ACTA
STOMATOLOGICA
CROATICA
www.ascro.hr

Acta stomatol Croat. 2023;57(2):155-166.
DOI: 10.15644/asc57/2/6

ORIGINAL SCIENTIFIC PAPER
IZVORNI ZNANSTVENI RAD

Elif Çiftçioğlu[1], Güher Barut[2], Vasfiye Işık[3], Burçin Arıcan[4], Işıl Karagöz-Küçükay[1]

Influence of Different Dentin Conditioning Protocols on Bond Strength of a Bioceramic Root Canal Filling

Utjecaj različitih protokola za kondicioniranje dentina na čvrstoću veze biokeramičkog ispuna korijenskog kanala

[1] Department of Endodontics, İstanbul Okan University Faculty of Dentistry, İstanbul, Turkey
Zavod za endodonciju Stomatološkog fakulteta Sveučilišta Okan, Istanbul, Turska
[2] Department of Endodontics, Yeditepe University Faculty of Dentistry, İstanbul, Turkey
Zavod za endodonciju Stomatološkog fakulteta Sveučilišta Yeditepe, Istanbul, Turska
[3] Department of Endodontics, İstanbul Health and Technology University, Faculty of Dentistry, İstanbul, Turkey
Zavod za endodonciju Sveučilišta za zdravlje i tehnologiju i Stomatološki fakultet, Istanbul, Turska
[4] Department of Endodontics, Bahçeşehir University Faculty of Dentistry, İstanbul, Turkey
Zavod za endodonciju Stomatološkog fakulteta Sveučilišta Bahçeşehir, Istanbul, Turska

Abstract

Objective: Bioceramic-based sealers, in combination with bioceramic-coated gutta-perchas, have become more commonly used in root canal obturation. The present study aimed to assess the influence of laser-assisted dentin conditioning compared with conventional conditioning protocols on the push-out bond strength (PBS) of a bioceramic-based root canal filling. **Material and Methods:** Sixty extracted mandibular premolars with one root canal were instrumented with EndoSequence rotary files up to size 40/0.04. Four types of dentin conditioning protocols were used: 1) 5.25% NaOCl (control), 2) 17% EDTA+5.25% NaOCl, 3) Diode laser-agitated 17% EDTA+5.25% NaOCl, 4) Er,Cr:YSGG laser irradiation+5.25% NaOCl. Teeth were obturated using the single-cone technique with EndoSequence BC sealer+BC points (EBCF). After having obtained 1-mm-thick horizontal slices from the apical, middle and coronal root thirds, push-out test was carried out, and failure modes were determined. The data were analyzed by two-way analysis of variance and Tukey's test with a significance level of $p<0.05$. **Results:** The apical segments showed the highest PBS in all groups ($p<0.05$). In the apical segments, EDTA+NaOCl and diode laser agitated EDTA increased the PBS compared to the control ($p=0.0001$) and Er, Cr: YSGG laser ($p=0.011$ and $p=0.027$, respectively) groups. Both laser-used groups revealed significantly higher PBS values in the middle and coronal segments than EDTA+NaOCl ($p<0.05$). The bond failure was predominantly cohesive without any significant difference among the groups ($p>0.05$). **Conclusions:** Laser-assisted dentin conditioning had distinct effects on the PBS of the EBCF at different root segments. Although Er, Cr: YSGG was ineffective in the apical segments, generally, laser-assisted dentin conditioning affected PBS more favorably than conventional irrigation groups, with a more pronounced effect in the diode laser-agitated EDTA group.

Received: January 15, 2023
Accepted: May 8, 2023

Address for correspondence
Elif Çiftçioğlu
İstanbul Okan University Faculty of Dentistry,
34959 Akfırat İstanbul,/Turkey
Phone:+905322564674
elifcif@yahoo.com

MeSH Terms: Root Canal Obturation; Root Canal Filling Materials; Organically Modified Ceramics; Laser Therapy; Shear Strength
Author Keywords: Bioceramic Root Canal Filling; Diode Laser; Er, Cr: YSGG laser, Bond Strength

Elif Çiftçioğlu: 0000000225780168
Güher Barut: 0000-0002-5990-5221
Vasfiye Işık: 0000-0003-1622-2698
Burçin Arıcan: 0000-0001-5757-0571
Işıl Karagöz-Küçükay: 0000-0002-4957-7850

Introduction

Three-dimensional (3D) obturation of the entire root canal system with an inert filling material that can adapt to root canal dentin should be the primary objective of root canal filling procedures (1). Numerous root canal filling techniques have been developed to achieve a total root canal obturation. Although the combination of gutta-percha and a sealer is the most used technique, the development of various materials and obturation techniques are ongoing (2, 3).

Ideally, a sealer would be expected to adhere to gutta-percha cones and canal walls and seal the root canal space to avoid leakage (4). Among clinically available sealers, Epoxy

Uvod

Trodimenzionalna (3D) opturacija cijelog sustava korijenskih kanala inertnim materijalom za punjenje, koji se može prilagoditi dentinu korijenskog kanala, trebao bi biti primarni cilj takvog postupaka (1). Razvijene su mnoge tehnike punjenja korijenskog kanala kako bi se postigla potpuna opturacija. Iako je kombinacija gutaperke i sealera najkorištenija tehnika, razvoj različitih materijala i tehnika opturacije još traje (2, 3).

U idealnom slučaju očekuje se da će sredstvo za brtvljenje prianjati na konuse gutaperke i stijenke kanala te zabrtviti prostor korijenskog kanala da bi se izbjeglo curenje (4).

resin-based sealers associated with gutta-percha cones have been widely used for many years. Although these sealers can bind to dentin structures naturally, a lack of bonding with gutta-percha prevents this technique from forming a natural monoblock system (5). The latest generations of root canal sealers have been bioceramics, based on tricalcium silicate or calcium phosphate, which are noted for their biocompatibility, bioactivity, dimensional stability, sealing ability, and potential to increase the fracture resistance of the tooth (6).

A new bioceramic-bonded obturation system with EndoSequence BC sealer and points (Brasseler USA, Savannah, GA, USA) has been introduced recently. The EndoSequence BC sealer (Brasseler USA) is a calcium-silicate-based, injectable, premixed, radiopaque, hydrophilic, and aluminium-free material that requires moisture to initiate and complete the setting reaction. EndoSequence BC points undergo a patented process where each cone is coated with bioceramic nanoparticles.

Better root canal sealer adherence to gutta-percha and dentin yields greater sealing ability and stability (7). However, the applied forces, including occlusal forces, may cause a dislodgement of the filling material from the dentinal walls or fractures in the material, leading to bond failure (8).

The interaction between the filling material and the dentin surface depends not only on the physical and mechanical properties of the material but also on the surface condition of the dentin, such as the presence of the smear layer (9).

Root canal irrigation is intended to remove organic and inorganic debris, smear layer, infected materials, and tissue debris from the root canals (10). The irrigants used for smear layer removal were also shown to alter the composition of the dentin surface (11, 12). The main endodontic irrigant, sodium hypochlorite (NaOCl) changes the mechanical properties of the dentin via the degradation of organic dentin matrix (13) but it is ineffective in removing the inorganic component of the smear layer (12). On the other hand, the combination of NaOCl and ethylenediamine tetra-acetic acid (EDTA) effectively removes the smear layer (12, 14). EDTA removes calcium from dentin by reacting with calcium ions in hydroxyapatite crystals (11). However, the effect of EDTA on the bond strength of EndoSequence BC sealer remains controversial (5, 15, 16). In a previous study, final irrigation with EDTA increased the adhesion of EndoSequence BC sealer (15), while in other studies (16, 17); EDTA and NaOCl resulted in low bond strengths.

Recently, lasers have been proposed as an alternative method for root canal irrigation and dentin conditioning to remove debris and the smear layer, open dentinal tubules, and create morphological changes in radicular surfaces (18).

In endodontic procedures, diode lasers are mostly used within an infrared range (810 to 980 nm) of the electromagnetic spectrum as Gallium-Aluminium-Arsenide (GaAlAs) (810 nm), Gallium-Arsenide (GaAs) (940 nm), and Indium-Gallium-Arsenide (InGaAs) (980 nm) (19, 20). They have advantages such as compactness and relatively low cost compared to other laser technologies (19, 21). Diode lasers also have thin optical fibres that allow penetration into the less-accessible areas of the root canal system (22, 23). Although a

Među klinički dostupnim brtvilima, ona na bazi epoksidne smole povezana s gutaperkom naširoko su korištena već godinama. Iako se ti zalivci mogu prirodno vezati za strukture dentina, nedostatak vezivanja s gutaperkom sprječava tu tehniku u stvaranju prirodnoga monoblok sustava (5). Najnovija generacija sredstava za brtvljenje korijenskih kanala jest biokeramika na bazi trikalcijeva silikata ili kalcijeva fosfata, poznata po svojoj biokompatibilnosti, bioaktivnosti, dimenzijskoj stabilnosti, svojstvu pečaćenja i potencijalu da poveća otpornost zuba na lom (6).

Nedavno je predstavljen novi biokeramički spojeni sustav opturacije s EndoSequence BC zatvaračem i točkama (Brasseler USA, Savannah, GA, SAD). EndoSequence BC sealer (Brasseler SAD) injektibilan je i već pripremljen hidrofilni materijal bez aluminija na bazi kalcijeva silikata koji zahtijeva vlagu da započne i završi reakciju stvrdnjavanja.

EndoSequence BC točke podvrgavaju se patentiranom procesu u kojemu je svaki štapić gutaperke obložen biokeramičkim nanočesticama.

Bolje prianjanje sredstva za brtvljenje korijenskih kanala na gutaperku i dentin omogućuje bolje svojstvo pečaćenja i stabilnost (7). No primijenjene sile, uključujući okluzalne, mogu prouzročiti pomicanje materijala za ispun sa stijenki dentina ili lomove materijala, što završava lomljenjem veze (8).

Interakcija između materijala za ispun i površine dentina ne ovisi samo o fizikalnim i mehaničkim svojstvima materijala, nego i o površinskom stanju dentina, kao što je prisutnost razmaznoga sloja (9).

Irigacija korijenskog kanala namijenjena je uklanjanju organskih i anorganskih ostataka, sloja mrlja, inficiranih materijala i ostataka tkiva iz tih kanala (10). Također se pokazalo da iriganси korišteni za uklanjanje razmaznoga sloja mijenjaju sastav površine dentina (11, 12). Kao glavni endodontski irigans, natrijev hipoklorit (NaOCl), mijenja mehanička svojstva dentina putem razgradnje organskoga dentinskoga matriksa (13), a neučinkovit je u uklanjanju anorganske komponente razmaznoga sloja (12). S druge strane, kombinacija natrijeva hipoklorita i etilendiamin-tetraoctene kiseline (EDTA) učinkovito uklanja mrljasti sloj (12, 14). EDTA uklanja kalcij iz dentina reakcijom s ionima kalcija u kristalima hidroksiapatita (11). No učinak EDTA-e na snagu veze EndoSequence BC sealera ostaje kontroverzan (5, 15, 16). U prethodnoj studiji završno ispiranje EDTA-om povećalo je prianjanje EndoSequence BC brtvila (15), a u drugim su studijama (16, 17) EDTA i NaOCl rezultirali niskom čvrstoćom veze.

Laseri su nedavno predloženi kao alternativna metoda za irigaciju korijenskog kanala i kondicioniranje dentina za uklanjanje krhotina i razmaznoga sloja, otvaranje dentinskih tubula i stvaranje morfoloških promjena na radikularnim površinama (18).

U endodontskim postupcima diodni se laseri uglavnom koriste unutar infracrvenog područja (810 do 980 nm) elektromagnetskoga spektra kao galij-aluminij-arsenid (GaAlAs) (810 nm), galij-arsenid (GaAs) (940 nm) i indij-galij-arsenid (InGaAs) (980 nm) (19, 20). Imaju prednosti kao što su kompaktnost i razmjerno niska cijena u usporedbi s drugim la-

980-nm diode laser has a high penetration power and a low interaction with water and hydroxyapatite, it could alter the surface morphology of radicular dentin (24). In addition to its antibacterial effect (25), a 980-nm diode laser was claimed to be effective in cleaning root canals and smear layer removal (21). However, since their water absorption is low, diode lasers may be more appropriate for soft tissue applications rather than dental hard tissues (18). Therefore, diode lasers are usually used with chemical irrigation solutions (23) for smear layer removal, mainly for agitation of EDTA (24, 26).

The erbium, chromium: yttrium–scandium–gallium–garnet (Er, Cr: YSGG) laser is a 2780-nm infrared laser. Diode lasers have sapphire optical fibres compatible with the dimensions of the root canals. Similarly, Er, Cr: YSGG lasers have sapphire optical fibres compatible with the dimensions of the root canals (27). Because of their high affinity toward hydroxyapatite and water, the Er, Cr: YSGG laser irradiation has been used for cleaning root canals (28), thus removing the smear layer (29, 30), and obturation material residues (31).

Dentin pre-treatment protocols have been shown to have different effects on the PBS of EndoSequence BC sealer (15, 17, 18, 32). However, the effect of both diode and Er, Cr: YSGG laser on the PBS of a bioceramic-based obturation system has not yet been evaluated. Therefore, the present study aimed to assess the influence of laser-assisted dentin conditioning (diode laser-agitated EDTA and Er, Cr: YSGG laser irradiation, followed by NaOCl irrigation) compared with conventional conditioning protocols (NaOCl and EDTA + NaOCl) on the PBS of a bioceramic-based root canal filling system (EndoSequence BC sealer and BC points filling system, EBCF). The null hypothesis was that the type of dentin conditioning protocol did not influence the PBS.

Material and methods

Preparation of specimens

The experimental protocol of the study was approved by the Ethical Committee on Clinical Research of the School of Dentistry, University of İstanbul, exemption file #2018/22.

In the power analysis performed with the G*power 3.1 (Heinrich-Heine-Universit*ä*t Düsseldorf, Germany), the minimum sample size required for statistical validity was calculated as 56 (n=14), with an alpha error probability of 0.05, test power of 0.8, and 0.46 for the effect size for the bond strength of the filling material (33).

Sixty extracted single-rooted mandibular premolars with a single straight canal were included in this study after verification with radiographs taken from buccolingual and mesiodistal directions. Teeth with immature apices, previous root canal treatments, cracks, fractures and resorptions were excluded. The crowns were removed near the cementoenamel junction using water-cooled diamond discs at a slow speed to standardize the root lengths at 15±1 mm. A size 15 K-file (Dentsply Maillefer, Ballaigues, Switzerland) was passively advanced in the root canal until its tip was visible at the apex.

serskim tehnologijama (19, 21). Diodni laseri također imaju tanka optička vlakna koja omogućuju prodor u teže dostupna područja sustava korijenskog kanala (22, 23). Iako diodni laser od 980 nm ima veliku moć prodiranja i nisku interakciju s vodom i hidroksiapatitom, mogao bi promijeniti morfologiju površine radikularnog dentina (24). Uz antibakterijski učinak (25), za diodni laser od 980 nm tvrdi se da je učinkovit u čišćenju korijenskih kanala i uklanjanju mrlja (21). Međutim, kako im je apsorpcija vode niska, diodni laseri mogu biti prikladniji za primjenu na mekanim tkivima nego na tvrdim tkivima zuba (18). Zato se za uklanjanje mrlja laseri obično koriste s kemijskim otopinama za irigaciju (23), uglavnom za miješanje EDTA-e (24, 26).

Erbij, krom: itrij–skandij–galij–granat (Er,Cr:YSGG infracrveni je laser od 2780 nm). Kao i diodni laseri, Er,Cr:YSGG laseri imaju safirna optička vlakna kompatibilna dimenzijama korijenskih kanala (27). Zbog visokoga afiniteta prema hidroksiapatitu i vodi, Er,Cr:YSGG lasersko zračenje koristi se za čišćenje korijenskih kanala (28) te uklanjanje razmaznoga sloja (29, 30) i ostataka opturacijskog materijala (31).

Pokazalo se da protokoli predtretmana dentina imaju različite učinke na PBS EndoSequence BC sealer (15, 17, 18, 32). Međutim, učinak i diodnoga i Er,Cr:YSGG lasera na PBS biokeramičkoga opturacijskog sustava još nije procijenjen.

Zato je cilj ove studije bio procijeniti utjecaj kondicioniranja dentina pomognutog laserom (diodno lasersko zračenje EDTA-om i Er,Cr:YSGG laserom, nakon čega slijedi irigacija natrijevim hipokloritom) u usporedbi s konvencionalnim protokolima kondicioniranja (NaOCl i EDTA + NaOCl) na PBS biokeramičkogaa sustava za punjenje korijenskog kanala (EndoSequence BC sealer i sustav za punjenje BC točaka – EBCF). Nulta hipoteza bila je da vrsta protokola za kondicioniranje dentina nije utjecala na PBS.

Materijal i postupci

Priprema uzoraka

Eksperimentalni protokol studije odobrio je Etički odbor za klinička istraživanja Stomatološkog fakulteta Sveučilišta u Istanbulu – dokument o izuzeću #2018/22.

U analizi snage provedenoj s G*powerom 3.1 (Heinrich-Heine-Universität Düsseldorf, Njemačka), minimalna veličina uzorka potrebna za statističku valjanost izračunata je kao 56 (n = 14), s vjerojatnošću alfa pogreške od 0,05, snaga testa bila je od 0,8 i 0,46 za veličinu učinka za čvrstoću veze materijala za punjenje (33).

Šezdeset ekstrahiranih jednokorijenskih mandibularnih pretkutnjaka s jednim ravnim kanalom uključeno je u ovu studiju nakon verifikacije rendgenskim snimkama iz bukolingvalnog i meziodistalnog smjera. Isključeni su zubi s nezrelim vrhovima, oni s prethodnim tretmanima korijenskih kanala, pukotinama, frakturama i resorpcijama. Krunice su uklonjene u blizini cementno-caklinskoga spoja korištenjem vodeno hlađenih dijamantnih diskova pri maloj brzini da bi se standardizirala duljina korijena na 15 ± 1 mm. K-turpija veličine 15 (Dentsply Maillefer, Ballaigues, Švicarska) pasiv-

The working length (WL) was determined to be 1 mm shorter than this length.

Root canals were instrumented with EndoSequence Xpress medium pack rotary files (Brasseler, USA) using an endo-motor (X-Smart Plus; Dentsply Maillefer) up to size 40/0.04 at the WL, with 550 rpm and 2 Ncm torque, following the manufacturer's instructions. The root canals were irrigated with 2 mL of 5.25% NaOCl (Cerkamed, Stalowa Wola, Poland) between each file. The teeth were randomly divided into four groups (n = 15) according to the dentin conditioning protocols they would undergo, as follows:

Group 1: Final irrigation was performed with 5 mL of 5.25% NaOCl for 1 min and used as a control.

Group 2: Final irrigation was performed with 2 mL of 17% EDTA (Cerkamed, Stalowa Wola, Poland) for 1 min, followed by 5 mL of 5.25% NaOCl for 1 min, to remove the smear layer.

Group 3: Final irrigation was performed with 2 mL of 17% EDTA, agitated with a diode laser (Epic X; Biolase, San Clemente, CA, USA) for 20 s.

The 940 nm diode laser was used at 1 W in continuous-wave mode. An E14 fibre tip with a diameter of 200 µm (Biolase) was introduced into the root canal, 1 mm shorter than the WL. The fibre tip was used parallel to the canal wall with a pulled-out motion. The EDTA was agitated in two cycles of 10 s, with a break of 20 s between the cycles. Subsequently, the root canals were irrigated with 5 mL of 5.25% NaOCl for 1 min.

Group 4: Final irrigation was performed using Er, Cr: YSGG laser (Waterlase iPlus; Biolase). The Er,Cr:YSGG laser, emitting at 2780 nm, was activated under the output power of 1.5 W and a repetition rate of 20 Hz in the H mode with a pulse duration of 60 µs set at a level of 30% water / 50% air (28). An RFT-2 conical fibre tip (Endolase; Biolase) with a diameter of 275 µm was introduced 1 mm shorter than the WL. The fibre tip was used parallel to the canal wall with a pulled-out motion for 10 s. This irradiation procedure was repeated twice with a 20-s interval. After the laser application, the root canals were irrigated with 5 mL of 5.25% NaOCl for 1 min.

In all groups, the irrigants were delivered with a 30-gauge side-vented needle (ProRinse; Dentsply Maillefer), which was applied with a back-and-forth motion at 1 mm short of the WL; 5 mL of distilled water was used between the irrigant regimens and as the final flush. After having dried them with paper points (Brasseler), all root canals were obturated using EBCF with the single-cone technique.

A disposable intracanal tip (Brasseler) was placed into the root canal 2 mm short of the WL, and the sealer was injected. A size-40 master BC point was coated with BC sealer and placed into the root canal at the WL. The teeth were radiographed to ensure that the root canals were densely obturated. The root canal entrances were sealed with a temporary filling material (Coltosol F, Coltene/Whaledent GmbH, Langeu, Germany). Subsequently, specimens were immediately stored in an incubator at 37 °C and 100% humidity for 15 days to allow the setting of the sealer. A single operator carried out all endodontic procedures. All laser applica-

no je napredovala u korijenskom kanalu sve dok njezin vrh nije bio vidljiv na vrhu. Utvrđeno je da je radna duljina (WL) 1 mm kraća od ove duljine.

Korijenski kanali obrađeni su, prema uputama proizvođača, rotirajućim turpijama EndoSequence Xpress iz srednjeg pakiranja (Brasseler, SAD) s pomoću endo-motora (X-Smart Plus; Dentsply Maillefer) do veličine 40/0,04 na WL-u, s 550 okretaja u minuti i okretnim momentom od 2 Ncm. Korijenski kanali isprani su s 2 mL 5,25-postotnoga natrijeva hipoklorita (Cerkamed, Stalowa Wola, Poljska) između svake datoteke. Zubi su nasumično podijeljeni u četiri skupine (n = 15) prema protokolima kondicioniranja dentina kojima bi bili podvrgnuti kako slijedi:

Skupina 1: Završno ispiranje provedeno je s 5 mL 5,25-postotnoga natrijeva hipklorita tijekom 1 minute i korišteno je kao kontrola.

Skupina 2: Završno ispiranje provedeno je s 2 mL 17-postotne EDTA-e (Cerkamed, Stalowa Wola, Poljska) tijekom 1 minute, nakon čega je slijedilo 5 mL 5,25-postotnoga natrijeva hipoklorita tijekom 1 minute kako bi se uklonio razmazni sloj.

Skupina 3: Završna irigacija obavljena je s 2 mL 17-postotne EDTA-e, uz 20-sekundno miješanje diodnim laserom (Epic X; Biolase, San Clemente, CA, SAD).

Diodni laser od 940 nm korišten je pri 1 W u kontinuiranom načinu rada. U korijenski kanal uveden je vlaknasti vrh E14 promjera 200 µm (Biolase), 1 mm kraći od WL-a. Vlaknasti vrh korišten je paralelno sa stijenkom kanala pokretom izvlačenja. EDTA je miješana u dva ciklusa od po 10 sekunda, sa stankom od 20 sekunda između ciklusa. Poslije toga korijenski su kanali 1 minutu irigirani s 5 mL 5,2-postotnoga natrijeva hipoklorita.

Skupina 4: Završna irigacija provedena je korištenjem Er,Cr:YSGG lasera (Waterlase iPlus; Biolase). Er,Cr:YSGG laser, koji emitira na 2780 nm, aktiviran je s izlaznom snagom od 1,5 W i brzinom ponavljanja od 20 Hz u H modu s trajanjem impulsa od 60 ms postavljenim na razini od 30 % vode / 50 % zraka (28). RFT-2, vrh konusnoga vlakna (Endolase; Biolase) promjera 275 µm uveden je 1 mm kraće od WL-a. Vlaknasti vrh korišten je paralelno sa stijenkom kanala s pokretom izvlačenja 10 sekunda. Ovaj postupak ozračivanja ponovljen je dva puta od 20 sekunda. Nakon aplikacije lasera, korijenski kanali irigirani su 1 minutu s 5 mL 5,25-postotnoga natrijeva hipoklorita.

U svim skupinama irigansi su ubrizgani iglom s bočnom ventilacijom veličine 30 (ProRinse; Dentsply Maillefer) koja je primijenjena pokretima naprijed-natrag na 1 mm ispod WL-a; 5 mL destilirane vode korišteno je između režima irigacije i kao posljednje ispiranje. Nakon sušenja papirnatim vrhovima (Brasseler), svi su korijenski kanali opturirani EBCF tehnikom jednog konusa.

Jednokratni intrakanalni vrh (Brasseler) postavljen je u korijenski kanal 2 mm ispod WL-a i ubrizgan je zatvarač. Glavna BC točka veličine 40 premazana je BC sealerom i postavljena u korijenski kanal na WL. Zubi su radiografski snimljeni kako bi se osiguralo da su korijenski kanali gusto opturirani. Ulazi korijenskih kanala zapečaćeni su privremenim materijalom za punjenje (Coltosol F, Coltene/Whaletions were performed by wearing protective eyewear within the safety precautions.

Evaluation of the push-out bond strength

The roots were embedded in an acrylic block of dimensions 2×2 cm^2. Each sample was sectioned horizontally using a low-speed diamond saw (IsoMet 1000; Buehler, Lake Buff, IL, USA) without water. Three 1 mm (±0.1 mm)-thick disc-shaped slices were obtained at distances 3–4, 6–7 and 9–10 mm from the apex, corresponding to the apical, middle and coronal root segments (Figure 1a).

Thus, 180 samples and 45 slices per group were obtained. The thickness of the slices (h) was measured with a digital caliper (Mitutoyo, Tokyo, Japan).

The images of the apical and coronal surfaces of each slice were taken under a dental operating microscope (Model M165C Microsystem; Leica, Wetzlar, Germany) at x40 magnification. These images were then transferred to the ImageJ program (National Institute of Health, Bethesda, MA, USA) to measure the apical and coronal perimeters (Pa and Pc, respectively) of the root canal fillings in millimeters.

Each root section was subjected to loading until bond failure occurred in a universal testing machine (Instron, Canton, MA, USA) used at a crosshead speed of 1 mm/min

dent GmbH, Langeu, Njemačka). Poslije toga uzorci su odmah pohranjeni u inkubatoru na 37 °C i 100 % vlažnosti tijekom 15 dana kako bi se omogućilo stvrdnjavanje brtvila. Sve endodontske zahvate obavljao je jedan operater. Sve primjene lasera učinjene su uz nošenje zaštitnih naočala u skladu s mjerama opreza.

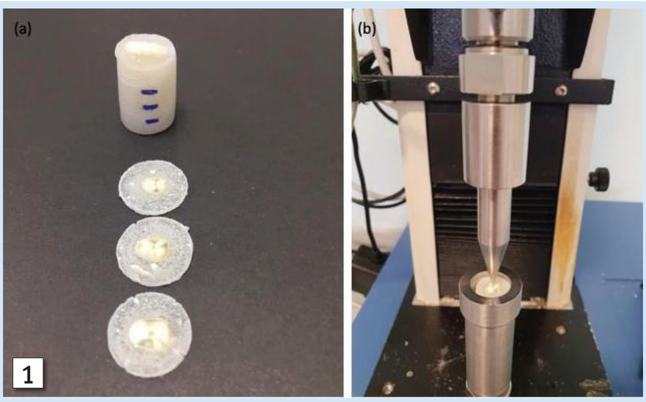
Procjena čvrstoće *push-out* veze

Korijen je ugrađen u akrilni blok dimenzija 2×2 cm^2. Svaki je uzorak razrezan vodoravno dijamantnom pilom niske brzine (IsoMet 1000; Buehler, Lake Buff, IL, SAD) bez vode. Dobivena su tri reza u obliku diska debljine 1 mm (± 0,1 mm) na udaljenostima od 3 do 4, 6 do 7 i 9 do 10 mm od vrha, što odgovara apikalnom, srednjem i koronalnom segmentu korijena (slika 1. a).

Tako je po skupini dobiveno 180 uzoraka i 45 rezova. Debljina rezova (h) izmjerena je digitalnim kaliperom (Mitutoyo, Tokio, Japan).

Slike apikalnih i koronarnih površina svakoga reza snimljene su pod dentalnim operativnim mikroskopom (model M165C Microsystem; Leica, Wetzlar, Njemačka) pri povećanju od 40 puta. Te su slike zatim prenesene u program ImageJ (Nacionalni institut za zdravlje, Bethesda, MA, SAD) za mjerenje apikalnoga i koronarnoga perimetra (Pa, odnosno Pc) ispuna korijenskog kanala u milimetrima.

Svaki dio korijena bio je podvrgnut opterećenju sve dok se nije dogodio prekid veze u univerzalnom stroju za ispitivanje (Instron, Canton, MA, SAD) korištenom pri brzini križ-



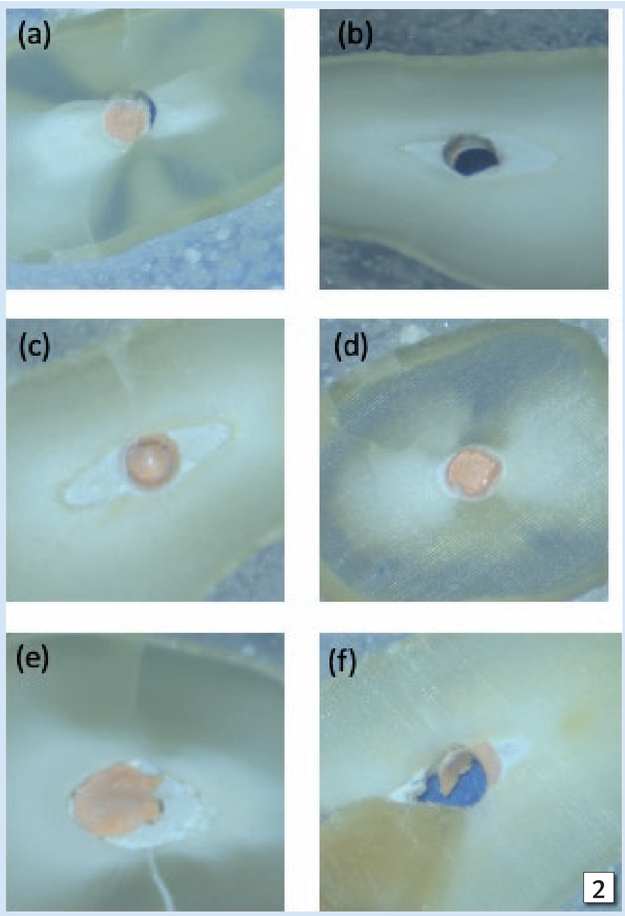


Figure 1 Representative images of 1 mm thick disc-shaped slices obtained at 3–4, 6–7 and 9–10 mm from the apex (a), and the push-out test (b).

Slika 1. Reprezentativne slike rezova u obliku diska debljine 1 mm dobivenih na 3–4, 6–7 i 9–10 mm od vrha (a) i test čišćenja kanala (b)

Figure 2 Representative images of the failure modes. (a-b) Adhesive failure. (c-d) Cohesive failure. (e-f) Mixed failure.

Slika 2. Reprezentativne slike načina kvara. (a-b) Otkazivanje ljepila. (c-d) Kohezivni neuspjeh. (e-f) Mješoviti neuspjeh

(Figure 1b). A cylindrical stainless-steel plunger with a diameter of 0.5 mm was used for all the root thirds, ensuring that it would only contact the BC point during loading. Loading procedures were carried out in the apical-coronal direction.

The maximum loading force (F) causing dislodgement of the filling material (BC point or BC point and BC sealer) was recorded in Newtons (N), and the PBS was calculated in megapascals (MPa) using the following formula (3, 34):

PBS = F/[(Pa+ Pc)/2]×h, where Pa and Pc are the perimeters of the apical and coronal aspects, respectively, and h is the thickness of the slice.

To evaluate the influence of lasers on the bond strength of EBCF, the energy densities generated in each root segment were calculated for the diode and Er, Cr: YSGG lasers, respectively (35). The laser parameters and the calculated data are given in Table 1.

ne glave od 1 mm/min (slika 1. b). Cilindrični klip od nehrđajućeg čelika promjera 0,5 mm korišten je za sve trećine korijena, osiguravajući da će dodirivati samo BC točku tijekom opterećenja. Postupci opterećenja provedeni su u apikalno-koronalnom smjeru.

Maksimalna sila opterećenja (F) koja uzrokuje pomicanje materijala za punjenje (BC točka ili BC točka i BC brtvilo) zabilježena je u njutnima (N), a PBS je izračunat u megapaskalima (MPa) s pomoću sljedeće formule (3, 34) : PBS = F/[(Pa+ Pc)/2] × h, gdje su Pa i Pc perimetri apikalnoga i koronarnoga aspekta, redom, a h je debljina presjeka.

Kako bi se procijenio utjecaj lasera na snagu veze EBCF-a, gustoće energije generirane u svakom segmentu korijena izračunate su za diodni laser, odnosno za Er,Cr:YSGG laser (35). Parametri lasera i izračunati podatci nalaze se u tablici 1.

Table 1 Laser parameters.
Tablica 1. Parametri lasera

Parameters • Parametri	Diode laser • Diodni laser	Er,Cr:YSGG laser
Average power	1 W	1.5 W
Pulse repetition rate	– (continuous wave)	20 Hz
Pulse duration	– (continuous wave)	60 µs
Duration	20 s	20 s
Tip area	0.000314 cm^2	0.00058 cm^2
Spot area (Apical)	0.000314 cm^2	0.00138 cm^2
Spot area (Middle)	0.000314 cm^2	0.00178 cm^2
Spot area (Coronal)	0.000314 cm^2	0.00270 cm^2
Total energy	20 J	30 J
Apical energy density	36.6 J/cm^2	54.34 J/cm^2
Middle energy density	31.7 J/cm^2	48.03 J/cm^2
Coronal energy density	25.47 J/cm^2	38.53 J/cm^2

Analysis of bond failure modes

After push-out testing, the slices were examined under a dental operating microscope at x40 magnification. The failure modes were classified as adhesive (between sealer–dentin or BC point–sealer interface), cohesive (within BC point or sealer), or mixed (both between sealer–dentin and BC point–sealer interface) (Figure 2). Two calibrated observers, blinded to dentin conditioning protocols, evaluated the apical aspects of each cross-section (n=180) to determine the failure modes. In cases of disagreement between the observers, the slices were examined again until a consensus was achieved.

Analiza oblika loma veze

Poslije *push-out* testiranja rezovi su pregledani pod stomatološkim operativnim mikroskopom pri povećanju od 40 puta. Načini neuspjeha klasificirani su kao adhezivni (između sealer-dentina ili BC point-sealer sučelja), kohezivni (unutar BC pointa ili sealera) ili mješoviti (između sealer-dentina i BC point-sealer sučelja) (slika 2.). Dva kalibrirana promatrača, slijepa za protokole kondicioniranja dentina, procijenila su apikalne aspekte svakoga poprečnog presjeka (n = 180) kako bi odredili načine kvara. U slučaju neslaganja između promatrača, rezovi su ponovno ispitivani dok se nije postigao konsenzus.

Statistical analysis

Data were analyzed using the Number Cruncher Statistical System (NCSS) 2007 statistical software (NCSS, Kaysville, UT, USA). In addition to descriptive statistical methods (mean, standard deviation), normally distributed variables were analyzed using a two-way analysis of variance and Tukey's multiple comparison tests were used for subgroup comparisons. The chi-square test was used for the comparison of failure modes. The significance level was set as $p<0.05$.

Statistička analiza

Podatci su analizirani u statističkom softveru Number Cruncher Statistical System (NCSS) 2007 (NCSS, Kaysville, UT, SAD). Uz deskriptivne statističke metode (srednja vrijednost, standardna devijacija), normalno distribuirane varijable analizirane su dvosmjernom analizom varijance, a za usporedbe podskupina korišteni su Tukeyjevi testovi višestruke usporedbe. Hi-kvadrat test korišten je za usporedbu oblika kvarova. Razina značajnosti postavljena je kao $p < 0,05$.

Results

The mean PBS values of the bioceramic root canal fillings are presented in Table 2. Regardless of the dentin conditioning procedure, the bond strength increased from coronal to apical in all groups with a significant difference (p=0.0001). The highest bond strengths were achieved in the apical segments. Overall, the laser groups revealed higher bond strengths.

In the apical segments, EDTA+NaOCl and agitation of EDTA with the diode laser significantly increased the bond strength of the BC filling material compared with the control (p=0.0001) and Er, Cr: YSGG laser (p=0.011 and p=0.027, respectively) groups. The difference between EDTA+NaOCl and diode laser agitated EDTA was insignificant. The EDTA+NaOCl group increased the bond strength in the apical segment and resulted in the lowest bond strength in the other root segments.

In the middle segments, laser-used (Group 3 and 4) and the control groups revealed significantly higher bond strength values compared to EDTA+NaOCl (p=0.0001 and p=0.017, respectively). Er, Cr: YSGG laser irradiation showed the highest bond strength values (4.59±0.34 MPa), followed by diode-laser agitation (4.29±0.19 MPa). The difference between Er, Cr: YSGG laser and control groups was significant (p=0.013).

In the coronal segments, all groups revealed significantly higher bond strength values than EDTA+NaOCl (p=0.0001 and p=0.001), without any significant difference among the laser-used and control groups (p>0.05).

Rezultati

Srednje PBS vrijednosti biokeramičkih ispuna korijenskog kanala prikazane su u tablici 2. Bez obzira na postupak kondicioniranja dentina, čvrstoća veze povećala se od koronarne do apikalne u svim skupinama sa značajnom razlikom (p = 0,0001). Najveća čvrstoća spoja postignuta je u apikalnim segmentima. Sveukupno, laserske skupine pokazale su veću snagu veze.

U apikalnim segmentima, EDTA+ NaOCl i miješanje EDTA-e diodnim laserom, značajno su povećali čvrstoću veze materijala za BC ispune u usporedbi s kontrolom (p = 0,0001) i Er,Cr:YSGG laserom (p = 0,011 i p = 0,027). Razlika između EDTA+NaOCl-a i EDTA-e, uz miješanje diodnim laserom, bila je beznačajna. Skupina EDTA+NaOCl povećala je snagu veze u apikalnom segmentu i rezultirala najnižom snagom veze u ostalim segmentima korijena.

U srednjim segmentima korišteni su laseri (skupina 3 i 4) i kontrolne skupine otkrile su značajno veće vrijednosti čvrstoće veze od EDTA+NaOCl-a (p = 0,0001, odnosno p = 0,017). Er,Cr:YSGG lasersko zračenje pokazalo je najviše vrijednosti čvrstoće veze (4,59 ± 0,34 MPa), a zatim diodno-lasersko miješanje (4,29 ± 0,19 MPa). Razlika između Er,Cr:YSGG lasera i kontrolnih skupina bila je značajna (p = 0,013).

U koronarnim segmentima sve su skupine pokazale značajno veće vrijednosti čvrstoće veze od EDTA-e + NaOCl (p = 0,0001 i p = 0,001), bez ikakve značajne razlike između skupina u kojima se koristio laser i kontrolne skupine (p > 0.05).

Table 2 Push-out bond strength of root filling (MPa).
Tablica 2. Čvrstoća prianjanja ispuna u kanalu (MPa)

Irrigation protocol	Root canal segments			
	Coronal	Middle	Apical	Overall
NaOCl	3.25 ± 0.38[a1]	4.00 ± 0.49[a2]	7.27 ± 0.36[a3]	4.84 ±1.81
EDTA + NaOCl	2.68 ± 0.10[b1]	3.43 ± 0.80[b2]	8.29 ± 0.47[b3]	4.80 ± 2.57
Diode laser agitated EDTA	3.05 ± 0.20[a1]	4.29 ± 0.19[a2]	8.23 ± 0.36[b3]	5.19 ± 2.24
Er,Cr:YSGG laser	3.19 ± 0.22[a1]	4.59 ± 0.34[c2]	7.67 ± 0.80[a3]	5.15 ± 1.96
Overall	3.04 ± 0.33	4.08 ± 0.66	7.87 ± 0.67	5.01 ± 2.15
***p*-value**	**0.0001**	**0.0001**	**0.0001**	

The different letters in the same column and different numbers in the same line indicate a statistically significant difference.

Table 3 Failure modes for all groups after the push-out test.
Tablica 3. Načini kvarova za sve skupine nakon testa

Root segment	Mode of failure	Group 1	Group 2	Group 3	Group 4	*p*-value
Coronal	Adhesive	26.67%	33.33%	20.00%	13.33%	0.820
	Cohesive	53.33%	46.67%	53.33%	73.33%	
	Mixed	20.00%	20.00%	26.67%	13.33%	
Middle	Adhesive	33.33%	26.67%	33.33%	13.33%	0.614
	Cohesive	60.00%	60.00%	60.00%	80.00%	
	Mixed	6.67%	13.33%	6.67%	6.67%	
Apical	Adhesive	26.67%	26.67%	13.33%	20.00%	0.260
	Cohesive	60.00%	46.67%	86.67%	73.33%	
	Mixed	13.33%	26.67%	0%	6.67%	

The failure modes of the samples are presented in Table 3. Examination of the specimens under a dental microscope revealed the bond failure to be predominantly cohesive in all three root segments, where the mixed failure mode was the least. Except for one specimen, all cohesive failures were detected within gutta-percha (BC points). In the diode and Er, Cr: YSGG laser groups, the incidence of cohesive failure was more pronounced than in the other irrigation groups. However, the difference was statistically insignificant regarding the incidence of cohesive, adhesive, and mix failures in all root segments ($p>0.05$).

Discussion

Root canal filling materials are expected to resist dislodgement when exposed to occlusal forces that are supposed to affect their sealing ability (34). Applying a load onto a set material via the push-out test provides valuable information on dislocation resistance and interfacial-failure behavior (36). Although bond strength testing may not wholly reflect the clinical performance of the tested filling material (36), the push-out test is a suitable and widely accepted method for evaluating root filling materials, even with conventional core materials (37).

In the present study, root canals were obturated using EndoSequence BC sealer and BC point combination, which is claimed to push the sealer radially and enhance its penetration into the dentinal tubules (3). Since the smear layer acts as a barrier (37), the influence of smear layer removal with various irrigation solutions and laser applications on the bond strength of bioceramic sealers has been investigated in several studies (15, 16, 18, 32). However, to our knowledge, the diode and Er, Cr: YSGG laser treatments on the PBS of bioceramic bonded obturation with EndoSequence BC points have yet to be studied. Our results revealed that using lasers for dentin conditioning differentially influenced the PBS of the tested bioceramic root canal filling at particular root segments. Therefore, the null hypothesis was rejected.

In previous studies evaluating the effectiveness of laser application in different parts of root canals, the amount of energy generated by the same power was considered constant in every square centimeter of the root canal or even not mentioned (21, 29, 30). However, the taper of the root canal is not standard and increases gradually in the apical-coronal direction. In this case, the energy densities on different parts of the root canal should not be expected to be the same with particular energy output and time. The amount of laser energy in different parts of the canal surface may influence the bond strength. Therefore, in the present study, the energy densities in each root segment were calculated for the diode and the Er, Cr: YSGG lasers and correlated with the bond strength of the filling material.

The bond strength of the EndoSequence BC filling material tended to increase in the coronal-apical direction, and the apical segments of all groups displayed the highest mean PBS. This finding was in line with a previous study (38), using EBCF for root canal obturation, as well. A circular cross-section of the root canal at the apical third might have led to

Načini loma uzoraka prikazani su u tablici 3. Ispitivanje uzoraka pod dentalnim mikroskopom pokazalo je da je lom spoja bio pretežno kohezivan u sva tri segmenta korijena, gdje je mješoviti način loma bio najmanji. Osim jednog uzorka, sva kohezivna oštećenja otkrivena su unutar gutaperke (BC točke). U diodnim i Er,Cr:YSGG laserskim skupinama učestalost kohezivnog kvara bila je izraženija nego u drugim irigacijskim skupinama. Međutim, razlika je bila statistički beznačajna u učestalosti kohezivnoga, adhezivnoga i neuspjeha mješavine u svim segmentima korijena ($p > 0.05$).

Rasprava

Očekuje se da će materijali za punjenje korijenskog kanala biti otporni na pomicanje kada su izloženi okluzijskim silama koje bi trebale utjecati na njihovo svojstvo brtvljenja (34). Primjena opterećenja na stvrdnuti materijal putem *push-out* testa pruža vrijedne informacije o otpornosti na dislokaciju i o ponašanju međupovršinskog loma (36). Iako ispitivanje čvrstoće veze možda neće u cijelosti odražavati kliničku učinkovitost testiranoga materijala za ispune (36), *push-out* test prikladna je i široko prihvaćena metoda za procjenu materijala za ispune korijena, čak i s konvencionalnim materijalima za jezgru (37).

U ovoj su studiji korijenski kanali opturirani EndoSequence BC sealerom i kombinacijom BC pointa, za koje se tvrdi da guraju sealer radijalno i pospješuju njegov prodor u dentinske tubule (3). Budući da razmazni sloj djeluje kao barijera (37), utjecaj uklanjanja razmaznoga sloja različitim otopinama za irigaciju i laserskim primjenama na čvrstoću veze biokeramičkih brtvila istražen je u nekoliko studija (15, 16, 18, 32). Međutim, prema našim saznanjima diodni i Er,Cr:YSGG laserski tretmani na PBS-u biokeramičke opturacije s EndoSequence BC točkama tek trebaju biti proučeni. Naši rezultati otkrili su da je primjena lasera za kondicioniranje dentina različito utjecala na PBS testiranoga biokeramičkog punjenja korijenskog kanala na pojedinim segmentima korijena. Nulta hipoteza je stoga odbačena.

U prijašnjim studijama koje su procjenjivale učinkovitost primjene lasera u različitim dijelovima korijenskih kanala i količina energije koju generira ista snaga smatrala se konstantnom u svakom kvadratnom centimetru korijenskog kanala ili se čak nije spominjala (21, 29, 30). No suženje korijenskog kanala nije standardno i postupno se povećava u apikalno-koronalnom smjeru. U ovom slučaju ne treba očekivati da će gustoće energije na različitim dijelovima korijenskog kanala biti iste s određenim energijskim izlazom i vremenom. Količina laserske energije u različitim dijelovima površine kanala može utjecati na snagu veze. Zato su u ovoj studiji gustoće energije u svakom segmentu korijena izračunate za diodu i Er,Cr:YSGG lasere i korelirane sa snagom veze materijala za punjenje.

Snaga veze EndoSequence BC materijala za punjenje imala je tendenciju povećanja u koronarno-apikalnome smjeru, a apikalni segmenti svih skupina pokazali su najveću srednju vrijednost PBS-a. Taj nalaz bio je u skladu s prethodnom studijom (38) koja se također koristila EBCF-om za higher resistance to the dislodgement forces (39). Also, the increased tendency in the energy densities of the diode and Er, Cr: YSGG lasers from the coronal to the apical aspects support these findings.

On the contrary, Pawar *et al.* (3) recorded the highest bond strengths in the coronal part of root canals when the root canals were obturated with EndoSequence BC sealer and C points together. The methodological difference between the studies may explain this contradiction.

At the apical segments, removing the smear layer with conventional methods and agitation of EDTA with the diode-laser + NaOCl increased the bond strength of EBCF, whereas Er,Cr:YSGG laser irradiation did not have a positive effect. In support of our findings, when used alone, the Er, Cr: YSGG laser has been demonstrated not to be appropriate for smear layer and debris removal from the apical third of root canals (29, 31). Unlike the Er, Cr: YSGG laser, the 980-nm diode laser revealed cleaner root canals than traditional shaping, especially in the apical region (21). Some researchers have proposed combining laser irradiation and chelating agent to obtain cleaner root canal walls in the apical third of root canals (26, 30, 40). In the present study, the high efficacy of EDTA and its agitation with the diode laser at the apical root segment could also be explained by a previous study, which reported that both conditioning protocols resulted in more open dentinal tubules compared with the NaOCl group (26). Considering the progressive decrease in the tubular lumen area from the coronal to the apical zone (41), EDTA may have widened the apical dentin tubule orifices, thus providing a better sealer penetration.

At the middle segments, both laser groups positively affect the bond strength of the bioceramic root-filling material. The difference was significant with the EDTA+NaOCl group. In accordance with our finding, in a recent study, the Er,Cr:YSGG laser groups presented better debris and smear layer removal than EDTA in the middle root thirds; however, the combination of laser with EDTA showed slightly better cleanliness results (30). When agitated with an 808 nm diode laser, improved smear layer removal efficacy of EDTA was confirmed in the middle and apical root segments (26). 980 nm diode laser-agitated EDTA also showed higher push-out values in the middle segment compared to EDTA alone (24). In a previous study using the same laser parameters as the present study, the diode laser also increased the bond strength of calcium silicate type of cements at the middle third of the root canal (18). The researchers attributed the increased bond strength to the laser irradiation at 1 W and continuous-wave mode to remove the smear layer and open dentinal tubules without melting the dentin surface (18). However, in the present study Er,Cr:YSGG laser irradiation yielded greater bond strength than the diode laser-agitation, possibly due to the greater energy density generated by the Er,Cr:YSGG laser in the middle region.

On the other hand, the lowest bond strength values were recorded in the EDTA+NaOCl group, which is consistent with the findings of Neelakantan *et al.* (17), who reported the decreased bond strength of EndoSequence BC following EDTA+NaOCl irrigation in the middle root segments.

opturaciju korijenskog kanala. Kružni poprečni presjek korijenskog kanala u apeksnoj trećini mogao je rezultirati većim otporom na sile pomicanja (39). Također, povećana tendencija gustoće energije diodnih i Er,Cr:YSGG lasera od koronarnog do apikalnoga aspekta, podupire ove nalaze.

Naprotiv, Pawar i suradnici (3) zabilježili su najveće snage veze u koronalnom dijelu korijenskih kanala kada su korijenski kanali opturirani EndoSequence BC sealerom i C-točkama zajedno. Ta se kontradikcija može objasniti metodološkim razlikama između studija.

Na apikalnim segmentima uklanjanje razmaznoga sloja konvencionalnim metodama i miješanje EDTA-e diodnim laserom + NaOCl, povećalo je čvrstoću EBCF veze, a Er,Cr:YSGG lasersko zračenje nije imalo pozitivan učinak. U prilog našim nalazima, kada se koristi sam, pokazalo se da Er,Cr:YSGG laser nije prikladan za uklanjanje mrlja i ostataka iz apikalne trećine korijenskih kanala (29, 31). Za razliku od Er,Cr:YSGG lasera, diodni laser od 980 nm otkrio je čišće korijenske kanale od tradicionalnog oblikovanja, osobito u apeksnoj regiji (21). Neki su istraživači predložili kombiniranje laserskoga zračenja i kelirajućeg sredstva za dobivanje čišćih stijenki korijenskog kanala u apikalnoj trećini korijenskog kanala (26, 30, 40). U ovoj se studiji visoka učinkovitost EDTA-e i njezina agitacija diodnim laserom na segmentu apikalnog korijena također može objasniti prethodnom studijom u kojoj je istaknuto da su oba protokola kondicioniranja rezultirala otvorenijim dentinskim tubulima u usporedbi sa skupinom koja je primala NaOCl (26). Uzimajući u obzir progresivno smanjenje područja lumena tubula od koronalne do apikalne zone (41), EDTA je možda proširila otvore tubula apikalnog dentina i omogućila bolju penetraciju sredstva za brtvljenje.

Na srednjim segmentima obje skupine lasera pozitivno utječu na čvrstoću veze biokeramičkog materijala za punjenje korijena. Razlika je bila značajna u skupini EDTA+NaOCl. U skladu s našim otkrićem, u nedavnoj su studiji skupine Er,Cr:YSGG lasera pokazale bolje uklanjanje krhotina i mrlja nego EDTA u srednjim trećinama korijena. Međutim, kombinacijom lasera s EDTA-om postignuti su nešto bolji rezultati čistoće (30). Kada se pomiješa s diodnim laserom od 808 nm, potvrđena je poboljšana učinkovitost uklanjanja razmaznoga sloja EDTA-e u srednjem i apikalnom segmentu korijena (26). 980 nm diodni laser uzburkan EDTA također je pokazao više vrijednosti *push-outa* u srednjem segmentu u usporedbi sa samom EDTA-om (24). U prethodnoj studiji koja se koristila jednakim laserskim parametrima kao i ova studija, diodni laser također je povećao čvrstoću veze kalcij-silikatnoga tipa cemenata u srednjoj trećini korijenskog kanala (18). Istraživači su povećanu čvrstoću spoja pripisali laserskom zračenju od 1 W i načinu kontinuiranog vala za uklanjanje razmaznoga sloja i otvaranje dentinskih tubula bez topljenja površine dentina (18). Međutim, u ovoj studiji Er,Cr:YSGG lasersko zračenje omogućilo je veću čvrstoću veze nego diodni laser-agitacija, vjerojatno zbog veće gustoće energije koju generira Er,Cr:YSGG laser u srednjem području.

S druge strane, najniže vrijednosti čvrstoće veze zabilježene su u skupini EDTA+NaOCl, što je u skladu s nalazima Neelakantana i suradnika (17) koji su izvijestili o

An analysis of the coronal segments revealed that the lowest bond strengths were measured for the EDTA+NaOCl group. Toward the coronal root canal, the tubule diameter is already becoming wider (41), thus eliminating the requirement of an extra enlargement with EDTA to provide better sealer penetration. Interestingly, unlike other segments of the root canal, the NaOCl group showed the highest bond strengths among all groups, although it was not statistically significant. The alterations in environmental pH values have influenced the hydration mechanism of bioceramic filling materials (42). While EDTA has an acidic pH, NaOCl is a strong base (17). The alkaline pH of NaOCl might have contributed to the process, which explains the higher bond strength values than EDTA+NaOCl. Within the laser groups, the lower bond strength values at the coronal segments than others may be attributed to the lowest energy densities released by the Er, Cr: YSGG, and diode lasers. Also, due to the more pronounced oval cross-section of the root canals in the coronal segments, the BC point may have failed to adequately push the sealer into the dentin tubules, resulting in decreased bond strength.

Materials with higher bond strength than dentin were reported to exhibit cohesive failure (42), which was also confirmed by the present study. Our findings are in agreement with those of Gade *et al.* (2) and Shokouhinejad *et al.* (32), who found the predominant failure mode to be cohesive for EndoSequence BC sealer, as well as Shokouhinejad *et al.* (16), who showed that the failure mode for EndoSequence BC sealer and gutta-percha combination was mainly cohesive both in the presence and absence of the smear layer.

One of the most critical limitations of this study was the use of a particular type of tooth and a single output power for laser-assisted conditioning. Although the effect of different laser output applications on smear layer removal has been demonstrated (29, 31), the required energy density to remove the smear layer in different parts of the root is unknown. The question of whether altering the energy densities by adjusting the laser parameters at different root segments will change the bond strength has remained unclear.

Conclusion

Within the limitations of the present study, dentin conditioning protocols had distinct effects on the PBS of the EndoSequence obturation system at particular root segments. Although Er, Cr: YSGG was ineffective in the apical segments, laser-assisted dentin conditioning generally revealed higher PBS values than the conventional irrigation groups. The findings of this study support the agitation of EDTA with diode laser + NaOCl for increasing the bond strength of Endosequence BC filling. The increment tendency in the bond strength from coronal to apical segments was consistent with the energy densities of the lasers.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

smanjenoj snazi veze EndoSequence BC-a poslije ispiranja EDTA+NaOCl-om u srednjim segmentima korijena. Analiza koronarnih segmenata otkrila je da su najniže snage veze izmjerene za skupinu EDTA+NaOCl. Prema koronalnom korijenskom kanalu, promjer tubula već postaje sve širi (41), čime se eliminira potreba za dodatnim proširenjem EDTA-om da bi se osiguralo bolje prodiranje brtvila. Zanimljivo, za razliku od ostalih segmenata korijenskog kanala, skupina NaOCl pokazala je najveću snagu veze među svim skupinama, iako to nije bilo statistički značajno. Promjene pH vrijednosti okoliša utjecale su na mehanizam hidratacije biokeramičkih materijala za ispune (42). Dok EDTA ima kiseli pH, NaOCl je jaka baza (17). Alkalni pH natrijeva hipoklorita mogao je pridonijeti procesu, što objašnjava veće vrijednosti čvrstoće veze od EDTA+NaOCl-a. Unutar skupina lasera niže vrijednosti čvrstoće veze na koronalnim segmentima od ostalih mogu se pripisati najnižoj gustoći energije koju oslobađaju Er, Cr:YSGG i diodni laseri. Također, zbog izraženijega ovalnog presjeka korijenskih kanala u kruničnim segmentima, BC točka možda nije uspjela adekvatno potisnuti sredstvo za brtvljenje u tubule dentina, što je rezultiralo smanjenom čvrstoćom veze.

Zabilježeno je da materijali s većom čvrstoćom veze od dentina pokazuju kohezijsko oštećenje (42), što je također potvrđeno u ovoj studiji. Naši su nalazi u skladu s onima Gadea i suradnika (2) i Shokouhinejada i suradnika (32) koji je utvrdio da je prevladavajući način kvara kohezivan za EndoSequence BC sealer, kao i Shokouhinejada i suradnika (16) koji je pokazao da je način neuspjeha za EndoSequence BC kombinaciju brtvila i gutaperke bio uglavnom kohezivan u prisutnosti i odsutnosti razmaznoga sloja.

Jedno od najkritičnijih ograničenja ove studije bilo je korištenje određene vrste zuba i jedne izlazne snage za laserski potpomognuto kondicioniranje. Iako je učinak različitih primjena izlaza lasera na uklanjanje razmaznoga sloja dokazan (29, 31), gustoća energije potrebna za njegovo uklanjanje iz različitih dijelova korijena nije poznata. Ostalo je nejasno hoće li promjena gustoće energije promijeniti snagu veze podešavanjem laserskih parametara na različitim segmentima korijena.

Zaključak

Unutar ograničenja ove studije, protokoli za kondicioniranje dentina imali su različite učinke na PBS EndoSequence opturacijskoga sustava u određenim segmentima korijena. Iako je Er,Cr:YSGG bio neučinkovit u apikalnim segmentima, laserski potpomognuto kondicioniranje dentina općenito je otkrilo više vrijednosti PBS-a od konvencionalnih skupina irigacije. Nalazi ove studije podupiru miješanje EDTA-e s diodnim laserom + NaOCl za povećanje čvrstoće veze Endosequence BC punjenja. Tendencija povećanja snage veze od koronarnih do apikalnih segmenata bila je u skladu s gustoćom energije lasera.

Financiranje

Autori nisu dobili nikakvu financijsku potporu za istraživanje, autorstvo i/ili objavljivanje ovog članka.

Conflict of interest

The authors declare that they have no conflicts of interest.

Acknowledgements

This research was orally presented in the 19th Biennial ESE Congress (11-14 September 2019, Vienna) with the title of "Influence of Diode and Er, Cr: YSGG Laser use on the push-out bond strength of a bioceramic-based root canal filling."

Author's contribution: The authors confirm contribution to the paper as follows: **E.Ç.** - designed the study and prepared the draft manuscript; **G.B.** - carried out the push-out tests and contributed to the writing; **V.I.** - collected data, contributed to failure mode analysis and manuscript's writing. **B.A.** - collected data and contributed to experimental process; I.K.K. - contributed to design and revision of the manuscript.

Sukob interesa

Autori nisu bili u sukobu interesa.

Zahvala

Ovo je istraživanje usmeno predstavljeno na 19. dvogodišnjem kongresu ESE (11. – 14. rujna 2019., Beč) pod naslovom „Utjecaj upotrebe diode i Er,Cr:YSGG lasera na snagu prianjanja biokeramičkoga punjenja korijenskog kanala."

Doprinos autora: E. Ç. – izrada studije i nacrta teksta; **G. B.** – *push-out* testovi i doprinos pisanju teksta; **V. I.** – prikupljanje podataka, doprinos analizi načina kvara i pisanju teksta; **B. A.** – prikupljanje podataka i doprinos eksperimentalnom procesu; **I. K. K.** – dizajn i revizija teksta

Sažetak

Cilj: Biokeramička punila, u kombinaciji s gutaperkama obloženim biokeramikom, sve su češće korišteni u opturaciji korijenskog kanala. Ova studija imala je kao cilj procijeniti utjecaj laserski potpomognutog kondicioniranja dentina u usporedbi s konvencionalnim protokolima kondicioniranja na čvrstoću prianjanja (PBS) ispuna korijenskog kanala na bazi biokeramike. **Materijal i metode:** Šezdeset ekstrahiranih pretkutnjaka donje čeljusti s jednim korijenskim kanalom instrumentirano je EndoSequence rotirajućim instrumentima do veličine 40/0,04. Korištena su četiri tipa protokola za kondicioniranje dentina: 1) 5,25 % NaOCl (kontrola), 2) 17 % EDTA+5,25 % NaOCl, 3) Diodni laser uz miješanje 17 % EDTA+5,25% NaOCl, 4) Er,Cr:YSGG laser zračenje +5,25 % NaOCl. Zubi su opturirani tehnikom jednog konusa EndoSequence BC sealer + BC pointom (EBCF). Nakon dobivanja vodoravnih rezova debljine 1 mm iz apikalne, srednje i krunske trećine korijena, proveden je *push-out* test i određeni su načini kvara. Podatci su analizirani dvosmjernom analizom varijance i Tukeyjevim testom s razinom značajnosti $p < 0,05$. **Rezultati:** Apikalni segmenti pokazali su najviši PBS u svim skupinama ($p < 0,05$). U apikalnim segmentima, EDTA+NaOCl i EDTA agitirana diodnim laserom, povećali su PBS u usporedbi s kontrolnim ($p = 0,0001$) i Er,Cr:YSGG laserom ($p = 0,011$, odnosno $p = 0,027$) skupinama. Obje skupine koje su se koristile laserom pokazale su značajno više vrijednosti PBS-a u srednjem i koronalnom segmentu nego EDTA+NaOCl ($p < 0,05$). Otkazivanje veze bilo je pretežno kohezivno bez značajne razlike među skupinama ($p = 0,05$). **Zaključci:** Kondicioniranje dentina potpomognuto laserom ima različite učinke na PBS EBCF u različitim segmentima korijena. Iako je Er,Cr:YSGG bio neučinkovit u apikalnim segmentima, općenito je kondicioniranje dentina s laserom povoljnije utjecalo na PBS nego na konvencionalne skupine za irigaciju, s izraženijim učinkom u skupini s EDTA agitiranom diodnim laserom.

Zaprimljen: 15. siječnja 2023.
Prihvaćen: 8. svibnja 2023.

Adresa za dopisivanje
Elif Çiftçioğlu
Stomatološki fakultet Sveučilišta Okan u Istanbulu,
34959 Akfırat İstanbul,/Turska
tel: +905322564674
elifcif@yahoo.com

MeSH pojmovi: punjenje korijenskog kanala; materijali za punjenje korijenskog kanala; organski preinačene keramike; liječenje laserom; posmična čvrstoća
Autorske ključne riječi: Biokeramičko punjenje korijenskog kanala, diodni laser, Er,Cr:YSGG laser, čvrstoća veze

References

1. Schilder H. Filling root canal in three dimensions. Dent Clin North Am. 1967 Nov;723-44.
2. Gade VJ, Belsare LD, Patils. Evaluation of push-out bond strength of endosequence BC sealer with lateral condensation and thermoplasticized technique: An in vitro study. J Conserv Dent. 2015 Mar-Apr;18(2):124-7.
3. Pawar AM, Pawar S, Kfir A. Push-out bond strength of root fillings made with C-Point and BC sealer versus gutta-percha and AH Plus after the instrumentation of oval canals with the Self-Adjusting File versus WaveOne. Int Endod J. 2016 Apr;49(4):374-81.
4. Caicedo R, von Fraunhofer JA. The properties of endodontic sealer cements. J Endod. 1988;14:527-534.
5. Neelankantan P, Subbarao C, Subbarao CV *et al.* The impact of root dentin conditioning on sealing ability and push-out bond strength of an epoxy resin root canal sealer. Int Endod J. 2011;44:491-498.
6. 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;54:3-9.
7. Saleh IM, Ruyter E, Nat R. Adhesion of endodontic sealers: scanning electron microscopy and energy dispersive spectroscopy. J Endod. 2003 Sep;29(9):595-601.
8. Saghiri MA, Shokouhinejad N, Lotfi M. Push-out bond strength of mineral trioxide aggregate in the presence of alkaline pH. J Endod. 2010 Nov;36(11):1856-9.
9. Winik R, Araki ÂT, Negrão JAA. Sealer penetration and marginal permeability after apicoectomy varying retrocavity preparation and retrofilling material. Braz Dent J2006;17(4):323-7.
10. Ozkan HB, Cobankara FK, Sayin Z, Ozer F. Evaluation of the Antibacterial Effects of Single and Combined use of Different Irrigation Solutions Against Intracanal *Enterococcus Faecalis*. Acta Stomatol Croat. 2020 Sep;54(3):250-262.
11. Calt S, Serper A. Time-dependent effects of EDTA on dentin structures. J Endod. 2002;28:17-19.
12. Boumgartner JC, Mader C. A scanning electron microscopic evaluation of four root canal irrigation regimens. J Endod. 1987 Apr;13(4):147-57.
13. Marending M, Luder HU, Brunner TJ. Effect of sodium hypochlorite on human root dentine--mechanical, chemical and structural evaluation. Int Endod J. 2007 Oct;40(10):786-93.
14. Zhender M. Root canal irrigants. J Endod. 2006;32:389-398.
15. Ozkocak I, Sonat B. Evaluation of effects on the adhesion of various root canal sealers after Er:YAG laser and irrigants are used on the dentine surface. J Endod. 2015 Aug;41(8):1331-6.
16. Shokouhinejad N, Hoseini A, Gorjestani H, Shamshiri AR. The effect of different protocols for smear layer removal on bond strength of a new bioceramic sealer. Iran Endod J. 2013 Winter;8(1):10-3. Epub 2013 Jan 20.
17. Neelakantan P, Nandagopal M, Shemesh H, Wesselink P. The effect of root dentine conditioning protocols on the push-out bond strength of three calcium silicate sealers. Int J Adhes Adhes. 2015;60:104-108.

18. Mohammadian F, Soufi S, Dibaji F. Push-out bond strength of calcium-silicate cements following Er:YAG and diode laser irradiation of root dentin. Lasers Med Sci. 2019 Feb;34(1):201-207.
19. Yammine S, Jabbour E, El Toum S, Cassia A. Histological Study of Induced Incisions on Rabbits' Tongues with Three Diode Lasers with Different Wavelengths in Continuous Mode. Scientifica (Cairo). 2018 May 2;2018:2691942.
20. Jurič IB, Anić I. The Use of Lasers in Disinfection and Cleanliness of Root Canals: a Review. Acta Stomatol Croat. 2014 Mar;48(1):6-15.
21. Wang X, Sun Y, Kimura Y, Kinoshita J. Effects of diode laser irradiation on smear layer removal from root canal walls and apical leakage after obturation. Photomed Laser Surg. 2005 Dec;23(6):575-81.
22. Schoop U, Kluger W, Dervisbegovic S. Innovative wavelengths in endodontic treatment. Lasers Surg Med. 2006 Jul;38(6):624-30.
23. Al-Karadaghi TS, Franzen R, Jawad HA, Gutknecht N. Investigations of radicular dentin permeability and ultrastructural changes after irradiation with Er,Cr:YSGG laser and dual wavelength (2780 and 940 nm) laser. Lasers Med Sci. 2015 Nov;30(8):2115-21.
24. Macedo HSD, Messias DCF, Rached-Júnior FJ. 1064-nm Nd:YAG and 980-nm diode laser EDTA agitation on the retention of an epoxy-based sealer to root dentin. Braz Dent J. 2016 Jul-Aug;27(4):424-9.
25. Gutknecht, N, Franzen R, Schippers M, Lampert F. Bactericidal effect of a 980-nm diode laser in the root canal wall dentin of bovine teeth. J Clin Laser Med Surg. 2004;22:9-13.
26. Arslan H, Ayrancı LB, Karatas E. Effect of agitation of EDTA with 808-nanometer diode laser on removal of smear layer. J Endod. 2013 Dec;39(12):1589-92.
27. Borges CC, Palma-Dibb RG, Rodrigues FCC *et al.* The effect of Diode and Er,Cr:YSGG Lasers on the bond strength of fibre posts. Photobiomodul Photomed Laser Surg. 2020 Feb;38(2):66-74.
28. Soares F, Varella CH, Pileggi R. Impact of Er,Cr:YSGG. Laser therapy on the cleanliness of the root canal walls of primary teeth. J Endod. 2008;34:474-477.
29. Bolhari B, Ehsani S, Etemadi A. Efficacy of Er,Cr:YSGG Laser in Removing Smear Layer and Debris with Two Different Output Powers. Photomed Laser Surg. 2014;32:527-532.
30. Montero-Miralles P, Torres-Lagares D, Segura-Egea JJ. Comparative study of debris and smear layer removal with EDTA and Er,Cr:YSGG laser. J Clin Exp Dent. 2018 Jun 1;10(6):e598-e602.
31. Abduljalil M, Kalender A. Efficacy of Er,Cr:YSGG Laser with different output powers on removing smear layer after retreatment of two different obturation techniques. Photobiomodul Photomed Laser Surg. 2020 Feb;38(2):84-90.
32. Shokouhinejad N, Gorjestani H, Nasseh AA. Push-out bond strength of gutta-percha with a new bioceramic sealer in the presence or absence of smear layer. Aust Endod J. 2013 Dec;39(3):102-6.
33. Böttcher DE, Hirai VH, Da Silva Neto UX, Grecca FS. Effect of calcium hydroxide dressing on the long-term sealing ability of two different endodontic sealers: an in vitro study. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2010;110:386-389.
34. El-Ma'aita AM, Qualtrough AJ, Watts DC. The effect of smear layer on the push-out bond strength of root canal calcium silicate cements. Dent Mater. 2013 Jul;29(7):797-803.
35. Selting W. Laser Operating Parameters for Hard and Soft Tissue, Surgical and PBM Management. In: Coluzzi DJ, Parker SPA (ed). Lasers in Dentistry-Current Concept, 1st ed. Springer; 2017:80-85.
36. Moinzadeh AT, Jongsma LA, Wesselink PR. Considerations about the use of the "push-out" test in endodontic research. Int Endod J. 2015;48:498-500.
37. Pane ES, Palamara JE, Messer HH. Critical evaluation of the push-out test for root canal filling materials. J Endod. 2013 May;39(5):669-73.
38. Varguez AC, Basoco BS, Vizcarra BG. Comparative in vitro study of the bond strength on dentin of two sealing cements: BC-Sealer and AH-Plus. Rev Mex Ing Bioméd. 2016;37:115-122.
39. Verma D, Taneja S, Kumari M. Efficacy of different irrigation regimes on the push-out bond strength of various resin-based sealers at different root levels: An in vitro study. J Conserv Dent. 2018 Mar-Apr;21(2):125-129.
40. George R, Meyers IA, Walsh LJ. Laser activation of endodontic irrigants with improved conical laser fiber tips for removing smear layer in the apical third of the root canal. J Endod. 2008;34:1524-1527.
41. Lo Giudice G, Cutroneo G, Centofanti A, et al. Dentin morphology of root canal surface: A quantitative evaluation based on a scanning electronic microscopy study. Biomed Res Int. 2015;2015:164065.
42. Lee KW, Williams MC, Camps JJ, Pashley DH. Adhesion of endodontic sealers to dentin and gutta-percha. J Endod. 2002 Oct;28(10):684-8.