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Efficacy of Reciprocating Instruments in Retreatment of Bioactive and Resin-Based Root Canal Sealers

Učinkovitost recipročnih instrumenata pri reviziji endodontskih ispuna na bazi bioaktivnih i epoksidnih punila

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Abstract
Objective: To compare the effectiveness of reciprocating instruments in removing gutta-percha and bioactive-based (BioRoot RCS and MTA Fillapex) and epoxy resin-based (AH Plus) sealers from root canals based on filling residues and the time required for root canal revision. **Material and methods:** Root canals of 90 teeth were instrumented with Reciproc R40. All root canals were obturated using the single-cone technique with Reciproc R40 gutta-percha and with one of the selected sealers. Samples with oval, straight canals were used and randomly divided into three groups: (i) filled with AH Plus sealer and gutta-percha (n=30); (ii) filled with MTA Fillapex and gutta-percha (n=30); (iii) filled with BioRoot RCS and gutta-percha (n=30). Each group was divided into two subgroups (n=15) according to the retreatment instrument used (Reciproc M-Wire R25/R40 or Reciproc blue RB25/RB40). Root canals were longitudinally split and analyzed with a stereomicroscope at 15 × magnifications in the coronal, middle, and apical third. Computational analyses were performed with the Image J software. Data were compared using the Kruskal-Wallis test and Mann-Whitney U test. **Results:** While no statistically significant differences in the residual material surface were found for Reciproc Blue, Reciproc M-Wire showed significantly higher residual material surface for AH Plus and MTA Fillapex compared to BioRoot RCS. For AH plus. Residual material surface was significantly lower for Reciproc Blue than for Reciproc M-Wire. In contrast, BioRoot RCS showed a significantly higher residual material surface for Reciproc Blue. **Conclusions:** Calcium silicate-containing sealers were more retrievable compared to AH Plus, with fewer sealer remnants and shorter retreatment time. Retreatment with Reciproc M-Wire instruments was superior to Reciproc blue instruments in retreatment of BioRoot RCS. However, none of the sealers were removed completely.

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Introduction

The failure of primary endodontic treatment necessitates retreatment of the entire endodontic space (1). This procedure is successful if it results in a healed condition and long-term dental retention. There are different retreatment approaches (2,3), the success of which is closely related to the retreatment method and type of root filler (4).

Despite improved and efficient endodontic techniques and materials, remnants of old fillers can remain in the cavity (5–7). The root canal is usually obturated with gutta-per-

Uvod

Neuspjelo primarno endodontsko liječenje zahtijeva ponovni tretman cijeloga endodontskog prostora (1). Taj je postupak uspješan ako rezultira izlječenjem i dugotrajnošću. Postoje različiti pristupi endodontske revizije (2, 3), a uspjeh je usko vezan uz metodu revizije i vrstu korijenskog punila (4). Unatoč poboljšanim i učinkovitim endodontskim tehnikama i materijalima, ostatci starih punila ostaju u kanalu (5 – 7). Korijenski kanal obično se opturira, zatvara gutaperkom i punilom. Odgovarajuća kemomehanička priprema korijen-

cha and a sealer. Appropriate chemo-mechanical preparation of the root canal system and good obturation with a central gutta-percha cone surrounded by a sealer are considered the major factors for the success of the primary endodontic treatment (8,9). Failures of endodontic treatment may occur due to various procedural errors, leading to the need for retreatment. The complete removal of the old filling, despite the development of new technologies, methodologies, fillings, and solvents, remains challenging in modern endodontics (10). The fast development of NiTi rotary instruments resulted in many different systems which simplified shaping and increased the predictability and effectiveness of the endodontic treatment. The sequences have become less invasive, the coronal taper is less pronounced, and apical finishing procedures have become more sophisticated to improve sealing (11).

Gutta-percha combined with an epoxy-resin sealer or zinc oxide eugenol sealer are considered the gold-standard endodontic materials for root canal obturation (12,13). To date, numerous studies have examined the removal efficacy of the aforementioned filling materials (14–16). AH Plus is popular because of its good sealing ability and adhesion (14) and low solubility and disintegration (17). Bioactive sealers have been developed to provide improved materials for root canal filling. Newer sealers are based on a bioactive technology to provide a better root canal obturation with minimal postoperative complications and are known for their antibacterial effect (16–18) and good biocompatibility (19,20).

Mineral trioxide-based sealers have been introduced based on the biological properties of mineral trioxide aggregates (MTAs). However, some studies have obtained conflicting results on their bioactivity. The bioactive properties of a salicylate resin-based sealer with 13.2% set MTA mixed in as a filler could not be determined *in vivo* (21). However, several studies have shown the bioactive potential of MTA Fillapex, the mineralizing ions (Ca^{2+}) of which bind biological active ions and nucleation of apatite precursors on the material surface with lower calcium release and less apatite deposition after aging in Hank's balanced salt solution (HBSS) compared to the BioRoot RCS (22). MTA Fillapex, on the other hand, is a salicylate resin-based sealer with 13.2% set MTA admixed as a filler (21,23). Furthermore, MTA Fillapex has also expressed bioactive potential in subcutaneous tissue *in vivo* (24). Therefore, *ex vivo* and *in vivo* studies are required to confirm the suitability of these salicylate resin-based sealers with MTA filler for clinical application.

The positive bioactive and regenerative properties of BioRoot RCS have shown the potential of bioactive materials to (19) create a hard barrier (19,22), provide antimicrobial activity (4,16,17) and high pH (>11) (4), and prolong calcium ion release, which are key factors in endodontic and periodontal tissue regeneration (22). Previous studies on the retrievability of hydraulic sealers have mostly used AH Plus sealers (25), but no consensus on its removal has been reached. Therefore, this study examines the success of hydraulic sealer retreatment to resolve the previously reported conflicting results.

The development of Nickel-Titanium motor-driven instruments has made mechanical retreatment easier and more

skoga kanalnog sustava i dobra tehnika punjenja središnjom gutaperkom i endodontskim punilom smatraju se glavnim čimbenicima uspjeha primarnoga endodontskoga liječenja (8,9). Neuspjelo endodontsko liječenje može se pak pojaviti zbog raznih proceduralnih pogrešaka i potrebno je ponovno liječenje. Potpuno uklanjanje starog ispuna, unatoč razvoju novih tehnologija, metodologija, ispuna i otapala, ostaje izazov u suvremenoj endodonciji (10). Brzi razvoj nikal-titanijevih (NiTi) rotirajućih instrumenata rezultirao je mnogim različitim sustavima koji su pojednostavnili oblikovanje i povećali predvidljivost i učinkovitost endodontskog liječenja. Sekvencije su postale manje invazivne, koronarno sužavanje manje je izraženo, a apikalni završni postupci postali su sofisticiraniji kako bi se poboljšalo endodontsko punjenje (11). Gutaperka u kombinaciji s brtvilom od epoksidne smole ili punilom od cink-oksidnoga eugenola smatra se zlatnim standardom endodontskih materijala za zatvaranje korijenskog kanala (12, 13). Do danas se u mnogobrojnim studijama ispitivala učinkovitost uklanjanja tih materijala za punjenje (14 – 16). AH Plus je popularan zbog dobrog svojstva brtvljenja i adhezije (14) te niske topljivosti i raspadanja (17). Bioaktivna punila razvijena su da bi se poboljšali materijali za punjenje korijenskih kanala. Tako se novi materijali temelje na bioaktivnoj tehnologiji kako bi se omogućila bolja opturacija korijenskog kanala s minimalnim postoperativnim komplikacijama i poznati su po svojem antibakterijskom učinku (16 – 18) i dobroj biokompatibilnosti (19, 20). Punila na bazi mineralnog trioksida uvedena su na temelju bioloških svojstava mineral trioksid-agregata (MTA). Međutim, u studijama su dobiveni proturječni rezultati kad je riječ o njihovoj bioaktivnosti. Bioaktivna svojstva punila na bazi salicilatne smole s 13,2 % postavljene MTA-e umiješane kao punilo, nisu se mogla odrediti *in vivo* (21). No autori nekoliko studija istaknuli su bioaktivni potencijal MTA Fillapexa, čiji mineralizirajući ioni (Ca^{2+}) vežu biološki aktivne ione i nukleaciju prekursora apatita na površini materijala uz manje oslobađanje kalcija i manje taloženje apatita nakon starenja u Hankovoj uravnoteženoj otopini soli (HBSS) u usporedbi s BioRoot RCS-om (22). MTA Fillapex, s druge strane, punilo je na bazi salicilatne smole s 13,2 % udjela MTA-e umiješane kao punilo (21, 23). Nadalje, MTA Fillapex također je pokazao bioaktivni potencijal u potkožnom tkivu *in vivo* (24). Zato su potrebne studije *ex vivo* i *in vivo* da bi se za kliničku primjenu potvrdila prikladnost tih punila na bazi salicilatne smole s MTA punilom. Pozitivna bioaktivna i regenerativna svojstva BioRoot RCS-a pokazala su potencijal bioaktivnih materijala za (19) stvaranje čvrste barijere (19,22), antimikrobnu aktivnost (4, 16, 17) i visoki pH (> 11) (4) te produljeno otpuštanje iona kalcija koji su ključni čimbenici u regeneraciji endodontskoga i parodontnoga tkiva (22). U dosadašnjim studijama, kada je riječ o mogućnosti revidiranja hidrauličnih punila, autori su se uglavnom koristili punilom AH Plus (25), ali nije postignut konsenzus o njihovu uklanjanju. Zato se u ovoj studiji ispituje uspjeh endodontske revizije hidrauličnih punila kako bi se riješili do sada objavljeni proturječni rezultati. Razvoj strojne endodoncije te nikal-titanijevih instrumenata učinio je endodontsku reviziju lakšom i učinkovitijom (5, 14, 26), jer su poboljšani obrada i čišćenje (26) te

effective (5,14,26), thus improving processing and the ability to clean (26) and reshaping of root canal system (27). Reciprocating one-instrument systems emerged in the autumn of 2011, enabling retention of the original root shape due to their improved mechanical properties and reciprocating movement (14) and simplifying the retreatment procedure of the endodontic space by saving time (12,26) and avoiding cross-infection (7,14). Reciproc blue instruments represent the next generation of reciprocating instruments, subjected to high temperatures after manufacturing procedures to improve their flexibility and cyclic fatigue resistance (28) and increase their life span. Their design and operation are the same as those of the Reciproc M-wire system. Reciproc blue and Reciproc M-wire instruments were previously used in initial root treatment and retreatment (29,30).

This *ex vivo* study uses extracted teeth to compare the efficacy and retreatment times of reciprocating instruments Reciproc M-Wire and Reciproc blue files in removing gold-standard epoxy resin-based sealer and two calcium silicate-based sealers, MTA Fillapex and BioRoot RCS. Various retreatment techniques have been used for many years, but the ideal method is still being sought. Our first null hypothesis was that retreatment remnants do not differ significantly among the three different sealers (AH Plus, MTA Fillapex, and BioRoot RCS) when treating root thirds and entire root canal using reciprocating instruments Reciproc blue and Reciproc M-Wire files. Our second null hypothesis was that time required for the retreatment procedure with reciprocating files would not differ significantly among the three materials.

Material and methods

Sample Size Calculation

Sample size calculation was performed considering the percentage of residual material surface as a primary parameter of interest. For an initial (orientational) power analysis, the article by Katunarić et al. (12) was used due to a similar methodology of evaluating the residual material. This power analysis determined an orientational sample size of n=15 and was followed by our preliminary study in which the root canals were retreated using Reciproc M-Wire, with the aim to evaluate the suitability of the determined sample size for identifying statistically significant differences between filing materials of 15% with a probability (statistical power) of 80% at a significance level of 0.05. This power analysis showed that a comparatively higher data variability obtained in our measurements compared to those from the article by Katunarić et al. (12) required increasing the sample size to n=30. Hence, this value was selected as a final sample size to be used in the study. To obtain n=30 by using 15 teeth per experimental group, both sides of the cross-sectioned specimens were used for the measurements. Due to the pronounced locality of residual material throughout the root canal and the amount of material removed in the process of sectioning and polishing, the two sides of the same canal were considered to be sufficiently unrelated to each other to be used in the statistical analysis as independent observations.

preoblikovanje sustava korijenskih kanala (27). Ujesen 2011. pojavili su se recipročni sustavi s jednim instrumentom koji su, zahvaljujući poboljšanim mehaničkim svojstvima i recipročnom kretanju, omogućili zadržavanje izvornog oblika korijena (14) te pojednostavnili postupak endodontske revizije, uštedjeli vrijeme (12, 26) te izbjegli križnu infekciju (7, 14). Instrumenti Reciproc blue sljedeća su generacija strojnih instrumenata koji se nakon proizvodnje podvrgavaju visokim temperaturama da bi se poboljšala njihova fleksibilnost i otpornost na ciklički umor (28) te produljila trajnost. Njihov dizajn i rad isti su kao i kod sustava Reciproc M-Wire. Instrumenti Reciproc blue i Reciproc M-Wire prethodno su korišteni u početnom endodontskom liječenju i reviziji korijena (29, 30). U ovoj studiji *ex vivo* korišteni su izvađeni zubi za usporedbu učinkovitosti i vremena revizije recipročnih instrumenata Reciproc M-Wire i Reciproc blue u uklanjanju zlatnog standarda za punjenje na bazi epoksidne smole i dvaju punila na bazi kalcijeva silikata – MTA Fillapexa i BioRoot RCS-a. Različite tehnike ponovnog tretmana (revizije) koriste se godinama, ali idealni postupak još se traži.

Naša prva nulta hipoteza bila je da se neuklonjeni ostatci poslije revizije ne razlikuju znatno između triju različitih sredstava za brtvljenje (AH Plus, MTA Fillapex i BioRoot RCS) kada se tretiraju trećine korijena i cijeli korijenski kanal recipročnim instrumentima Reciproc blue i Reciproc M-Wire.

Naša druga nulta hipoteza glasila je da se vrijeme potrebno za postupak endodontske revizije neće znatno razlikovati između tih triju materijala.

Materijal i metode

Izračun veličine uzorka

Izračun veličine uzorka proveden je uzimajući u obzir postotak površine zaostalog materijala kao primarni parametar. Za početnu (orijentacijsku) analizu snage korišten je članak autorice Katunarić i suradnika (12) zbog slične metodologije procjene zaostalog materijala. Ovom analizom snage utvrđena je orijentacijska veličina uzorka od n = 15, nakon čega je slijedila naša preliminarna studija u kojoj su korijenski kanali revidirani s pomoću Reciproc M-Wirea, da bi se procijenila prikladnost utvrđene veličine uzorka za utvrđivanje statistički značajnih razlika između arhiviranja materijala od 15 % s vjerojatnošću (statističkom snagom) od 80 % na razini značajnosti od 0,05. Ova analiza snage pokazala je da je razmjerno veća varijabilnost podataka dobivena u našim mjerenjima, u usporedbi s onima iz članka I. Katunarić i suradnika (12), zahtijeva povećanje veličine uzorka na n = 30. Zato je ta vrijednost odabrana kao konačna veličina uzorka koja će se koristiti u studiji. Da bi se dobilo n = 30 korištenjem 15 zuba po eksperimentalnoj skupini, za mjerenja su korištene obje strane presječenih uzoraka. Zbog izražene lokalizacije zaostaloga materijala u cijelom korijenskom kanalu i količine materijala uklonjenog u procesu rezanja i poliranja, smatralo se da su dvije strane istog kanala dovoljno nepovezane da bi se koristile u statističkoj analizi kao neovisna zapažanja.

Sample Selection and Preparation

This study was approved by the Ethics Committee of the Faculty of Dentistry at the University of Zagreb (Zagreb, Croatia; 01-PA-35-29-14.1.2/2018). It was performed using 90 human teeth with oval, straight canals extracted for periodontal, orthodontic, or other health reasons that were immediately rinsed under tap water, cleaned of blood residues by immersion in a 3% hydrogen solution (Beyers GmbH; Mönchengladbach, Germany), and stored in a 0.5% chloramine solution (Stadt Apotheke; Gaggenau, Germany) until needed. The inclusion criteria were teeth with fully developed roots, no signs of external resorption or root caries, and no previous endodontic treatment. The soft tissue of the periodontal ligament and the calculus on the root surface were removed with manual curettes (ASA Dental; Bozzano, Brazil). Samples were cleaned and sterilized in an autoclave. Before being used for instrumentation and obturation, all teeth were trimmed to a length of 16 mm in order to establish a standardized working length of 15 mm. Then the markings for apical, middle, and cervical sections were made by dividing the working length into three parts (each 5 mm long). The root canal orifice was prepared with a diamond fissure drill No. 016 (Comet; Rock Hill, SC, USA) mounted on a turbine with water cooling. The dental pulp was removed with a pulp extirpator (Maillefer; Ballaigues, Switzerland). The length of each root canal was measured using an endodontic instrument, ISO 10 K-file (Maillefer), that was inserted into the canal up to the tip of the root and then pulled back 1 mm. The average canal length was 15 mm.

All 90 root canals were instrumented using a motor-driven Reciproc Gold device (VDW GmbH; Munich, Germany) and a Reciproc M-Wire instrument R40. During instrumentation, each root canal was rinsed with 2.5% sodium hypochlorite (NaOCl; Legeartis Pharma GmbH; Dettenhausen, Germany) using a 30G needle (BD Microlance; Becton Dickinson; Madrid, Spain) and 5 mL syringe. The residual layer was removed by rinsing the root canals with 1mL of 15% ethylenediaminetetraacetic acid (EDTA [Calcinase]; Legeartis) that was left inside the canal for 3 min. The canals were finally rinsed with 1 mL of 0.9% saline (NaCl; Braun; Melsungen, Germany) and dried with sterile R40 paper points (VDW GmbH). All endodontic procedures were performed by a single experienced operator in random order. Due to visually apparent differences and different handling properties of the sealers, the operator blinding was not possible. Only single-rooted teeth with round or oval canals were used to limit the heterogeneity of the root canal anatomy.

Obturation

The prepared samples were randomly divided into three experimental groups (n=30 each) that were filled with a Reciproc R40 gutta-percha (GP) point (VDW GmbH) and three different sealers during the retreatment procedure (Table 1): AH Plus sealer (De Trey; Ballaignes, Switzerland) - AHP/GP; MTA Fillapex (Angelus; Londrina, Brazil) - MTAF/GP; BioRoot RCS (Septodont; Saint-Maur-des Fosses, France) - BRRCS/GP. All root canals were filled using a single cone technique. The filling materials were prepared ac-

Izbor i priprema uzorka

Ovu studiju odobrilo je Etičko povjerenstvo Stomatološkog fakulteta Sveučilišta u Zagrebu (Zagreb, Hrvatska; 01-PA-35-29-14.1.2/2018). Provedeno je na 90 ljudskih zuba s ovalnim, ravnim kanalima izvađenima zbog parodontnih, ortodontskih ili drugih zdravstvenih razloga, te su odmah isprani pod vodom iz slavine, očišćeni od ostataka krvi uranjanjem u 3-postotnu otopinu vodika (Beyers GmbH; Mönchengladbach, Njemačka) i do početka postupka pohranjeni u 0,5-postotnoj otopini kloramina (Stadt Apotheke; Gaggenau, Njemačka). Kriteriji za uključivanje bili su zubi s potpuno razvijenim korijenom, bez znakova vanjske resorpcije ili karijesa korijena te bez endodontskog liječenja. Mekano tkivo parodontnog ligamenta i kamenac na površini korijena uklonjeni su ručnim kiretama (ASA Dental; Bozzano, Brazil). Uzorci su očišćeni i sterilizirani u autoklavu. Prije upotrebe za instrumentiranje i punjenje, svi su zubi trimirani, skraćeni na 16 mm kako bi se uspostavila standardizirana radna dužina od 15 mm. Zatim su napravljene oznake za apikalni, srednji i cervikalni presjek dijeljenjem radne dužine na tri dijela (svaki 5 mm). Ušće korijenskog kanala preparirano je dijamantnim fisurnim svrdlom br. 016 (Komet; Rock Hill, SC, SAD) montiranim na turbinu s vodenim hlađenjem. Zubna pulpa uklonjena je ekstirpatorom pulpe (Maillefer; Ballaigues, Švicarska). Dužina svakoga korijenskog kanala izmjerena je endodontskim instrumentom ISO 10 K-turpijom (Maillefer) koji je umetnut u kanal do vrha korijena i zatim povučen 1 mm unatrag. Prosječna dužina kanala bila je 15 mm. Svih 90 korijenskih kanala obrađeno je strojnim uređajem Reciproc Gold (VDW GmbH; München, Njemačka) i instrumentom Reciproc M-Wire R 40. Tijekom instrumentacije svaki je korijenski kanal ispran 2,5-postotnim natrijevim hipokloritom (NaOCl; Legeartis Pharma GmbH; Dettenhausen, Njemačka) s pomoću igle od 30 G (BD Microlance; Becton Dickinson; Madrid, Španjolska) i štrcaljke od 5 mL. Zaostali sloj uklonjen je ispiranjem korijenskih kanala jednim mililitrom15-postotne etilendiamintetraoctene kiseline [EDTA (Calcinase); Legeartis] koja je ostavljena u kanalu 3 minute. Kanali su na kraju isprani jednim mililitrom 0,9-postotne fiziološke otopine (NaCl; Braun; Melsungen, Njemačka) i osušeni sterilnim papirnatim štapićima R 40 (VDW GmbH). Sve endodontske postupke obavljao je nasumičnim redoslijedom jedan iskusni operater koji izvrsno uočava i poznaje vizualno vidljive razlike i različita svojstva rukovanja punilima. Korišteni su samo jednokorijenski zubi s okruglim ili ovalnim kanalima da bi se ograničila heterogenost anatomije korijenskog kanala.

Punjenje

Pripremljeni uzorci nasumično su podijeljeni u tri pokusne skupine (svaka n = 30) koje su napunjene gutaperkom Reciproc R 40 (GP) i trima različitim punilima (tablica 1.): AH Plus (De Trey; Ballaignes, Švicarska), AHP/GP; MTA Fillapex (Angelus; Londrina, Brazil) MTAF/GP; BioRoot RCS (Septodont; Saint-Maur-des Fosses, Francuska) BRRCS/GP. Svi korijenski kanali ispunjeni su tehnikom jednoga štapića gutaperke. Materijali za ispune pripremljeni su prema uputama proizvođača i uneseni u korijenski kanal „master point“

Table 1 Composition of the three root canal sealers.
Tablica 1. Sastav tri sredstva za brtvljenje korijenskih kanala

Root canal sealers • xxx	Manufacture • xxx	Composition • xxx
BioRoot RCS	Septodont (Saint-Maur-des Fosses, France)	Powder: tricalcium silicate, zirconium oxide, and povidone. Liquid: aqueous solution of calcium chloride and polycarboxylate.
MTA Fillapex	Angelus (Londrina, Brazil)	Base paste: salicylate resin, natural resin, calcium tungstate, nanoparticulated silica, and pigments. Catalyst paste: diluting resin, mineral trioxide aggregate (set), nanoparticulated silica, and pigments.
AH Plus	Dentsply (Konstanz, Germany)	Paste A: bisphenol-A epoxy resin, bisphenol-F epoxy resin, calcium tungstate, zirconium oxide, silica, and iron oxide pigments. Paste B: dibenzyldiamine, aminoadamantane, tricyclodecane-diamine, calcium tungstate, zirconium oxide, silica, and silicone oil.

cording to the manufacturer's instructions and entered the root canal with the master point gutta-percha point R40. Excess material was removed with a heated plugger 1mm below the root canal entrance, and the cavities were temporarily closed with Cavit (ESPE, Seefeld, Germany)**.** Digital X-rays were recorded for homogeneity and lengths check of canal fillings. According to the manufacturers, the setting times of MTA Fillapex, Bio Root, and AH Plus amount to 2, 4, and 8 hours, respectively. To ensure the setting of hydraulic sealers in a moist environment (31), specimens were stored in an incubator at 37 °C and 100% humidity for seven days. The storage in a humidified incubator was performed according to the previous studies (32,33).

Root canal retreatment

An R25 file with a taper of 0.08 over the first apical mm was used to remove filling material until a working length was reached, followed by an R40 file with a taper of 0.06 over the first apical mm (5). Reciproc M-Wire R25, followed by Reciproc R40 instruments (VDW GmbH; n=15) and Reciproc blue RB25, and Reciproc blue RB40 instruments (VDW GmbH; n=15), were used for root canal retreatment in all groups. Alternate rinsing was performed using NaOCl and EDTA and drying using standard paper points (size #40/0.04; VDW GmbH). The protocol was performed according to the manufacturer`s instructions (12). The retreatment was considered complete when there were no visible traces of filling material on the instruments, and the retreatment time was recorded. The total time required to remove the root fillings was measured from when the instruments were first applied in the canal until they regained apical patency. The stopwatch was started when the retreatment proceeded and stopped when the instrument was removed from the canal. Time to reach working length (T1) and that for complete gutta-percha removal and preparation to size 40 (T2) were recorded. Time for instrument changes and irriga-

gutaperkom R 40. Višak je uklonjen grijanim instrumentom 1 mm ispod ulaza korijenskog kanala, a kaviteti su privremeno zatvoreni Cavitom (ESPE, Seefeld, Njemačka). Snimljene su digitalne rendgenske snimke radi provjere homogenosti i dužine ispuna kanala. Prema proizvođačima, vrijeme stvrdnjavanja MTA Fillapexa, Bio Roota i AH Plusa iznosi 2, 4, odnosno 8 sati. Kako bi se osiguralo postavljanje hidrauličnih punila u vlažnom okruženju (31), uzorci su bili pohranjeni sedam dana u inkubatoru na temperaturi od 37 °C i izloženi 100-postotnoj vlažnosti. Pohranjivanje u ovlaženi inkubator provedeno je prema istovrsnom postupku u prethodnim studijama (32, 33).

Revizija korijenskog kanala

Instrument R 25, s konusom od 0,08 preko prvoga apikalnoga milimetra, korišten je za uklanjanje materijala za ispun dok se ne postigne radna dužina, nakon čega je slijedio endodontski instrument R 40 s konusom od 0,06 preko prvoga apeksnoga milimetra (5). Reciproc M-Wire R 25, zatim instrumenti Reciproc R 40 (VDW GmbH; n=15) i Reciproc blue RB 25, te Reciproc blue RB 40 (VDW GmbH (n = 15) korišteni su za reviziju korijenskih kanala u svim skupinama. Naizmjenično ispiranje obavljeno je korištenjem NaOCl-a i EDTA-e, a zatim su osušeni papirnatim štapićima s odgovarajućim promjerom na vrhu (veličina #40/0,04; VDW GmbH). Protokol je primijenjen prema uputama proizvođača (12). Revizija se smatrala završenom kada na instrumentima nije bilo vidljivih tragova materijala za punjenje, a vrijeme endodontske revizije je zabilježeno. Ukupno vrijeme potrebno za uklanjanje korijenskih ispuna mjereno je od trenutka kada su instrumenti prvi put primijenjeni u kanalu do ponovnoga uspostavljanja apikalne prohodnosti. Štoperica je pokrenuta kada je revizija nastavljena, a zaustavljena je kada je instrument uklonjen iz kanala. Zabilježeno je vrijeme do postizanja radne dužine (T 1) potpunog uklanjanja gutaper-

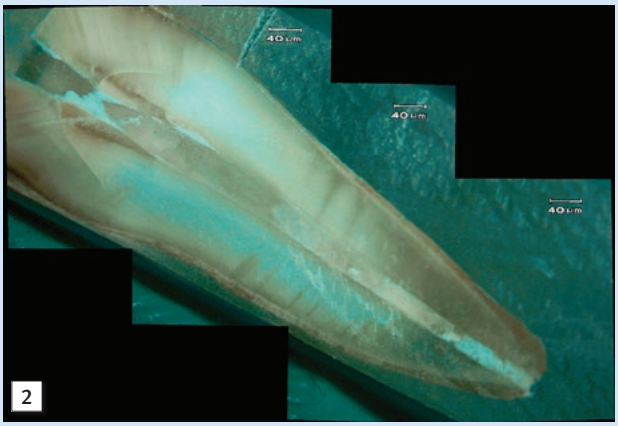

Figure 1 Specimens placed in marked acrylic blocks, and split longitudinally into two equal parts.
Slika 1. Uzorci postavljeni u označene akrilne blokove i uzdužno podijeljeni na dva jednaka dijela.
Figure 2 The area of the entire root canal wall and residual filling material (BioRoot RCS) under a stereomicroscope (15x magnification).
Slika 2. Područje cijele stijenke korijenskog kanala i zaostalog materijala za punjenje (BioRoot RCS) pod stereomikroskopom (povećanje 15x).

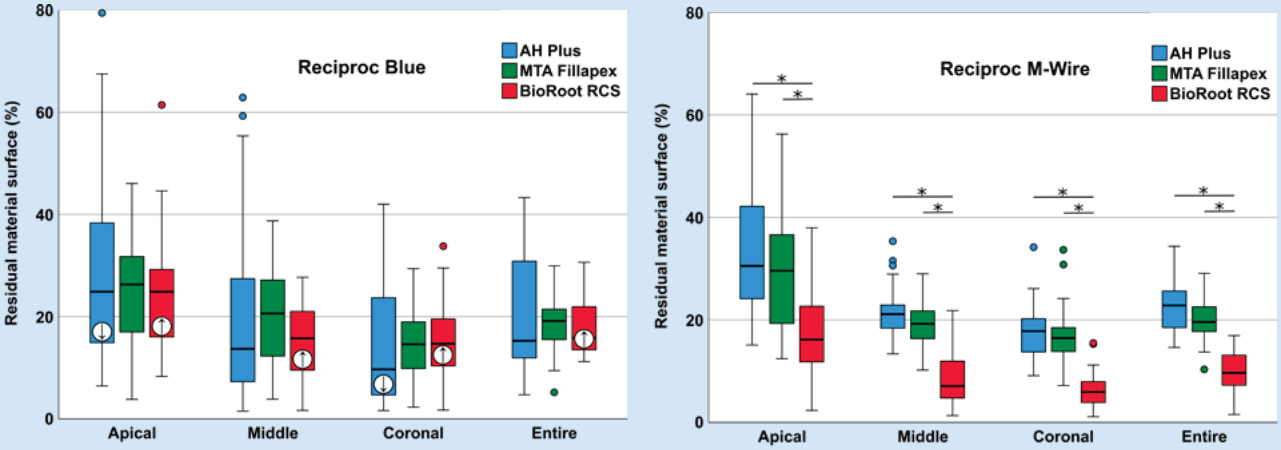

Figure 3 Percentages of root canal surface covered with residual material. The boxplots show the medians (bold black lines), the boxes represent the 25% and 75% quartiles, while the whiskers represent 1.5 × interquartile range (IQR), or minima and maxima of the distribution if below 1.5 × IQR. Outliers are presented by circles. For comparisons among retreatment instruments, arrows denote significantly higher (↑) or significantly lower (↓) values for Reciproc Blue compared to Reciproc M-Wire. Horizontal lines with asterisks (*) denote statistically significant differences among root filling materials. These differences were identified only for Reciproc M-Wire, while for Reciproc Blue all materials showed statistically similar values.
Slika 3. Postoci površine korijenskog kanala prekrivene ostatkom materijala. Okvirni dijagrami prikazuju medijane (podebljane crne linije), okviri predstavljaju 25% i 75% kvartile, dok gornje i donje horizontalne linije predstavljaju 1,5 x interkvartilni raspon (IQR) ili minimume i maksimume distribucije ako su ispod 1,5 × IQR. Outlieri su predstavljeni kružićima. Za usporedbu instrumenata za ponovnu obradu, strelice označavaju značajno više (↑) ili značajno niže (↓) vrijednosti za Reciproc Blue u usporedbi s Reciproc M-Wire. Horizontalne crte sa zvjezdicama (*) označavaju statistički značajne razlike među materijalima za punjenje korijena. Te su razlike identificirane samo za Reciproc M-Wire, dok su za Reciproc Blue svi materijali pokazali statistički slične vrijednosti.

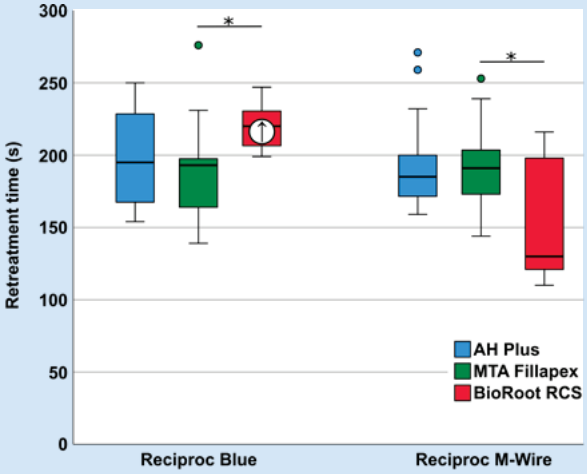

Figure 4 Retreatment time as a function of root canal filling material and retreatment instrument. The boxplots show the medians (bold black lines), the boxes represent the 25% and 75% quartiles, while the whiskers represent 1.5 × interquartile range (IQR), or minima and maxima of the distribution if below 1.5 × IQR. Outliers are presented by circles. For comparisons among retreatment instruments, arrows denote significantly higher (↑) or significantly lower (↓) values for Reciproc Blue compared to Reciproc M-Wire. Horizontal lines with asterisks (*) denote statistically significant differences among root filling materials.
Slika 4. Vrijeme ponovnog liječenja kao funkcija materijala za punjenje korijenskog kanala i instrumenta za ponovno liječenje. Okvirni dijagrami prikazuju medijane (podebljane crne linije), okviri predstavljaju 25% i 75% kvartile, dok gornje i donje horizontalne linije predstavljaju 1,5 x interkvartilni raspon (IQR) ili minimume i maksimume distribucije ako su ispod 1,5 × IQR. Outlieri su predstavljeni kružićima. Za usporedbu instrumenata za ponovnu obradu, strelice označavaju značajno više (↑) ili značajno niže (↓) vrijednosti za Reciproc Blue u usporedbi s Reciproc M-Wire. Horizontalne crte sa zvjezdicama (*) označavaju statistički značajne razlike među materijalima za punjenje korijena.

tion was excluded. Total working time was calculated by adding T1 and T2.

Stereomicroscope images

After retreatment, samples were placed in marked acrylic blocks and split longitudinally into two equal parts (Figure 1.), each consisting of three sections, apical, middle, and coronal. The length of each section was 5 mm. The samples were analyzed using a stereomicroscope (SZX12; Olympus; Tokyo, Japan) calibrated at 40 micrometers under a 15× magnification (Figure 2.). The areas of the residual filling material were measured using the Image J software (US National Institutes of Health; Bethesda, MD, USA).

Statistical analysis

Since the Shapiro-Wilk's test indicated significant deviations from normality, a statistical analysis was performed using non-parametric tests. The values of the residual material surface were compared among three obturation materials using the Kruskal-Wallis test (a non-parametric equivalent of one-way ANOVA) followed by multiple comparisons with Bonferroni adjustment. The comparisons were performed separately for each instrument and each root canal section, as well as for the entire root canal. Analogously, retreatment time was compared among three obturation materials using the Kruskal-Wallis test with Bonferroni adjustment, separately for each instrument.

The effects of the retreatment instrument on residual material surface and retreatment time were evaluated by comparing the values measured for Reciproc Blue to those for Reciproc M-Wire using the nonparametric Mann-Whitney U test for independent observations, separately for each material. Additionally, the analysis of residual root canal surface was performed separately for each of the three root canal sections, as well as for the entire root canal. All analyses were performed at an overall significance level of 0.05, using the software SPSS (version 25; IBM, Armonk, NY, USA).

Results

Figure 3 shows percentages of root canal surfaces covered with residual material as a function of the root canal section, filling material, and instruments used in retreatment. For Reciproc Blue, no statistically significant differences in the residual material surface were found for any root canal section (p=0.162-0.823). In contrast, all sections of the root canal instrumented with Reciproc M-Wire had significantly higher residual material surface if previously obturated with AH Plus and MTA Fillapex compared to BioRoot RCS (p<0.001 for all root canal sections). At the same time, there was no significant difference between AH Plus and MTA Fillapex instrumented with Reciproc M-Wire.

The pairwise comparisons between instruments showed that for AH plus residual material the surface was significantly lower for Reciproc Blue than for Reciproc M-Wire at the apical (p=0.030) and coronal (p=0.011) sections of the canal. The opposite was the case for BioRoot RCS, which showed a significantly higher residual material surface for Reciproc

ke i pripreme do veličine 40 (T 2). Vrijeme za promjenu instrumenata i ispiranje nije se mjerilo. Ukupno radno vrijeme izračunato je zbrajanjem T 1 i T 2.

Stereomikroskopske slike

Nakon ponovne obrade uzorci su stavljeni u označene akrilne blokove i uzdužno podijeljeni na dva jednaka dijela (slika 1.), od kojih se svaki sastoji od triju dijelova - apikalnoga, srednjega i koronarnoga. Dužina svakoga dijela bila je 5 mm. Uzorci su analizirani stereomikroskopom (SZX12; Olympus; Tokio, Japan) kalibriranim na 40 mikrometara pod povećanjem od 15 puta (slika 2.). Površine zaostaloga materijala za punjenje izmjerene su s pomoću softvera Image J (Nacionalni zdravstveni institut SAD; Bethesda, MD, SAD).

Statistička analiza

Kako je Shapiro-Wilkov test pokazao znatna odstupanja od normale, statistička analiza provedena je korištenjem neparametrijskih testova. Vrijednosti površine zaostaloga materijala uspoređene su između triju materijala za zatvaranje koristeći se Kruskal-Wallisovim testom (neparametrijski ekvivalent jednosmjerne ANOVA-e) nakon čega su slijedile višestruke usporedbe s Bonferronijevom prilagodbom. Usporedbe su provedene zasebno za svaki instrument i svaki dio korijenskog kanala te za cijeli korijenski kanal. Analogno tomu, vrijeme ponovnog tretmana uspoređeno je između triju opturacijskih materijala s pomoću Kruskal-Wallisova testa s Bonferronijevom prilagodbom, također zasebno za svaki instrument. Učinci instrumenta za ponovnu obradu na zaostalu površinu materijala i vrijeme ponovne obrade procijenjeni su usporedbom vrijednosti izmjerenih za Reciproc blue s onima za Reciproc M-Wire korištenjem neparametrijskoga Mann-Whitneyjeva U-testa za neovisna promatranja, zasebno za svaki materijal. Nadalje, analiza rezidualne površine korijenskog kanala obavljena je zasebno za svaki od triju dijelova korijenskog kanala te za cijeli korijenski kanal. Sve analize provedene na su ukupnoj razini značajnosti od 0,05, korištenjem SPSS softvera (verzija 25; IBM, Armonk, NY, SAD).

Rezultati

Na slici 3. su postotci površina korijenskog kanala prekriveni rezidualnim materijalom u ovisnosti o dijelu korijenskog kanala, materijalu za punjenje i instrumentu za reviziju. Za Reciproc blue nisu pronađene statistički značajne razlike u površini zaostaloga materijala za bilo koji dio korijenskog kanala (p = 0,162 – 0,823). Suprotno tomu, svi dijelovi korijenskog kanala instrumentirani Reciproc M-Wireom imali su znatno veću površinu zaostaloga materijala ako su prethodno opturirani AH Plusom i MTA Fillapexom u usporedbi s BioRoot RCS-om (p<0,001 za sve dijelove korijenskog kanala). Istodobno nije bilo značajne razlike između AH Plusa i MTA Fillapexa instrumentiranih Reciproc M-Wireom. Usporedbe parova između instrumenata pokazale su da je za AH plus površina zaostaloga materijala bila znatno niža za Reciproc blue nego za Reciproc M-Wire na apikalnim (p = 0,030) i koronalnim (p = 0,011) dijelovima kanala. Suprotan je slučaj kad je riječ o BioRoot RCS-u koji je pokazao znatno veću površinu zaostalog materijala za Reciproc blue u

Blue at all canal sections (p<0.001). For MTA, the residual material surface was statistically similar for both instruments at all root canal sections.

Figure 4 shows retreatment time as a function of root canal filling material and retreatment instrument. Comparisons for retreatment time identified a statistically significant difference between MTA Fillapex and BioRoot RCS, while the direction of the difference differed between the instruments; Reciproc Blue took significantly longer to retreat BioRoot RCS than MTA Fillapex (p=0.005), while with Reciproc M-Wire, BioRoot RCS was re-treated significantly faster than MTA Fillapex (p=0.048). It should be noted that the latter difference was only marginally significant.

In comparisons for retreatment time between instruments, a significant effect was found only for BioRoot RCS, which took a significantly longer time to retreat with Reciproc Blue compared to Reciproc M-Wire (p<0.001).

Discussion

Our study showed that the retreatment ability of the two instrument types varied depending on the sealer used. While Reciproc Blue was more effective than Reciproc M-Wire in the retreatment of canals sealed with AH Plus, the opposite was the case for BioRoot RCS, for which Reciproc M-Wire was more effective. In the retreatment of MTA Fillapex, no statistically significant effect between the instruments was observed. When Reciproc M-Wire was used, the bioactive filler BioRoot RCS showed a better ability to be re-treated than the other two materials, as evidenced by a significantly lower amount of remaining material and a shorter retreatment time.

Significant differences were found between reciprocating files, with greater efficiency and fewer BioRoot RCS remnants with Reciproc M-Wire files (10%) compared to Reciproc blue files (18%) in the entire root canal. Consequently, we rejected our first null hypothesis. These results are consistent with the results of previous studies (25,32,34) and might be explained by the lower bond strengths of hydraulic sealers (4). However, AH Plus chemically interacts with root dentin collagen via covalent bonds between epoxy rings and the amine groups exposed in collagen (16). Moreover, its high flow ability and penetration in the dentine tubules prevent its removal from the root canal (17,32), which is consistent with the sealer remnant and retreatment time findings of this study. However, contrary to our findings, more sealer remnants were found with hydraulic sealers than resin-based sealers in some previous studies (6,35). Therefore, further studies are required to provide a definitive assessment.

Retreatment time with M-Wire reciprocating files was significantly faster than with Reciproc blue files for BRRCS/GP. Consequently, we rejected our second null hypothesis. The success of removing the old filling is closely related to the retreatment method (2). Differences in efficiency and duration of the retreatment procedure were recorded within the Reciproc technique. In previous research (28,29), Reciproc blue showed significantly higher cyclic resistance as Reciproc M-Wire and retreatment time was significantly lower for ep-

svim dijelovima kanala (p < 0,001). Za MTA je površina zaostalog materijala bila statistički slična za oba instrumenta na svim dijelovima korijenskog kanala. Na slici 4. je vrijeme revizije s obzirom na utjecaj vrste materijala za punjenje korijenskog kanala i instrumenta rabljenog za reviziju. Usporedbe vremena revizije identificirale su statistički znatnu razliku između MTA Fillapexa i BioRoot RCS-a, a smjer razlike razlikovao se između instrumenata; Reciproc blue instrumentu trebalo je znatno više vremena za ponovno tretiranje BioRoot RCS-om nego MTA Fillapexu (p = 0,005), a Reciproc M-Wire, BioRoot RCS revidiran je znatno brže nego MTA Fillapex (p = 0,048). Treba napomenuti da je ta razlika bila samo marginalno važna. U usporedbama vremena ponovnog tretmana između instrumenata, značajan učinak pronađen je samo za BioRoot RCS kojemu je trebalo znatno više vremena za ponovno tretiranje Reciproc blueom nego Reciproc M-Wireom (p < 0,001).

Rasprava

Naše je istraživanje pokazalo da se učinkovitost revizije dviju vrsta instrumenata razlikuje ovisno o korištenom punilu. Dok je Reciproc Blue bio učinkovitiji od Reciproc M-Wirea u reviziji kanala punjenih punilom AH Plus, suprotan je slučaj s BioRoot RCS-om u čijoj je reviziji bio učinkovitiji Reciproc M-Wire. U reviziji kanala punjenih MTA Fillapexom nije uočen statistički značajan učinak između instrumenata. Revizija sustavom Reciproc M-Wire bila je učinkovitija za bioaktivno punilo BioRoot RCS u odnosu na druga dva materijala, što dokazuje znatno manja količina zaostaloga materijala i kraća revizija.

Uočene su značajne razlike između recipročnih instrumenata, s većom učinkovitošću i manje ostataka BioRoot RCS-a poslije revizije instrumentima Reciproc M-Wire (10 %) u odnosu prema instrumentima Reciproc blue (18 %) na razini cijeloga korijenskog kanala. Posljedično, odbacili smo našu prvu nultu hipotezu. Ovi rezultati u skladu su s onima dobivenima u dosadašnjim studijama (25, 32, 34) i mogu se objasniti nižom snagom veze hidrauličnih punila (4). AH Plus kemijski stupa u interakciju s kolagenom korijenskog dentina putem kovalentnih veza između epoksidnih prstenova i aminskih skupina izloženih u kolagenu (16). Štoviše, njegova visoka viskoznost i prodiranje u tubule dentina sprječavaju njegovo uklanjanje iz korijenskog kanala (17, 32), što je u skladu s rezultatima ovog istraživanja koji opisuju količinu zaostaloga punila i trajanje revizije. Međutim, suprotno našim rezultatima, u nekim dosadašnjim istraživanjima pronađeno je više zaostaloga materijala nakon upotrebe hidrauličnih punila nego kod onih na bazi smole (6, 35). Zato su potrebne dodatne studije da bi se dala konačna procjena.

Trajanje revizije recipročnim instrumentima M-Wire bilo je znatno kraće nego instrumentima Reciproc Blue za BRRCS/GP. Posljedično, odbacili smo našu drugu nultu hipotezu. Uspješnost uklanjanja starog punjenja usko je povezana s metodom revizije (2). Uočene su razlike u učinkovitosti i trajanju revizije pri uporabi Reciproc tehnike. U dosadašnjim istraživanjima (28, 29) Reciproc Blue pokazao je znatnu cikličku otpornost kao Reciproc M-Wire i trajanje

oxy resin-based sealer compared with hydraulic sealers, which is not in accordance with this study.

With the development of Reciproc technology, a new chapter in endodontics has begun due to its simplicity. Moreover, the reciprocating motion shows good effectiveness in the retreatment procedure while keeping the file centered throughout the canal (15). This study showed that the greatest amount of remaining filling material was in the apical third of root canals, which is consistent with previous studies (36) and potentially reflecting the filling material lodging into the canal irregularities, thus making it difficult to remove during retreatment.

The Reciproc system includes Reciproc Gutta-Percha cones for use with the single-cone technique with apical sizes of #25, #40, and #50. In prior research, the obturation of straight root canals using reciprocating file-matched single cones was shown to result in a similar quality as that obtained with manual instrumentation followed by the lateral compaction technique (37). Single-cone filling is attractive from a clinical standpoint as it produces good results, while also being simpler and less time-consuming compared to other obturation techniques (38).

Only straight root canals were retreated in this study. Consequently, our findings cannot be specifically applied to the teeth with curved, ramified canals. The final apical preparation size R40 was based on the previous filling R40 because a re-instrumentation that is excessively wide might weaken the root and make it more prone to fractures, which should be avoided (18). Therefore, the preparation size of the primary treatment has not increased following the removal of the obturation material, potentially causing a greater volume of the residual filling material to remain in the apical third. Consequently, further studies are needed to evaluate the effect of canal retreatment with larger-sized instruments after the retreatment procedure to obtain better apical cleaning. The results of this study may vary from *in vivo* conditions based on the setting characteristics of the sealer in the root canal system. In this study, a stereomicroscope with its illumination and magnification of 15× was used to assess the remaining amount of filling material because it is sufficiently sensitive to measure the size of a small area of residual sealer/gutta-percha on the root canal walls, which were calculated using the Image J software for root thirds and the entire root canal. Therefore, regardless of the retreatment technique or the filling material used, a complete removal of the previous root filling has not yet been achieved (5,7,14).

Since the literature data on the retreatment ability of hydraulic sealers compared to epoxy resin-based sealer are inconclusive, the present study aimed to provide more insight into this topic by evaluating the amounts of remaining sealer on root canal walls and the time needed for retreatment. Donnermeyer et al. reported significantly greater amounts of remnants for an epoxy-based sealer (AH Plus) compared to a hydraulic sealer, as well as a longer retreatment time for the epoxy-based sealer, which is in accordance with this study (32). Crozeta et al. also reported less residual material for a hydraulic sealer compared to AH Plus (27). These results could be explained by the adhesion of epoxy resin-based sealer

revizije bilo je znatno kraće za punilo na bazi epoksidne smole u usporedbi s hidrauličnim punilima, što nije u skladu s ovom studijom.

Razvoj sustava Reciproc svojom je jednostavnošću započeo novo poglavlje u endodonciji. Štoviše, zadržavajući instrument cijelo vrijeme u središtu kanala, recipročna kretnja omogućuje učinkovitu reviziju (15). Ovo je istraživanje pokazalo da je najveća količina zaostaloga materijala za punjenje bila u apikalnoj trećini korijenskih kanala, što je u skladu s dosadašnjim istraživanjima (36) i potencijalno posljedica ulaska punila u nepravilnosti kanala, što otežava njegovo uklanjanje tijekom revizije.

Sustav Reciproc uključuje štapiće gutaperke Reciproc za punjenje tehnikom jednog štapića gutaperke s apikalnim veličinama #25, #40 i #50. U dosadašnjim istraživanjima pokazalo se da punjenje ravnih korijenskih kanala korištenjem jednoga štapića gutaperke koji veličinom odgovara recipročnom instrumentu kojim je obrađen kanal, rezultira sličnom kvalitetom kao i kod obrade kanala ručnim instrumentima i punjenja tehnikom hladne lateralne kondenzacije (37). Punjenje tehnikom jednoga štapića gutaperke atraktivno je s kliničkog stajališta jer daje dobre rezultate, a istodobno je jednostavnije i brže u usporedbi s drugim tehnikama punjenja (38).

U ovoj studiji revidirani su samo ravni korijenski kanali. Posljedično, naši se rezultati ne mogu specifično primijeniti na zube sa zakrivljenim, razgranatim kanalima. Konačna veličina apikalne preparacije, R 40, temeljila se na prethodnom punjenju R 40 jer bi preširoka ponovna instrumentacija mogla oslabiti korijen i učiniti ga sklonijim frakturama, što bi trebalo izbjeći (18). Zbog toga se veličina preparacije nakon primarne instrumentacije revizijom nije povećala, što može biti uzrok zaostajanju veće količine materijala za punjenje u apikalnoj trećini. Posljedično, potrebna su daljnja istraživanja da bi se procijenila učinkovitost revizije većim instrumentima kojima bi se postiglo bolje čišćenje apeksa. Rezultati ovog istraživanja mogu se razlikovati od istraživanja *in vivo*, zbog svojstava stvrdnjavanja punila u sustavu korijenskog kanala u stvarnim uvjetima usne šupljine. U ovom istraživanju korišten je stereomikroskop s osvjetljenjem i povećanjem od 15 puta za procjenu preostale količine materijala za punjenje jer je dovoljno osjetljiv za mjerenje veličine maloga područja zaostalog punila/gutaperke na stijenkama korijenskog kanala koji su kvantificirani s pomoću računalnog programa Image J na razini cijeloga kanala i po trećinama. Bez obzira na korištenje različitih revizijskih tehnika i različitih materijala za punjenje, još nije postignuto potpuno uklanjanje materijala za punjenje iz korijenskog kanala (5, 7, 14).

Budući da podatci iz literature o učinkovitosti revizije hidrauličnih punila u usporedbi s punilima na bazi epoksidne smole nisu uvjerljivi, svrha ove studije bila je dati bolji uvid u tu temu procjenjujući količinu preostalog punjenja na stijenkama korijenskog kanala i vremena potrebnog za reviziju. Donnermeyer i suradnici uočili su znatno više ostataka epoksidnog punila (AH Plus) u usporedbi s hidrauličnim punilom te dulje trajanje revizije punila na bazi epoksida, što je u skladu s ovom studijom (32). Crozeta i suradnici također su zapazili manje zaostaloga hidrauličnog punila u usporedbi s

er to dentin (16,39), differences in quality of adaptation to root canal walls that is related to initial material flowability (e.g., AH Plus is more flowable than BioRoot RCS (40), as well as differences in the cohesive properties of the materials that affect the capability of reciprocal instruments to remove them from the root canal walls. In contrast, a study by Kim et al. showed that AH Plus sealer has retreatment characteristics comparable to those of a hydraulic sealer (41). The retreatment ability of the two instrument types in the present study varied depending on the sealer used. In this context, our results partly agree with a study by De-Deus et al., which showed similar effectiveness of Reciproc M-Wire and Reciproc Blue for removing filling materials from oval-shaped straight canals (42).

The comparability of results from different studies is made difficult by methodological differences regarding root canal selection (straight vs. curved canals), obturation techniques used, time period between obturation and retreatment, as well as instruments and methods used for retreatment. Some of these factors are likely to have interaction effects. For example, a particular type of sealant may not be generally easier to remove than another in all cases but particular instruments may be more effective for removing certain sealers and can be less effective for others. The same reasoning may be applied to different obturation techniques. Hence, the results of the present should be viewed considering the conditions under which the evaluation was performed, i.e., in straight, round to slightly oval canals that were retreated relatively early (7 days post-obturation), while avoiding extrapolations to other clinical scenarios.

It has been a known fact that hydraulic sealers are difficult to remove in retreatment procedures, which is probably due to their interaction with dentin (15–18), which results in a certain extent of chemical bonding (19). Since the post-setting maturation of sealers can occur slowly over an extended time period (43) and the kinetics of this process can be additionally modulated by multiple proprietary additives that are never completely disclosed by the manufacturers (44), the timing of the retreatment may be another important factor leading to differences in retreatment ability between hydraulic and epoxy resin-based sealers.

A limitation of the present study is the short period of 7 days between obturation and retreatment. Although this period is longer than the nominal setting times for all sealers as specified by the manufacturers (2-8 hours), the chemical changes in the sealers are known to continue beyond the initial setting and may have lasted longer than 7 days, thus improving both the cohesive strength of the sealers and their adhesion to dentin. Retreatment after 7 days may simulate the clinical scenario of "early revision" due to unsatisfactory obturation noted shortly after the completion of root canal treatment. However, for simulating the retreatment of late failures, longer time periods between obturation and revision are needed.

An additional limitation was the fact that the data in several experimental groups deviated significantly from normal distribution, which precluded the use of a full-factorial ANOVA with three factors (retreatment instrument, root canal AH Plus punilom (27). Ti se rezultati mogu objasniti adhezijom punila na bazi epoksidne smole na dentin (16, 39), razlikama u kvaliteti prilagodbe na stijenke korijenskog kanala koja je povezana s početnom tečnošću materijala (AH Plus je viskoznji od BioRoot RCS-a (40)), kao i razlike u kohezivnim svojstvima materijala koja utječu na mogućnost njihova uklanjanja sa stijenki korijenskog kanala s pomoću recipročnih instrumenata. Suprotno tomu, Kim i suradnici u svojem su istraživanju uočili da punilo AH Plus ima revizijska svojstva usporediva s onima hidrauličnoga punila (41). Učinkovitost revizije dviju vrsta instrumenata u ovoj studiji varirala je ovisno o korištenom punilu. U tom kontekstu naši se rezultati djelomično slažu sa studijom De-Deusa i suradnika koja je pokazala sličnu učinkovitost Reciproc M-Wirea i Reciproc Bluea pri uklanjanju materijala za punjenje iz ravnih kanala ovalnog oblika (42).

Usporedivost rezultata iz različitih studija otežana je metodološkim razlikama u pogledu odabira korijenskog kanala (ravni ili zakrivljeni), korištenih tehnika punjenja, razdoblja između punjenja i revizije te instrumenata i metoda korištenih tijekom revizije. Neki od tih čimbenika uzajamno mogu imati interakcije pa, na primjer, određena vrsta punila nije uvijek lakša za uklanjanje od druge, ili pak određeni instrumenti mogu biti učinkovitiji za uklanjanje određenih punila i manje učinkoviti za druge. Takvo razmišljanje može se primijeniti na različite tehnike punjenja. Zato sadašnje rezultate treba promatrati uzimajući u obzir uvjete pod kojima je evaluacija provedena, tj. u ravnim, okruglim do blago ovalnim kanalima koji su revidirani razmjeno rano (7 dana poslije punjenja), uz izbjegavanje ekstrapolacije na druge kliničke scenarije.

Poznato je da se hidraulična punila teško uklanjaju u postupku revizije, vjerojatno zbog njihove interakcije s dentinom (15 – 18) koja rezultira određenim stupnjem kemijskog povezivanja (19). Budući da maturacija punila nakon stvrdnjavanja može biti polagana tijekom duljeg razdoblja (43), a kinetika tog procesa može se dodatno modulirati brojnim aditivima koje proizvođači nikada u cijelosti ne otkrivaju (44), vrijeme pristupanja reviziji može biti još jedan važan čimbenik koji rezultira razlikama u mogućnosti revizije između hidrauličnih punila i onih na bazi epoksidne smole.

Ograničenje ove studije jest kratko razdoblje između punjenja i revizije (7 dana). Iako je to razdoblje dulje od vremena stvrdnjavanja svih punila prema navodima proizvođača (2 – 8 sati), poznato je da se kemijske promjene u punilima nastavljaju i poslije početnog stvrdnjavanja i mogu trajati dulje od 7 dana, po svojoj prilici poboljšavajući kako kohezijsku čvrstoću punila tako i njihovu adheziju na dentin. Revizija nakon 7 dana može simulirati klinički scenarij „rane revizije" zbog nezadovoljavajuće opturacije uočene ubrzo nakon završetka liječenja korijenskog kanala. No za simulaciju revizije kojoj se pristupa zbog kasnije manifestiranog neuspjeha bilo bi potrebno više vremena između punjenja i revizije.

Dodatno ograničenje bila je činjenica da su podatci u nekoliko eksperimentalnih skupina znatno odstupali od normalne distribucije, što je onemogućilo upotrebu potpune faktorske ANOVA-e s trima čimbenicima (instrument za reviziju, sredstvo za brtvljenje korijenskog kanala i dio korijen-

nal sealer, and root canal section). Such an analysis would allow evaluation of the relative effect sizes for each factor and their possible interactions. Nevertheless, the nonparametric evaluation performed due to non-normal data distributions was able to identify the effects of individual factors that were compared and performed at fixed levels of other factors.

The main strength of this study was the simulation of a realistic clinical scenario in which retreatments were performed with reciprocating files commonly used for initial root canal treatment, rather than an idealized scenario in which specialized retreatment instruments (45) are used. This is similar to the situation in a general practice where the practitioner often has only a basic set of instruments available, resulting in "universal" instruments being used for multiple purposes (e.g., initial treatment and retreatment) rather than having multiple sets of instruments for specific purposes. An additional strength in terms of specimen standardization is the selection of only straight canals, with round to oval cross-sections, which helped reduce data variability, and the preparation of samples in random order to avoid bias due to the training curve and various extrinsic factors.

Conclusions

Removal of bioactive-based sealers with Reciproc M-Wire was better compared to AH Plus because fewer sealant residues were found in the root canals, and a shorter time was required to remove these two fillers compared to AH Plus. In contrast, Reciproc Blue was similarly effective for the retreatment of all three filler types tested. However, the sealers were not completely removed in any experimental group. Nevertheless, the type of sealant changed the amount of sealant remaining in the root canal system.

Clinical significance

The calcium silicate-containing sealers showed significantly fewer sealer remnants and shorter retreatment times than epoxy resin-based sealers.

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The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflict of interest

The authors declare no conflict of interest related to this study.

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skog kanala). Takva bi analiza omogućila procjenu relativne veličine učinka za svaki čimbenik i njihove moguće interakcije. Unatoč tomu, neparametrijska procjena provedena zbog nenormalnih distribucija podataka uspjela je identificirati učinke pojedinačnih čimbenika u usporedbama izvedenima na fiksnim razinama drugih čimbenika.

Glavni zadatak ove studije bio je simulacija stvarnoga kliničkog scenarija u kojemu se revizija obavlja recipročnim instrumentima koji se obično koriste za početnu instrumentaciju korijenskog kanala, a ne idealnog scenarija u kojemu bi se koristili specijalizirani instrumenti za reviziju (45). To je slično situaciji u općoj ordinaciji gdje praktičar često ima na raspolaganju samo osnovni set instrumenata, što rezultira korištenjem „univerzalnih" instrumenata za više namjena (npr. početno liječenje i revizija), umjesto da nabavi više kompleta instrumenata za specifične namjene. Dodatno je važan, u smislu standardizacije uzoraka, odabir samo ravnih kanala s okruglim do ovalnim poprečnim presjekom, što je pomoglo u smanjenju varijabilnosti podataka te priprema uzoraka nasumičnim redoslijedom da bi se izbjegla sustavna pogreška zbog krivulje učenja i raznih eksternih čimbenika.

Zaključak

Uklanjanje bioaktivnih punila sustavom Reciproc M-Wire bilo je bolje u odnosu na punilo AH Plus, u korijenskim kanalima pronađeno je manje zaostalog punila, a za uklanjanje tih dvaju punila bilo je potrebno kraće vrijeme u odnosu na AH Plus. Suprotno tomu, Reciproc blue bio je podjednako učinkovit u reviziji svih triju ispitanih vrsta punila. Ni u jednoj eksperimentalnoj skupini punilo nije bilo potpuno uklonjeno. Ipak, vrsta korištenog punila utjecala je na količinu zaostaloga punila u sustavu korijenskih kanala.

Kliničko značenje

Punila koja sadržavaju kalcijev silikat ostavljala su znatno manje zaostaloga materijala i za reviziju je bilo potrebno kraće vrijeme, nego ako su bila na bazi epoksidne smole.

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Podatci koji podupiru nalaze iz ove studije mogu se dobiti od odgovarajućeg autora ako je zahtjev razuman.

Sukob interesa

Autori nisu bili u sukobu interesa.

Doprinos autora: Svaki autor zadovoljio je uvjete autorstva. **D. J. K., A. T. i P. D.** – koncept i dizajn studije te prikupljanje podataka; **J. M.** – analiza i interpretacija podatka; **D. J. K., J. M., A. T., P. D., A. K., M. T. G. i N. G.**(svi autori) – pretraživanje literature i pisanje teksta. Uz to, svi su autori kritički revidirali tekst zbog važnoga intelektualnog sadržaja te su se složili s objavljenom verzijom.

Sažetak

Cilj: Željela se usporediti učinkovitost instrumenata Reciproc u uklanjanju gutaperke i endodontskog punila na bazi bioaktivnih (BioRoot RCS i MTA Fillapex) i epoksidnih smola (AH Plus) iz korijenskih kanala na temelju ostataka punjenja i vremena potrebnog za reviziju korijenskog kanala. **Materijal i metode:** Korijenski kanali 90 zuba instrumentirani su Reciprocom R 40. Svi su zabrtvljeni tehnikom jednoga štapića gutaperke s Reciproc R 40 gutaperkom i jednim od punila. Svi uzorci imali su ovalne, ravne kanale te su nasumično podijeljeni u tri skupine: (i) ispunjeni punilom AH Plus i gutaperkom (n = 30); (ii) ispunjeni MTA Fillapexom i gutaperkom (n = 30); (iii) ispunjeni BioRoot RCS-om i gutaperkom (n = 30). Svaka je skupina podijeljena u dvije podskupine (n = 15) prema instrumentu koji se rabio za reviziju (Reciproc M-Wire R25/R 40 ili Reciproc blue RB 25/RB 40). Korijenski kanali uzdužno su prerezani i analizirani stereomikroskopom pri povećanju od 15 puta u koronalnoj, srednjoj i apikalnoj trećini. Računalne analize obavljene su u programu Image J. Podatci su uspoređeni Kruskal-Wallisovim i Mann-Whitneyjevim U testom. **Rezultati:** Iako nisu pronađene statistički značajne razlike u površini zaostalog materijala za Reciproc blue i Reciproc M-Wire, nakon revizije instrumentom Reciproc M-Wire uočena je znatno veća površina neuklonjenog ispuna na bazi AH Plusa i MTA Fillapexa u usporedbi s BioRoot RCS-om. Kod ispuna na bazi AH plusa površina zaostalog materijala bila je znatno niža nakon revizije instrumentom Reciproc blue nego nakon Reciproc M-Wireom. Suprotno tomu, BioRoot RCS imao je znatno veću površinu zaostalog materijala nakon revizije instrumentom Reciproc Blue. **Zaključci:** U usporedbi s brtvilima na bazi AH Plusa, brtvila koja sadržavaju kalcijev silikat bilo je lakše ukloniti i bila je pronađena manja površina neuklonjenog punila poslije revizije, a vrijeme potrebno za taj postupak bilo je kraće. Instrumenti Reciproc M-Wire bili su bolji od Reciproc bluea pri reviziji BioRoot RCS-om. No ni jedno punilo nije potpuno uklonjeno.

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