuju preostali materijal za punjenje u kanalima poslije revizije: a; AH Plus, b; Well-Root ST, c; AH Plus biokeramičko brtvilo
Figure 2 Representative micro-CT images show that the axial section of coronal, middle and apical regions: 1a; AH Plus coronal, 2a; Well-Root ST coronal, 3a; AH Plus Bioceramic Sealer coronal, 1b; AH Plus middle, 2b; Well-Root ST middle, 3b; AH Plus Bioceramic Sealer middle, 1c; AH Plus apical, 2c; Well-Root ST apical, 3c; AH Plus Bioceramic Sealer apical
Slika 2. Reprezentativne mikro-CT slike pokazuju aksijalni presjek koronarne, srednje i apikalne regije: 1a; AH Plus koronarno, 2a; Well-Root ST krunica, 3a; AH Plus Bioceramic Sealer koronarno, 1b; AH Plus sredina, 2b; Well-Root ST sredina, 3b; AH Plus Bioceramic Sealer sredina, 1c; AH Plus apikalno, 2c; Well-Root ST apikalno, 3c; AH Plus Bioceramic Sealer apikalno

Results

The mean values of the percentage of total remaining root canal filling materials are presented in Table 1. There was no statistically significant difference between the AH Plus Bioceramic Sealer and Well Root-ST groups in terms of total remaining root canal filling (p>0.05). The AH Plus group had a lower percentage of total remaining canal filling than the other groups (p p<0.05). Pairwise comparisons of the groups are presented in Table 2.

Rezultati

Srednje vrijednosti postotka ukupnoga preostalog materijala za punjenje u korijenskom kanalu prikazane su u tablici 1. Nije bilo statistički značajne razlike između skupina AH Plus Bioceramic Sealer i Well Root-ST kad je riječ o ukupnome preostalom materijalu za punjenje korijenskog kanala (p > 0,05). Skupina AH Plus imala je niži postotak ukupnoga preostalog materijala za punjenje kanala od ostalih skupina (p < 0,05). Usporedbe parova skupina prikazane su u tablici 2.

Table 1 Total Percentage of Remaining Root Canal Filling Materials (%)
Tablica 1. Ukupni postotak preostaloga materijala za punjenje korijenskog kanala (%)

	N	Mean • Prosjek	Mean Rank • Prosjek rangova	Min	Max
AH Plus	9	2.36 [a]	4.00	1.07	5.50
Well-Root ST	9	14.44 [b]	12.20	6.62	27.08
AH Plus Bioceramic Sealer	9	11.13 [b]	11.33	1.39	15.69

* Different superscript letters indicate statistically significant differences. The significance level is p<0,05.

Table 2 Pairwise Comparisons of Groups
Tablica 2. Usporedbe skupina u paru

	Std. Error • Std. pogreška	Significance • Razina značajnosti
AH Plus - AH Plus Bioceramic Sealer	2.915	p=0.012*
AH Plus - Well Root ST	3.058	p=0.007*
AH Plus Bioceramic Sealer-Well Root ST	3.058	p=0.777

*The significance level is p<0.05. • *Razina značajnosti p < 0,05

There was no difference between the coronal, middle, and apical thirds of the root in terms of the volume of remaining canal filling material in the AH Plus group. Similarly, no significant difference was observed between coronal, middle, and apical in the AH Plus Bioceramic Sealer group. ($p>0.05$) However, the middle and apical thirds showed higher remaining canal filling volume than the coronal third in the Well-Root ST group ($p<0.05$). All mean values are presented in Table 3. Figures 1 and 2 represent remaining materials that are visualized with micro-CT.

Discussion

In case of failed root canal treatment, the retreatment procedure is a conservative way to preserve the affected tooth. In clinical studies, nonsurgical primary endodontic treatments have resulted in several success rates between 73.5% and 92.3% (20). Nonsurgical retreatment enables healing of periapical tissue and long-term survival of the tooth (21). Initial root canal filling should be removed for the success of the retreatment procedure (22). The removal of a sealer is an important factor for endodontic retreatment because the sealer accounts for the greatest percentage of the remaining filling material on the canal surfaces after re-instrumentation (23).

Radiopacity, flowability, leak-proofing, setting characteristics, and time are the chemical and physical properties of root canal sealers (24). Although there are many studies on the physicochemical and biocompatibility properties of root canal sealers in the literature, there are few studies on retreatability. Previous studies mostly evaluated the retreatability of Endosequence BC Sealer, which is another paste containing calcium silicate (5, 25-27). In the mentioned studies, a consensus was not reached on the remaining material ratio of AH Plus and Endosequence BC Sealer after retreatment. However, there is no study on Well-Root ST and AH Plus Bioceramic Sealer. For this reason, this study compared the removal of AH Plus, Well-Root ST, and AH Plus Bioceramic Sealer.

Micro-CT is commonly used in endodontics research for many purposes, such as visualizing canal morphology and analyzing prepared and filled canals (28). In our study, it was preferred for the detailed examination of the MB canals of mandibular molars and the assessment of the remaining canal filling volumes. MB canals of mandibular molar teeth show morphological variations due to their long, narrow, or curved anatomy and cause challenges during root canal treatment (29). For this reason, the first root canal treatment can result in failure, thus requiring a retreatment.

According to our findings, canal filling materials could not be completely removed from the root canal in any group. The Well-Root ST and AH Plus Bioceramic Sealer groups had a higher percentage of total remaining filling material than the AH Plus group. The penetration of the root canal sealer into the dentin is related to its retreatability (30). Calcium silicate-based sealers form hydroxyapatite crystals at the interface between dentin and canal filling, thus providing a chemical interaction (25, 31). In addition, after mixing, calcium silicate-based sealers continue micro-expansion

Nije bilo razlike između koronarne, srednje i apikalne trećine korijena kad je riječ o volumenu preostaloga materijala za punjenje kanala u skupini AH Plus. Slično tomu, nije zabilježena značajna razlika između koronarne, srednje i apikalne trećine u skupini AH Plus Bioceramic Sealer ($p > 0,05$). No srednja i apikalna trećina pokazale su veći preostali volumen materijala za punjenje kanala od koronarne trećine u skupini Well-Root ST ($p < 0,05$). Sve srednje vrijednosti prikazane su u tablici 3. Na slikama 1. i 2. ostatci su materijala za punjenje koji su vizualizirani mikro-CT-om.

Rasprava

U slučaju neuspješnoga endodontskog liječenja, postupak revizije je konzervativni način očuvanja zahvaćenog zuba. U kliničkim istraživanjima nekirurško primarno endodontsko liječenje rezultiralo je stopama uspjeha između 73,5 % i 92,3 % (20). Nekirurška revizija omogućuje cijeljenje periapikalnoga tkiva i dugotrajno preživljenje zuba (21). Primarno punjenje korijenskog kanala treba ukloniti da bi se osigurao uspjeh revizije (22). Uklanjanje cementa za brtvljenje važan je čimbenik za uspjeh revizije jer taj cement čini većinu preostaloga materijala za punjenje na površini stijenki kanala poslije reinstrumentacije (23).

Radiokontrastnost, protočnost, otpornost na curenje, karakteristike stvrdnjavanja i vrijeme kemijska su i fizikalna svojstva sredstava za brtvljenje korijenskih kanala (24). Iako u literaturi postoje mnoga istraživanja o fizikalno-kemijskim svojstvima i biokompatibilnosti sredstava za brtvljenje korijenskih kanala, malo je istraživanja o mogućnosti reinstrumentacije. U dosadašnjim istraživanjima uglavnom je ocjenjivana mogućnost revizije cementa Endosequence BC Sealer, još jedne paste koja sadržava kalcijev silikat (5, 25 – 27). U spomenutim istraživanjima nije postignut konsenzus o omjeru preostaloga cemenata AH Plus i Endosequence BC Sealer nakon reinstrumentacije. No ne postoji istraživanje o cementima Well-Root ST i AH Plus Bioceramic Sealer. Iz tog je razloga u ovom istraživanju uspoređeno uklanjanje cemenata AH Plus, Well-Root ST i AH Plus Bioceramic Sealer.

Mikro-CT obično se koristi u endodontskim istraživanjima u mnoge svrhe, kao što je vizualizacija morfologije kanala i analiza instrumentiranih i ispunjenih kanala (28). U našem istraživanju odabrano je za detaljni pregled MB kanala donjih kutnjaka i procjenu preostalog volumena materijala za punjenje kanala. MB kanali donjih kutnjaka pokazuju morfološke varijacije zbog svoje duge, uske ili zakrivljene anatomije i uzrokuju izazove tijekom endodontskog liječenja (29). To je razlog da primarno endodontsko liječenje može rezultirati neuspjehom i zahtijevati reviziju.

Prema našim nalazima materijali za punjenje kanala nisu se mogli potpuno ukloniti iz korijenskog kanala ni u jednoj skupini. Skupine Well-Root ST i AH Plus Bioceramic Sealer imale su veći postotak ukupnoga preostalog materijala za punjenje od skupine AH Plus. Prodiranje sredstva za brtvljenje korijenskih kanala u dentin povezano je s mogućnošću njegova uklanjanja (30). Cementi na bazi kalcijeva silikata stvaraju kristale hidroksiapatita na granici između dentina i punila kanala, čime se postiže kemijska interakcija (25, 31).

hardening in the canal due to their hydrophilic feature (32). The more difficult removal of Well-Root ST and AH Plus Bioceramic Sealer can be explained by their strong dentinal adaptation and bond strength (5).

In the single cone technique, a master gutta-percha cone of suitable size and taper of the final shaper instrument is placed into the root canal (33). Hydraulic pressure is created that pushes the sealer into the lateral canals and dentinal tubules by fully fitting the master cone to the canal (34). Previous studies have shown that there is no significant difference between the single cone and lateral compaction techniques in terms of filling quality in the mesial canals of mandibular molars (35, 36). The sealer placement method is crucial when filling root canals with the single cone technique. The fact that these sealers are injectable can have contributed to the formation of a monoblock structure with the single cone gutta-percha (11, 37). Moreover, previous studies showed that the removal of calcium silicate sealers requires a longer time to reach apical patency, hence it was a challenge to re-establish the working length (15, 38).

Egemen *et. al.* reported that Well-Root ST adversely affected the retreatment process in the middle and apical regions due to the depth of dentinal penetration (39). In line with this, our results showed more remaining material in the middle and apical regions than in coronal regions in the Well Root ST group. On the other hand, no significant difference was observed between the coronal, middle, and apical groups in other groups. This result can be due to the homogeneous distribution of AH Plus in the curved root canal with its low film thickness (40, 41). These results are also in agreement with the results of Kacunic *et al.* (13). The results of the study suggested that the exopy resin-based sealers showed more remnants (13). Yang *et al.* suggested that the retreatability of sealers was associated with low film thickness and good flow ability (43). Remarkably, AH Plus Bioceramic Sealer also showed similar retreatability in each canal section.

Most studies have found that the use of solvent does not provide benefits for gutta-percha removal regardless of the solvent composition (43, 44). Based on the available data, it has been reported that the use of solvents during retreatment may cause disadvantages in root canal cleaning and the formation of softened gutta-percha films on the root canal surface (43). For this reason, no solvent was applied in the removal of root canal filling in our study.

The limitation of this study is the supplementary technique in which passive ultrasonic activation after rotary file instrumentation was not used for the removal of canal filling. The study was also performed under *in vitro* conditions; further clinical studies can be conducted on the prognosis of retreatment.

Conclusion

This study points out to the fact that calcium silicate-based sealers cause more remaining materials than resin-based sealers into curved root canals.

Osim toga, poslije miješanja, cementi na bazi kalcijeva silikata nastavljaju stvrdnjavanje mikroekspanzijom u kanalu zbog svojih hidrofilnih značajki (32). Teže uklanjanje cemenata Well-Root ST i AH Plus Bioceramic Sealer može se objasniti njihovom snažnom prilagodbom dentinu i snagom veze (5).

U tehnici punjenja jednom gutaperkom u korijenski se kanal postavlja glavni štapić gutaperke koničnog oblika odgovarajuće veličine (33). Stvara se hidraulični tlak koji gura sredstvo za brtvljenje u lateralne kanale i dentinske tubule do potpunog ispunjavanja kanala štapićem gutaperke (34). U dosadašnjim istraživanjima autori su pokazali da ne postoji značajna razlika između tehnike jedne gutaperke i lateralne kondenzacije kad je riječ o kvaliteti punjenja u mezijalnim kanalima donjih kutnjaka (35, 36). Metoda brtvljenja ključna je pri punjenju korijenskih kanala tehnikom jednog štapića. Činjenica da se ti materijali za brtvljenje mogu ubrizgati mogla je pridonijeti stvaranju monoblokne strukture s gutaperkom (11, 37). Štoviše, u dosadašnjim istraživanjima pokazano je da je za uklanjanje kalcij-silikatnih cemenata potrebno dulje vrijeme da se postigne apikalna prohodnost, te je bio izazov ponovno uspostaviti radnu duljinu (15, 38).

Egemen i suradnici izvijestili su da je Well-Root ST nepovoljno utjecao na proces reinstrumentacije u srednjoj i apikalnoj regiji zbog dubine prodiranja u dentin (39). U skladu s tim, naši su rezultati pokazali više preostaloga materijala u srednjim i apikalnim regijama nego u koronalnima u skupini Well Root ST. S druge strane, nije uočena značajna razlika između koronarnih, srednjih i apikalnih trećina u ostalim skupinama. Taj rezultat može biti posljedica homogene distribucije cementa AH Plus u zakrivljenome korijenskom kanalu s malom debljinom filma (40, 41). Ti rezultati također su u skladu s rezultatima Kaćunića i suradnika (13). Rezultati istraživanja sugeriraju da su cementi za brtvljenje na bazi epoksidne smole imali više ostataka (13). Yang i suradnici sugerirali su da je mogućnost reinstrumentacije kanala povezana s malom debljinom filma i dobrom protočnošću (43). AH Plus Bioceramic Sealer također je pokazao sličnu mogućnost reinstrumentacije u svakom dijelu kanala.

U većini istraživanja otkriveno je da uporaba otapala nije korisna u uklanjanju gutaperke, bez obzira na sastav otapala (43, 44). Na temelju dostupnih podataka istaknuto je da uporaba otapala tijekom revizije može unazaditi čišćenje kanala stvaranjem omekšanoga gutaperkina filma na površini stijenke korijenskog kanala (43). Iz tog razloga u našem istraživanju nije primijenjeno otapalo za uklanjanje punjenja korijenskog kanala.

Ograničenje ovog istraživanja je dopunska tehnika kod koje se pasivna ultrazvučna aktivacija poslije instrumentacije rotirajućom turpijom nije koristila za uklanjanje materijala za punjenje kanala. Istraživanje je također provedeno u uvjetima *in vitro*; mogu se provesti daljnja klinička istraživanja o prognozi revizije.

Zaključak

Ovo je istraživanje pokazalo da u zakrivljenim korijenskim kanalima cementi na bazi kalcijeva silikata ostavljaju više preostaloga materijala nego oni na bazi smole.

Conflict of interest: The authors state that there is no conflict of interest in this study.

Funding: This study was not supported by any organization.

Author Contributions: Conceptualization: **C. B**; Data curation: **B. A;** Formal analysis: **B. A;** Funding acquisition: Investigation: **O. A, K. M**; Methodology: **O. A, T. E. O**; Project administration: **B. A;** Resources: **C. B**; Software: **O. K;** Supervision, Validation: **H. Y;** Visualization: **K. M**; Writing - original draft: **O. A, B. A;** Writing - review & editing: **H. Y.**

Acknowledgments: There is no financial support by any institution.

Ethics approval: This study was conducted with the approval of the Ethical Committee of Ankara University Faculty of Dentistry (no:18/01).

Sukob interesa: Autori nisu bili u sukobu interesa.

Financiranje: Ovo istraživanje nije poduprla ni jedna organizacija.

Doprinos autora: **C. B.** – konceptualizacija i softver; **B. A.** – prikupljanje podataka, formalna analiza, izvori i administracija projekta; **O. A i K. M.** – prikupljanje sredstava, istraživanje; **O. A , T. E. O.** – metodologija; **O. K.** – softver; **H. Y.** – supervizija i validacija, pisanje teksta, pregled i uređivanje; **K. M.** – vizualizacija; **O. A, B. A.** – pisanje izvornoga teksta.

Zahvala: Nije bilo financijske potpore.

Etičko odobrenje: Ovo istraživanje odobrio je Etički odbor Stomatološkog fakulteta Sveučilišta u Ankari (br:18/01).

Sažetak

Cilj: Uklanjanje sredstva za brtvljenje korijenskog kanala važan je čimbenik u nekirurškoj reviziji. Cilj ovog istraživanja bio je usporediti uklanjanje cemenata za brtvljenje AH Plus, Well Root ST i AH Plus Bioceramic Sealer korištenjem instrumenata za reviziju Protaper Universal. **Metode:** Zakrivljeni mezio-obukalni kanali ekstrahiranih kutnjaka donje čeljusti obrađeni su sustavom instrumenata Protaper Gold (do F2). Uzorci su nasumično podijeljeni u tri skupine i napunjeni tehnikom jedne gutaperke koristeći se AH Plusom, Well-Rooomt ST-om i AH Plus Bioceramic Sealerom. Poslije dva tjedna uklonjeno je punjenje korijenskog kanala svih uzoraka s pomoću instrumenata za reviziju Protaper Universal. Svi uzorci skenirani su mikro-CT-om. Preostali volumen materijala za punjenje u korijenskom kanalu zabilježen je u ukupnom iznosu te u koronarnoj, srednjoj i apikalnoj trećini svakog uzorka. **Rezultati: S**kupine Well-Root ST i AH Plus Bioceramic Sealer imale su veći postotak ukupnoga preostalog materijala za punjenje od skupine AH Plus ($P < 0,05$). **Zaključak: O**vo je istraživanje pokazalo da je volumen preostaloga materijala za punjenje korijenskog kanala bio značajno veći u uzorcima ispunjenima cementima na bazi kalcijeva silikata.

Zaprimljen: 8. prosinca 2023.
Prihvaćen: 13. ožujka 2024.

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MeSH pojmovi: materijali za punjenje korijenskog kanala; ponovljeno liječenje; sintetičke smole; silikatni cement
Autorske ključne riječi: mikro-CT; revizija; sredstva za brtvljenje korijenskih kanala

References

1. da Silva PJP, Marceliano-Alves MF, Provenzano JC, Dellazari RL, Gonçalves LS, Alves FR. Quality of root canal filling using a bioceramic sealer in oval canals: a three-dimensional analysis. Eur J Dent. 2021;15:475-80.
2. Siqueira Junior JF, Rôças IdN, Marceliano-Alves MF, Pérez AR, Ricucci D. Unprepared root canal surface areas: causes, clinical implications, and therapeutic strategies. Braz Oral Res. 2018 Oct 18;32(suppl 1):e65.
3. Almohareb RA, Barakat RM, Aljarallah N, Mudhish H, Almutairi A, Algahtani FN. Efficiency of diode laser and ultrasonic-activated irrigation in retreatment of gutta percha and bioceramic sealer: An in vitro study. Aust Endod J. 2023 Aug;49(2):318-323.
4. Tomson RM, Polycarpou N, Tomson P. Contemporary obturation of the root canal system. Br Dent J. 2014;216:315 - 22.
5. Oltra E, Cox TC, LaCourse MR, Johnson JD, Paranjpe A. Retreatability of two endodontic sealers, EndoSequence BC Sealer and AH Plus: a micro-computed tomographic comparison. Restor Dent Endod. 2017 Feb;42(1):19-26.
6. Candeiro GTdM, Lavor AB, Lima ITdF, Vasconcelos BCd, Gomes NV, Iglecias EF, et al. Penetration of bioceramic and epoxy-resin endodontic cements into lateral canals. Braz Oral Res. 2019;33epub:1 - 7.
7. Šimundić Munitić M, Budimir A, Jakovljević S, Anić I, Bago I.. Short-term antibacterial efficacy of three bioceramic root canal sealers against Enterococcus faecalis biofilms. Acta Stomatol Croat. 2020 Sep;54(3):294-301.
8. Park MG, Kim IR, Kim HJ, Kwak SW, Kim HC. Physicochemical properties and cytocompatibility of newly developed calcium silicate-based sealers. Aust Endod J. 2021 Dec;47(3):512-519.
9. Kim J-h, Cho S-Y, Choi Y, Kim D-h, Shin S-J, Jung I-Y. Clinical efficacy of sealer-based obturation using calcium silicate sealers: a randomized clinical trial. J Endod 2022;48:144 - 51.
10. Reszka P, Nowicka A, Lipski M, Dura W, Droździk A, Woźniak K. A comparative chemical study of calcium silicate-containing and epoxy resin-based root canal sealers. Biomed Res Int. 2016:2016:9808432.
11. Drukteinis S. Hydraulic calcium silicate-based materials for root canal obturation. Clin Dent Rev 2022;6:1 - 13.
12. Dentsply Sirona Accesed [02.10.2022]. Available from: https://www.dentsplysirona.com/en-ie/categories/endodontics/ah-plus-bioceramic-sealer-.html.
13. Jurić Kaćunić D, Tadin A, Dijanić P, Katunarić A, Matijević J, Trutina-Gavran M, et al. Efficacy of Reciprocating Instruments in Retreatment of Bioactive and Resin-Based Root Canal Sealers. Acta Stomatol Croat. 2022 Dec;56(4):338-350.
14. Jamleh A, Nassar M, Alfadley A, Alanazi A, Alotiabi H, Alghilan M, et al. Retreatment of oval-shaped root canals filled with TotalFill bioceramic or AH plus sealer. Sci Rep. 2023 Jun 8;13(1):9357.
15. Baranwal HC, Mittal N, Garg R, Yadav J, Rani P. Comparative evaluation of retreatability of bioceramic sealer (BioRoot RCS) and epoxy resin (AH Plus) sealer with two different retreatment files: An in vitro study. J Conserv Dent. 2021 Jan-Feb;24(1):88-93.
16. Khedmat S, Azari A, Shamshiri AR, Fadae M, Fakhar HB. Efficacy of ProTaper and Mtwo retreatment files in removal of guttapercha and GuttaFlow from root canals. Iran Endod J. 2016 Summer;11(3):184-7.
17. Huang Y, Celikten B, de Faria Vasconcelos K, Ferreira Pinheiro Nicolielo L, Lippiatt N, Buyuksungur A, et al. Micro-CT and nano-CT analysis of filling quality of three different endodontic sealers. Dentomaxillofac Radiol. 2017 Dec;46(8):20170223.
18. Ciftcioglu E, Barut G, Isik V, Arican B, Karagöz-Kücükay I. Different Dentin Conditioning Protocols on Bond Strength of a Bioceramic Root Canal Filling. Acta Stomatol Croat. 2023 Jun;57(2):155-166.
19. Schneider SW. A comparison of canal preparations in straight and curved root canals. Oral Surg Oral Med Oral Pathol Oral Radiol 1971;32:271-5.
20. García-Guerrero C, Delgado-Rodríguez CE, Molano-González N, Pineda-Velandia GA, Marín-Zuluaga DJ, Leal-Fernandez MC, et al. Predicting the outcome of initial non-surgical endodontic procedures by periapical status and quality of root canal filling: a cohort study. Odontology. 2020 Oct;108(4):697-703.
21. Lee A, Cheung G, Wong M. Long-term outcome of primary non-surgical root canal treatment. Clin Oral Investig. 2012 Dec;16(6):1607-17.

22. Jamleh A, Nassar M, Alfadley A, Alanazi A, Alotiabi H, Alghilan M, et al. Assessment of Bioceramic Sealer Retreatability and Its Influence on Force and Torque Generation. Materials (Basel). 2022 May 5;15(9):3316.
23. Colmenar D, Tamula T, Zhu Q, Ahn C, Primus C, Komabayashi T. Micro CT pilot evaluation of removability of two endodontic sealers. J Oral Sci. 2021 Oct 1;63(4):306-309.
24. Almeida M-M, Rodrigues C-T, Matos A-A, Oliveira R-C, Bernardineli N. Analysis of the physicochemical properties, cytotoxicity and volumetric changes of AH Plus, MTA Fillapex and TotalFill BC Sealer. J Clin Exp Dent. 2020 Nov 1;12(11):e1058-e1065.
25. Kim H, Kim E, Lee S-J, Shin S-J. Comparisons of the retreatment efficacy of calcium silicate and epoxy resin–based sealers and residual sealer in dentinal tubules. J Endod. 2015;41(12):2025-30.
26. Hess D, Solomon E, Spears R, He J. Retreatability of a bioceramic root canal sealing material. J Endod. 2011;37:1547-9.
27. Romeiro K, de Almeida A, Cassimiro M, Gominho L, Dantas E, Chagas N, et al. Reciproc and Reciproc Blue in the removal of bioceramic and resin-based sealers in retreatment procedures. Clin Oral Investig. 2020 Jan;24(1):405-416.
28. Aksoy U, Küçük M, Versiani M, Orhan K. Publication trends in micro-CT endodontic research: a bibliometric analysis over a 25-year period. Int Endod J. 2021 Mar;54(3):343-353.
29. Nagmode PS, Chavan KM, Rathi RS, Tambe VH, Lokhande N, Kapse BS. Radiographic evaluation of root canal curvature in mesiobuccal canals of mandibular molars by different methods and its correlation with canal access angle in curved canals: An in vitro study. J Conserv Dent. 2019 Sep-Oct;22(5):425-429.
30. Uzunoglu E, Yilmaz Z, Sungur DD, Altundasar E. Retreatability of root canals obturated using gutta-percha with bioceramic, MTA and resin-based sealers. Iran Endod J. 2015;10(2):93.
31. Crozeta BM, Lopes FC, Menezes Silva R, Silva-Sousa YTC, Moretti LF, Sousa-Neto MD. Retreatability of BC Sealer and AH Plus root canal sealers using new supplementary instrumentation protocol during non-surgical endodontic retreatment. Clin Oral Investig. 2021;25:891-9.
32. Koch K, Brave D, Nasseh AA. A review of bioceramic technology in endodontics. CE article. 2012;4:6-12.
33. Kalantar Motamedi MR, Mortaheb A, Zare Jahromi M, Gilbert BE. Micro-CT evaluation of four root canal obturation techniques. Scanning. 2021 Feb 25:2021:6632822. d
34. Savannah G. Bioceramic technology–the game changer in endodontics. Endod Pract. 2009;13.
35. Hörsted-Bindslev P, Andersen MA, Jensen MF, Nilsson JH, Wenzel A. Quality of molar root canal fillings performed with the lateral compaction and the single-cone technique. J Endod. 2007 Apr;33(4):468-71.
36. Wu M-K, Bud MG, Wesselink PR. The quality of single cone and laterally compacted gutta-percha fillings in small and curved root canals as evidenced by bidirectional radiographs and fluid transport measurements. Oral Surg Oral Med Oral Pathol Oral Radiol. 2009;108:946-51.
37. Tay FR, Pashley DH. Monoblocks in root canals: a hypothetical or a tangible goal. J Endod. 2007 Apr;33(4):391-8.
38. Agrafioti A, Koursoumis AD, Kontakiotis EG. Re-establishing apical patency after obturation with Gutta-percha and two novel calcium silicate-based sealers. Eur J Dent. 2015;9:457-61.
39. Egemen A, Belli S. The effect of primary root-canal treatment on dentinal tubule penetration of calcium silicate-based sealers during endodontic re-treatment. J Endod. 2022 Sep;48(9):1169-1177.
40. Versiani M, Carvalho-Junior J, Padilha M, Lacey S, Pascon E, Sousa-Neto M. A comparative study of physicochemical properties of AH PlusTM and EpiphanyTM root canal sealants. Int Endod J. 2006 Jun;39(6):464-71.
41. Kaul S, Kumar A, Badiyani BK, Sukhtankar L, Madhumitha M, Kumar A. Comparison of sealing ability of bioceramic sealer, AH Plus, and guttaflow in conservatively prepared curved root canals obturated with single-cone technique: an in vitro study. J Pharm Bioallied Sci. 2021 Jun;13(Suppl 1):S857-S860.
42. Yang R, Tian J, Huang X, Lei S, Cai Y, Xu Z, et al. A comparative study of dentinal tubule penetration and the retreatability of EndoSequence BC Sealer HiFlow, iRoot SP, and AH Plus with different obturation techniques. Clin Oral Investig. 2021 Jun;25(6):4163-4173.
43. Dotto L, Sarkis-Onofre R, Bacchi A, Pereira GKR. The use of solvents for gutta-percha dissolution/removal during endodontic retreatments: A scoping review. J Biomed Mater Res B Appl Biomater. 2021 Jun;109(6):890-901.
44. Takahashi CM, Cunha RS, De Martin AS, Fontana CE, Silveira CFM, da Silveira Bueno CE. In vitro evaluation of the effectiveness of ProTaper universal rotary retreatment system for gutta-percha removal with or without a solvent. J Endod. 2009 Nov;35(11):1580-3.