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Effect of Root Canal Drying Methods on Bioceramic Sealer Bond Strength

Utjecaj metoda sušenja korijenskog kanala na čvrstoću veze biokeramičkog punila

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Abstract

Aim: This study evaluated the effects of paper point drying, microsuction, and 70% isopropyl alcohol on the push-out bond strength and interfacial adaptation of a premixed bioceramic sealer. **Materials and Methods:** Thirty extracted maxillary central incisors were prepared using NiTi rotary instruments and irrigated with NaOCl and EDTA. Specimens were randomly assigned to three groups (n = 10): paper point drying, microsuction, or 70% isopropyl alcohol. All canals were obturated with a calcium silicate-based bioceramic sealer using the single-cone technique. After one week of incubation, root slices from the coronal, middle, and apical thirds (n = 90) were subjected to push-out bond strength testing. Failure modes were evaluated stereomicroscopically, and selected specimens underwent scanning electron microscopy (SEM) analysis. Statistical analysis was performed using nonparametric tests ($\alpha = 0.05$). **Results:** The drying protocol significantly affected bond strength ($p < 0.001$). The isopropyl alcohol (3.23 MPa) and paper point (2.97 MPa) groups demonstrated significantly higher bond strength than the microsuction group (1.23 MPa). Apical slices showed higher bond strength than coronal and middle slices. Mixed failures predominated, while cohesive failures were more frequent in the alcohol and paper point groups. SEM revealed improved sealer-dentin adaptation with fewer interfacial gaps in these groups. **Conclusions:** Bioceramic sealer adhesion is strongly influenced by the drying method. Paper point drying and isopropyl alcohol enhance bond strength and interfacial adaptation, whereas microsuction results in inferior performance.

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Introduction

Endodontic sealers play a critical role in achieving three-dimensional sealing of the root canal system by filling the spaces between the gutta-percha cones and the dentinal walls (1). Currently, bioceramic-based sealers have gained prominence due to their advantageous properties, including alkaline pH, antibacterial activity, adequate radiopacity, and biocompatibility (2, 3). These materials are chemically stable in biological environments, do not undergo volumetric shrinkage, and contribute to strengthening the bond between dentin and the filling material through their ability to form hydroxyapatite during the setting process (3, 4). However, some concerns remain regarding their solubility, which may affect their long-term sealing capability (5).

Uvod

Endodontska punila ključna su u postizanju trodimenzionalnog brtvljenja korijenskog kanala jer ispunjavaju prostor između gutaperkina konusa i dentinskih stijenki (1). Trenutačno su punila na bazi biokeramike iznimno važna zbog svojih povoljnih svojstava, uključujući alkalni pH, antibakterijsko djelovanje, odgovarajuću radiopaktnost i biokompatibilnost (2, 3). Ti su materijali kemijski stabilni u biološkim okružjima, ne podliježu volumetrijskom skupljanju i pridonose jačanju veze između dentina i materijala za punjenje zato što stvaraju hidroksiapatit tijekom procesa stvrdnjavanja (3, 4). No ostaje zabrinutost u vezi s topljivošću, što može utjecati na njihovo dugoročno svojstvo brtvljenja (5).

It has been suggested that the adhesion of calcium silicate-based sealers to dentin occurs through the formation of a mineral infiltration zone, created by the penetration of the sealer into the dentinal tubules (6). This adhesion can be influenced by moisture of the root canal. Therefore, drying the canal before obturation is critically important for ensuring the sealer's retention to both the dentinal walls and the filling material (7-9). Calcium silicate-based materials are capable of exhibiting both solubility and fluid absorption simultaneously (10). Consequently, the presence of excessive moisture may adversely affect the properties of the sealer and depending on the formulation of the material, may inhibit, delay, or accelerate the setting reaction, thereby increasing the likelihood of infiltration (9, 11). Conversely, excessive drying may eliminate residual water and impair the penetration of hydrophilic sealers into the dentinal tubules (12).

Manufacturers recommend keeping root canals moist to take advantage of hydrophilic properties of sealers. However, the exact degree of moisture ideal for their products and the method to achieve it are not specified (13). Since no clear guidelines are provided to obtain an optimal residual moisture level, various chemicals, including alcohol in different concentrations, have been tested in the literature to enhance dentin wettability (13-15).

Although absorbent paper points are commonly used for canal drying prior to obturation, Nagas et al. (11) reported that moisture may remain in irregular areas and lateral canals even after drying with paper points. To improve drying outcomes, the use of organic solvents (9, 11, 13, 14, 16, 17) and various heat sources (18) has been suggested. Mechanical devices such as microsuction systems have also been proposed to facilitate root canal drying; however, no reports regarding the performance of these devices are available in the literature. Moreover, the potential role of different drying techniques used in clinical protocols, as well as the effect of chemically (using alcohol) versus purely physically dried canals, has not yet been investigated. Since calcium silicate-based sealers bond directly to calcium in the hard tissue phase, not only moisture interferes with their setting reaction but also the wetness of the canal wall. Additionally, the hydration of collagen may influence adhesion success (19). Therefore, the present study aimed to evaluate the effects of three different root canal drying methods—paper point, microsuction, and 70% isopropyl alcohol—on the push-out bond strength of a bioceramic sealer. In addition, sealer penetration into dentinal tubules was examined using scanning electron microscopy (SEM), and the failure modes following the push-out test were analyzed.

The null hypothesis of the study was that the method of root canal drying (paper point, microsuction, or 70% isopropyl alcohol) would not have a significant effect on the push-out bond strength of the bioceramic sealer to dentin.

Materials and Methods

This study was conducted in accordance with the principles of the Declaration of Helsinki. The research protocol was approved by the Non-Interventional Clinical Research

Sugerira se da se prijanjanje punila na bazi kalcijeva silikata na dentin događa stvaranjem zone infiltracije minerala nastale prodiranjem punila u dentinske tubule (6). Na to prijanjanje može utjecati i vlaga u korijenskom kanalu. Stoga je njegovo sušenje prije punjenja iznimno važno kako bi se zadržalo brtvilo i na dentinskim stijenkama i na materijalu za punjenje (7 – 9). Materijali na bazi kalcijeva silikata mogu istodobno pokazivati i topljivost i apsorpciju tekućine (10). Posljedično, prisutnost prekomjerne vlage može negativno utjecati na svojstva brtvila i, ovisno o formulaciji materijala, može inhibirati, odgoditi ili ubrzati reakciju stvrdnjavanja, čime se povećava mogućnost infiltracije (9, 11). Suprotno tomu, prekomjerno sušenje može ukloniti preostalu vodu i otežati prodiranje hidrofilnih brtvila u dentinske tubule (12).

Proizvođači preporučuju održavanje kanala vlažnima kako bi se iskoristila hidrofilna svojstva brtvila. No ne navode točan stupanj vlažnosti idealan za njihove proizvode i metode kako to postići (13). Budući da nisu dane jasne smjernice kako postići optimalnu razinu preostale vlage, da bi se poboljšala vlažnost dentina u literaturi su testirane različite kemikalije, uključujući alkohol u različitim koncentracijama (13 – 15).

Iako se upijajući papirnati štapići često koriste za sušenje kanala prije punjenja, Nagas i suradnici (11) izvjestili su da vlaga može ostati u neravnim područjima i lateralnim kanalima čak i nakon sušenja papirnatim štapićima. Kako bi se poboljšali rezultati sušenja, predložena je upotreba organskih otapala (9, 11, 13, 14, 16, 17) i različitih izvora topline (18). Mehanički uređaji poput sustava mikrousisavanja također su predloženi za olakšavanje sušenja korijenskog kanala. No u literaturi nema dostupnih izvješća o učinkovitosti tih uređaja. Štoviše, potencijalna uloga različitih tehnika sušenja koje se koriste u kliničkim protokolima nije istražena, kao ni kemijski učinak (korištenje alkohola) u odnosu na isključivo fizički sušene kanale. Budući da se punila na bazi kalcijeva silikata izravno vežu za kalcij u fazi tvrdoga tkiva, na uspjeh adhezije može utjecati ne samo vlaga koja ometa njihov reakciju stvrdnjavanja, nego i vlažnost stijenke kanala i hidratacija kolagena (19). Zato je cilj ove studije bio procijeniti učinke triju različitih metoda sušenja korijenskog kanala – papirnatoga vrha, mikrousisavanja i 70-postotnoga izopropilnog alkohola – na čvrstoću veze istiskivanjem biokeramičkog punila. Osim toga, prodiranje punila u dentinske tubule bit će ispitano skenirajućom elektronskom mikroskopijom (SEM) i analizirat će se načini loma nakon testa istiskivanja.

Nulta hipoteza studije bila je da metoda sušenja korijenskog kanala (papirnati štapić, mikrousisavanje ili 70-postotni izopropilni alkohol) neće značajno utjecati na čvrstoću veze istiskivanjem biokeramičkog punila s dentinom.

Materijali i metode

Ova je studija provedena u skladu s načelima Helsinške deklaracije. Istraživački protokol odobrilo je Etičko povjerenstvo za neintervencijska klinička istraživanja Stomatološ-

Ethics Committee of the Faculty of Dentistry at Marmara University (Istanbul, Turkey) (approval no:2025-85). Extracted human teeth were used in this study. Prior to extraction, patients were informed about the possible use of their teeth for research purposes. Also, written informed consent was obtained for scientific use of patients' teeth.

In this *in vitro* study, thirty extracted human maxillary central incisors with single roots, removed due to caries or periodontal reasons, were used. Teeth with immature apices, root resorption, root cracks or fractures, previous root canal treatment, calcified canals, or anatomical anomalies were excluded from the study. The sample size was determined *a priori*, which is described in the Statistical Analysis section.

The crowns of all teeth were sectioned under water cooling using a low-speed precision saw (Isomet 1000; Buehler, Lake Bluff, IL, USA) to obtain a standardized root length of 16 mm. Canal patency was verified with a #15 K-file, and the root canals were prepared using nickel-titanium rotary instruments (Smart Gold, EndoArt, Inci Dental, Istanbul, Turkey) up to size 40/.04 at the working length, determined as 1 mm short of the apical foramen. During preparation, 5 mL of 2.5% sodium hypochlorite (Werax, Turkey) was used for irrigation after each file change. Final irrigation was performed with 5 mL of 17% EDTA (Sigma-Aldrich, USA), followed by 5 mL of distilled water. The specimens were then randomly divided into three groups (n = 10 teeth per group):

Group 1 – Drying with Paper Points

Following coronal aspiration, the canals were dried up to the working length (WL) using size 40/.04 paper points. At least three paper points were used until the final one emerged completely dry.

Group 2 – Drying with Microsuction

After irrigation, flexible silicone microcannulas (SS Plus, Maringá, Brazil) were used to aspirate the coronal and middle thirds of the root canal for 5 seconds. Microsuction was the sole active drying method in this group. Subsequently, a single paper point was gently inserted only to verify the presence of residual moisture and not as an additional drying procedure, in accordance with previously described microsuction-based drying protocols (22, 23).

Group 3 – Drying with 70% Isopropyl Alcohol

Using a 30G needle, 1 mL of 70% isopropyl alcohol (Nailfun, SCHÜTZ Neue Medien GmbH, Offenburg, Germany) was delivered, 1 mm short of the WL. After a 1-minute dwell time, the solution was aspirated, and the final drying was performed using a single paper point to standardize the residual moisture condition, rather than to achieve complete canal dryness.

In all specimens, the canals were obturated using EndoArt Biosealer (EndoArt, Turkey) in accordance with the manufacturer's instructions. The filling was performed using the single-cone technique, whereby #40/.04 gutta-percha cones (DiaDent, Korea) coated with sealer were inserted to the working length and gently condensed apically. The canal orifices were sealed with temporary restorative material, and

kog fakulteta Sveučilišta Marmara (Istanbul, Turska) (broj odobrenja: 2025-85). U ovoj su studiji korišteni ekstrahirani ljudski zubi, a prije vađenja pacijenti su obaviješteni o mogućoj upotrebi njihovih zuba u istraživačke svrhe pa su potpisali informirani pristanak za njihovu znanstvenu upotrebu.

U ovoj studiji *in vitro* korišteno je trideset ekstrahiranih ljudskih maksimalnih središnjih sjekutića s jednim korijenom, izvađenih zbog karijesa ili parodontalnih razloga. Zubi s nezrelim vrhovima, resorpcijom korijena, pukotinama ili frakturama korijena, s liječenim korijenskim kanalima, kalcificiranim kanalima ili anatomskim anomalijama, isključeni su iz studije. Veličina uzorka određena je unaprijed i opisana je u odjeljku Statistička analiza.

Krunice svih zuba prerezane su pod vodenim hlađenjem preciznom pilom male brzine (Isomet 1000; Buehler, Lake Bluff, IL, SAD) da bi se dobila standardizirana duljina korijena od 16 mm. Prohodnost kanala provjerena je K-turpijom #15, a korijenski kanali pripremljeni su rotacijskim instrumentima od nikla i titanija (Smart Gold, EndoArt, Inci Dental, Istanbul, Turska) do veličine 40/.04 na radnoj duljini, određenoj kao 1 mm ispod apikalnog foramena. Tijekom pripreme, za ispiranje je poslije svake izmjene turpije, korišteno 5 mL 2,5-postotnoga natrijeva hipoklorita (Werax, Turska). Završno ispiranje obavljeno je s 5 mL 17-postotne EDTA-e (Sigma-Aldrich, SAD), a zatim s 5 mL destilirane vode. Uzorci su nakon toga nasumično podijeljeni u tri skupine (n = 10 zuba po skupini):

Skupina 1 – sušenje papirnatim štapićima

Nakon koronalne aspiracije kanali su osušeni do radne duljine (WL) papirnatim štapićima veličine 40/.04. Korištena su najmanje tri papirnata štapića dok posljednji nije izvučen potpuno suh.

Skupina 2 – sušenje mikrousisavanjem

Nakon irigacije, fleksibilne silikonske mikrokanile (SS Plus, Maringá, Brazil) korištene su za aspiraciju koronalne i srednje trećine korijenskog kanala tijekom 5 sekunda. Mikrousisavanje je bila jedina aktivna metoda sušenja u toj skupini. Nakon toga jedan je papirnat štapić nježno umetnut samo radi provjere prisutnosti preostale vlage, a ne kao dodatni postupak sušenja, u skladu s već opisanim protokolima sušenja temeljenima na mikrousisavanju (22, 23).

Skupina 3 – sušenje 70-postotnim izopropilnim alkoholom

Koristeći se iglom od 30G, 1 mL 70-postotnoga izopropilnog alkohola (Nailfun, SCHÜTZ Neue Medien GmbH, Offenburg, Njemačka) umetnut je 1 mm prije korijenskog kanala. Nakon jednominutnoga zadržavanja otopina je aspirirana, a konačno sušenje obavljeno je s pomoću jednoga papirnata štapića radi standardizacije stanja preostale vlage, a ne da bi se postigla potpuna suhoća kanala.

U svim uzorcima kanali su opturirani EndoArt Biosealerom (EndoArt, Turska) u skladu s uputama proizvođača. Punjenje je provedeno tehnikom jednog konusa, pri čemu su gutaperkini konusi od #40/.04 (DiaDent, Koreja) obloženi punilom umetnuti do radne duljine i lagano apikalno kondenzirani. Ušća kanala zapečaćena su privremenim re-

the specimens were stored at 37 °C and 100% humidity for one week. Subsequently, from each tooth, two slices of 2 mm thickness were obtained from the coronal, middle and apical thirds using a low-speed, water-cooled precision saw (Isomet 1000; Buehler, Lake Bluff, IL, USA). In accordance with previous studies, the first and last apical slices were excluded from the analysis (20, 21). A total of six slices were thus prepared from each tooth, as follows:

Three slices (one coronal, one middle, and one apical; a total of 90 specimens) were allocated for the push-out test, while the remaining three slices (one coronal, one middle, and one apical; a total of 90 specimens) were designated for SEM analysis. The apical surface of each slice was marked with a permanent marker to ensure that the loading force was applied in an apical-to-coronal direction. The push-out test was performed using a universal testing machine (Shimadzu AGS-X, Shimadzu Corporation, Kyoto, Japan) at a crosshead speed of 0.5 mm/min until bond failure occurred. Stainless steel plungers with diameters of 0.40 mm, 0.50 mm, and 0.70 mm were used for the apical, middle, and coronal sections, respectively.

The bond strength (MPa) was calculated by dividing the applied load (N) by the bonded surface area. Following testing, each slice was examined under a stereomicroscope (Leica M205C; Leica Microsystems, Wetzlar, Germany) at 20× magnification, and the failure modes were classified as follows (Figure 1):

- Adhesive failure: Separation occurring at the sealer–dentin interface.
- Cohesive failure: Fracture occurring within the sealer itself.
- Mixed failure: A combination of both adhesive and cohesive failure characteristics.

The slices designated for SEM analysis were dehydrated in a graded series of ethanol solutions and sputter-coated with gold-palladium. Examinations were performed at an

staurativnim materijalom, a uzorci su pohranjeni na 37 °C i izloženi 100-stopostotnoj vlažnosti tijekom jednog tjedna. Nakon toga od svakog su zuba dobivena dva dijela debljine 2 mm iz koronalne, srednje i apikalne trećine s pomoću precizne pile niske brzine, hladene vodom (Isomet 1000; Buehler, Lake Bluff, IL, SAD). U skladu s dosadašnjim studijama, prvi i posljednji apikalni rezovi isključeni su iz analize (20, 21). Ukupno šest rezova dobiveno je od svakoga zuba, kako slijedi:

tri reza (jedan koronalni, jedan srednji i jedan apikalni; ukupno 90 uzoraka) namijenjena su za test istiskivanja, a preostala tri (jedan koronalni, jedan srednji i jedan apikalni; ukupno 90 uzoraka) određeni su za SEM analizu. Apikalna površina svakog reza označena je permanentnim markerom kako bi se osiguralo da se sila opterećenja primjenjuje u smjeru od apikalnoga do koronalnoga dijela. Test istiskivanja proveden je s pomoću univerzalnoga stroja za ispitivanje (Shimadzu AGS-X, Shimadzu Corporation, Kyoto, Japan) pri brzini poprečne glave od 0,5 mm/min dok se nije dogodilo pucanje veze. Klipovi od nehrđajućeg čelika promjera 0,40 mm, 0,50 mm i 0,70 mm korišteni su za apikalni, srednji i koronalni dio.

Čvrstoća veze (MPa) izračunata je dijeljenjem primijenjenog opterećenja (N) s površinom lijepljenja. Nakon ispitivanja svaki je rez pregledan stereomikroskopom (Leica M205C; Leica Microsystems, Wetzlar, Njemačka) pri povećanju od 20 puta, a načini loma klasificirani su na sljedeći način (slika 1.):

- adhezivni lom: odvajanje se događa na granici između brtvila i dentina
- kohezivni lom: lom se događa unutar samog brtvila
- mješoviti lom: kombinacija adhezivnih i kohezivnih karakteristika loma.

Rezovi određeni za SEM analizu dehidrirani su u postupnom nizu otopina etanola i presvučeni raspršivanjem zlata i paladija. Ispitivanja su provedena pri ubrzavajućem

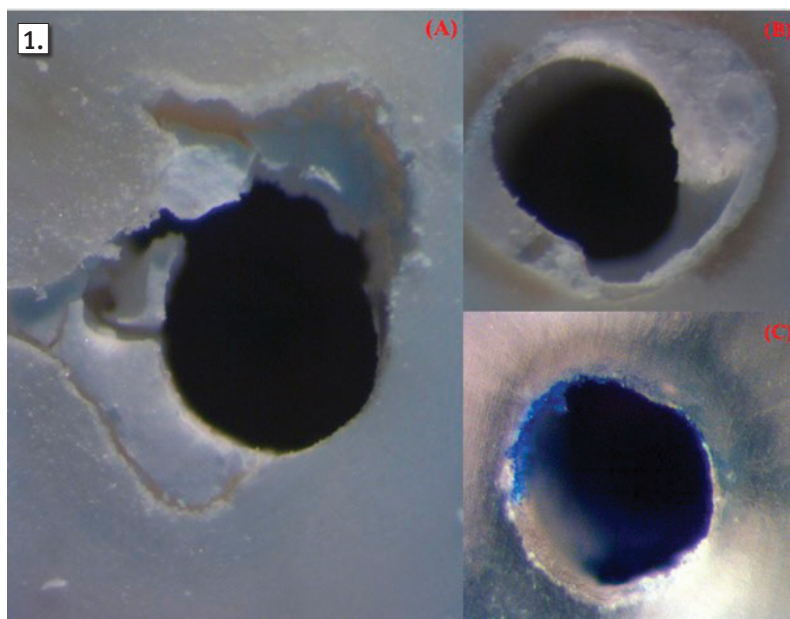


Figure 1 Representative stereomicroscopic images of different failure modes observed after the push-out test: (a) Mixed failure; (b) Cohesive failure within the sealer; (c) Adhesive failure at the dentin–sealer interface.

Slika 1. Reprezentativne stereomikroskopske slike različitih oblika kvarova uočenih poslije testa istiskivanja: (a) mješoviti kvar; (b) kohezivno oštećenje unutar brtvila; (c) neuspjela adhezija na spoju dentina i brtvila.

accelerating voltage of 15 kV under 200× and 500× magnifications. Adhesive penetration, interfacial morphology, and void formation were recorded separately according to the root region and drying method by a single experienced operator. To assess intra-operator reliability, 20% of the specimens were re-evaluated after a two-week interval, and a high level of consistency was observed (ICC = 0.91).

Statistical Analyses

The minimum sample size was determined based on the design and variance structures of similar *in vitro* studies in the literature (20, 21). For a three-group comparison, Cohen's effect size conventions were applied; assuming a large effect size ($f = 0.40$), $\alpha = 0.05$, and power ($1 - \beta$) = 80%, a one-way ANOVA-based power analysis was performed. This calculation indicated that at least 22 specimens per group were required. To increase statistical power and compensate for potential specimen loss, 30 samples per group were included, resulting in a total of 90 slices evaluated in the push-out test. In this study, the tooth was considered the experimental unit for group allocation, whereas root slices were defined as the measurement units for bond strength evaluation, consistent with the nature of the push-out test. Each slice represents a distinct anatomical region (coronal, middle, or apical) with different dentinal characteristics, tubule density, and moisture dynamics, and was therefore analyzed as a separate measurement unit. Potential intra-tooth dependency among slices was addressed by using statistical approaches appropriate for repeated measurements and clustered data.

Statistical analyses were performed using IBM SPSS Statistics for macOS, Version 31.0 (IBM Corp., Armonk, NY, USA). The Fisher–Freeman–Halton test was used to evaluate the distribution of failure modes according to the drying method, while the distribution of failure modes by slice level was analyzed using Generalized Linear Mixed Models (GLMM). The Kruskal–Wallis test was employed to compare bond strength values among different drying methods, and the Friedman test was used to compare bond strength across slice levels within each method. When significant differences were detected in the Kruskal–Wallis or Friedman tests, pairwise comparisons were performed using the Mann–Whitney U and Wilcoxon Signed-Rank tests, respectively, with Bonferroni correction applied. A significance level of 5% ($\alpha = 0.05$) was adopted for all analyses. Measurements obtained from different root levels of the same tooth were analyzed using statistical methods suitable for repeated measures to account for within-tooth correlation.

Results

The median (1st–3rd quartile) bond strength was 2.97 MPa (1.94–6.62) in the Paper Point group, 3.23 MPa (2.02–4.05) in the Alcohol group, and 1.23 MPa (0.41–3.36) in the Microsuction group. The difference among the groups was statistically significant (Kruskal–Wallis test, $p < 0.001$). Pairwise comparisons revealed no significant difference between the Paper Point and Alcohol groups, whereas the Microsuction group demonstrated significantly lower values than both (Mann–Whitney U test with Bonferroni correction) (Table 1).

naponu od 15 kV pod povećanjima od 200 i 500 puta. Prodiranje adheziva, morfologija međupovršine i stvaranje šupljina zabilježeni su odvojeno prema području korijena i metodi sušenja, što je učinio jedan iskusni operater. Kako bi se procijenila pouzdanost unutar operatera, 20 % uzoraka ponovno je procijenjeno nakon dvotjednoga intervala i uočena je visoka razina konzistentnosti (ICC = 0,91).

Statistička analiza

Minimalna veličina uzorka određena je na temelju dizajna i struktura varijance sličnih studija *in vitro* u literaturi (20, 21). Za usporedbu triju skupina primijenjene su Cohenove konvencije veličine učinka; pretpostavljajući veliki učinak ($f = 0,40$), $\alpha = 0,05$ i snagu ($1 - \beta$) = 80 %, provedena je jednosmjerna ANOVA-ina analiza snage. Taj je izračun pokazao da su potrebna najmanje 22 uzorka po skupini. Kako bi se povećala statistička snaga i kompenzirao potencijalni gubitak uzoraka, pripremljeno je 30 uzoraka po skupini, što je rezultiralo s ukupno 90 rezova procijenjenih u testu istiskivanja. U ovoj studiji zub se smatrao eksperimentalnom jedinicom za raspodjelu skupina, a rezovi korijena definirani su kao mjerne jedinice za procjenu čvrstoće veze, u skladu s prirodom testa istiskivanja. Svaki presjek zasebna je anatomska regija (koronalna, srednja ili apikalna) s različitim dentinskim značajkama, gustoćom tubula i dinamikom vlage te je zato analiziran kao zasebna mjerna jedinica. Potencijalna ovisnost unutar zuba među presjecima riješena je korištenjem statističkih pristupa prikladnih za ponovljena mjerenja i klasterirane podatke.

Statističke analize obavljene su u programu IBM SPSS Statistics za macOS, verzija 31.0 (IBM Corp., Armonk, NY, SAD). Fisher–Freeman–Haltonov test korišten je za procjenu raspodjele načina loma prema metodi sušenja, a raspodjela načina loma prema razini presjeka analizirana je korištenjem generaliziranih linearnih miješanih modela (GLMM). Kruskal–Wallisovim testom uspoređene su vrijednosti čvrstoće veze među različitim metodama sušenja, a Friedmanovim testom obavljena je usporedba čvrstoće veze na razinama presjeka unutar svake metode. Kada su otkrivene značajne razlike u Kruskal–Wallisovu ili Friedmanovu testu, provedene su parne usporedbe korištenjem Mann–Whitneyjeva U testa i Wilcoxon–Signed–Rankova testa, uz primjenu Bonferronijeve korekcije. Za sve analize usvojena je razina značajnosti od 5 % ($\alpha = 0,05$). Mjerenja dobivena s različitih razina korijena istoga zuba analizirana su statističkim metodama prikladnima za ponovljena mjerenja kako bi se objasnila korelacija unutar zuba.

Rezultati

Medijan (1.–3. kvartil) čvrstoće veze bio je 2,97 MPa (1,94 – 6,62) u skupini s papirnatim štapićima, 3,23 MPa (2,02 – 4,05) u skupini s alkoholom i 1,23 MPa (0,41 – 3,36) u skupini s mikrousisavanjem. Razlika između skupina bila je statistički značajna (Kruskal–Wallisov test, $p < 0,001$). Usporedbe po parovima nisu otkrile značajnu razliku između skupina s papirnatim štapićem i alkoholom, a skupina s mikrousisavanjem pokazala značajno niže vrijednosti od prvih dviju (Mann–Whitneyjev U test s Bonferronijevom korekcijom) (tablica 1).

Table 1 Push-out bond strength values (MPa) according to different root canal drying methods
Tablica 1. Vrijednosti čvrstoće prijanjanja (MPa) prema različitim metodama sušenja korijenskog kanala

Protocol	MPa	p value*
	Median (1st–3rd quartile)	
Paper Point (n=30)	2.97 (1.94 – 6.62)a	<0.001
Isopropyl Alcohol (n=30)	3.23 (2.02 – 4.05)a	
Microsuction (n=30)	1.23 (0,41 – 3.36)b	

*Kruskal–Wallis test; pairs without statistically significant differences in the post hoc analysis are indicated by the same letter (Mann–Whitney U test with Bonferroni correction). • *Kruskal–Wallisov test; parovi bez statistički značajnih razlika u post hoc analizi označeni su istim slovom (Mann–Whitneyjev U test s Bonferronijevom korekcijom).

Table 2 Push-out bond strength values (MPa) at different root levels according to the root canal drying methods
Tablica 2. Vrijednosti čvrstoće prijanjanja (MPa) na različitim razinama korijena prema metodama sušenja korijenskog kanala

Protocol	Middle	Apical	Coronal	p value*
Paper Point	2.45 (1.74 – 5.42)a	7.84 (3.05 – 10.3)b	2.39 (1.37 – 4.49)a	0.020
Isopropyl Alcohol	3.32 (2.45 – 4.03)a	4.06 (2.08 – 6.49)a	2.81 (1.38 – 3.20)b	0.025
Microsuction	1.20 (0,22 – 3,11)	2.51 (0.89 – 4.07)	0.92 (0.41 – 1.60)	0.301

*Friedman test; pairs without statistically significant differences in the post hoc analysis are indicated by the same letter (Wilcoxon signed-rank test with Bonferroni correction). • *Friedmanov test; parovi bez statistički značajnih razlika u post hoc analizi označeni su istim slovom (Wilcoxonov signed-rank test s Bonferroni korekcijom).

Table 3 Distribution of failure modes after the push-out bond strength test according to different root canal drying methods
Tablica 3 Distribucija načina neuspjeha nakon testa čvrstoće veze prema različitim metodama sušenja korijenskog kanala

Protocol	Failure Mode		
	Mixed Number (%*)	Cohesive Number (%*)	Adhesive Number (%*)
Paper Point (n=30)	16 (53.3)	12 (40.0)	2 (6.7)
Isopropyl Alcohol (n=30)	13 (43.3)	15 (50.0)	2 (6.7)
Microsuction (n=30)	21 (70.0)	8 (26.7)	1 (3.3)
Total (n=90)	50 (55.6)	35 (38.9)	5 (5.6)

Fisher-Freeman-Halton Test, $p=0,337$ • Fisher-Freeman-Haltonov test, $p = 0,337$

*Row percentages are presented. • *Prikazani su postotci redaka.

In the Paper Point group, a significant difference was observed among the slices, with the apical slice (7.84 [3.05–10.3] MPa) showing higher bond strength values than the middle (2.45 [1.74–5.42] MPa) and coronal (2.39 [1.37–4.49] MPa) slices (Friedman test, $p = 0.020$). Similarly, in the Alcohol group, significant differences were detected among the slices, with the apical (4.06 [2.08–6.49] MPa) and middle (3.32 [2.45–4.03] MPa) slices exhibiting higher values than the coronal slice (2.81 [1.38–3.20] MPa) (Friedman test, $p = 0.025$). In contrast, no statistically significant difference was found among the slices in the Microsuction group, where the median bond strength values were 1.20 MPa (0.22–3.11) for the middle slice, 2.51 MPa (0.89–4.07) for the apical slice, and 0.92 MPa (0.41–1.60) for the coronal slice (Friedman test, $p = 0.301$) (Table 2).

In the Paper Point group, cohesive failures were the most common (40.0%), while cohesive failures also predominated in the Alcohol group (50.0%). In the Microsuction group, mixed failures were most frequently observed (70.0%). When all groups were evaluated collectively, mixed failures were the most prevalent (55.6%), followed by cohesive (38.9%) and adhesive (5.6%) failures. No statistically significant difference was found among the groups (Fisher–Freeman–Halton test, $p = 0.337$). When the distribution of failure modes was

U skupini s papirnatim štapićem uočena je značajna razlika među rezovima, pri čemu apikalni rez [7,84 (3,05 – 10,3) MPa] pokazuje veće vrijednosti čvrstoće veze od srednjih [2,45 (1,74 – 5,42) MPa] i koronalnih [2,39 (1,37 – 4,49) MPa] rezova (Friedmanov test, $p = 0,020$). Slično tomu, u grupi s alkoholom otkrivene su značajne razlike među rezovima, pri čemu apikalni [4,06 (2,08 – 6,49) MPa] i srednji [3,32 (2,45 – 4,03) MPa] rezovi pokazuju veće vrijednosti nego koronalni rez [2,81 (1,38 – 3,20) MPa] (Friedmanov test, $p = 0,025$). Suprotno tomu, nije pronađena statistički značajna razlika među rezovima u skupini s mikrousisavanjem gdje su srednje vrijednosti čvrstoće veze bile 1,20 MPa (0,22 – 3,11) za srednji rez, 2,51 MPa (0,89 – 4,07) za apikalni rez i 0,92 MPa (0,41 – 1,60) za koronalni rez (Friedmanov test, $p = 0,301$) (tablica 2.).

U skupini s papirnatim štapićem kohezivni neuspjesi bili su najčešći (40,0 %), a kohezivni neuspjesi također su prevladavali u skupini s alkoholom (50,0 %). U skupini s mikrousisavanjem najčešće su zabilježeni mješoviti neuspjesi (70,0 %). Kada su sve skupine procijenjene zajedno, mješoviti neuspjesi bili su najzastupljeniji (55,6 %), a slijede kohezivni (38,9 %) i adhezivni (5,6 %). Nije utvrđena statistički značajna razlika između skupina (Fisher–Freeman–Haltonov test, $p 0,337$). Kada je distribucija neuspjeha analizirana prema razini kori-

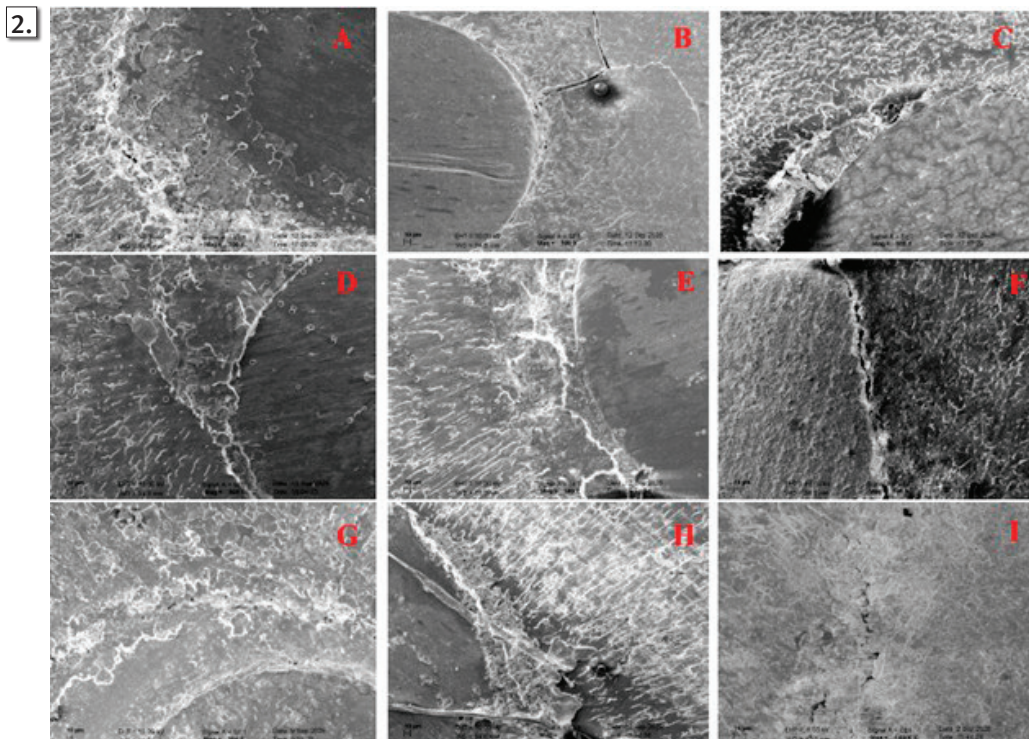


Figure 2 Representative SEM images ($\times 200$) of the dentin–sealer interface. Images labeled A–C correspond to the coronal third; D–F to the middle third; and G–I to the apical third. A, D, and G represent the Paper Point group; B, E, and H the 70% isopropyl alcohol group; and C, F, and I the Microsuction group.

Slika 2. Reprezentativne SEM slike ($\times 200$) sučelja dentina i brtvila; slike označene od A do C odgovaraju koronalnoj trećini; od D do F do srednje trećine; a od G do I do apikalne trećine; A, D i G označuju skupinu s papirnatim štapićima; B, E i H skupinu sa 70-postotnim izopropilnim alkoholom i C, F i I skupinu s mikrosukcijom

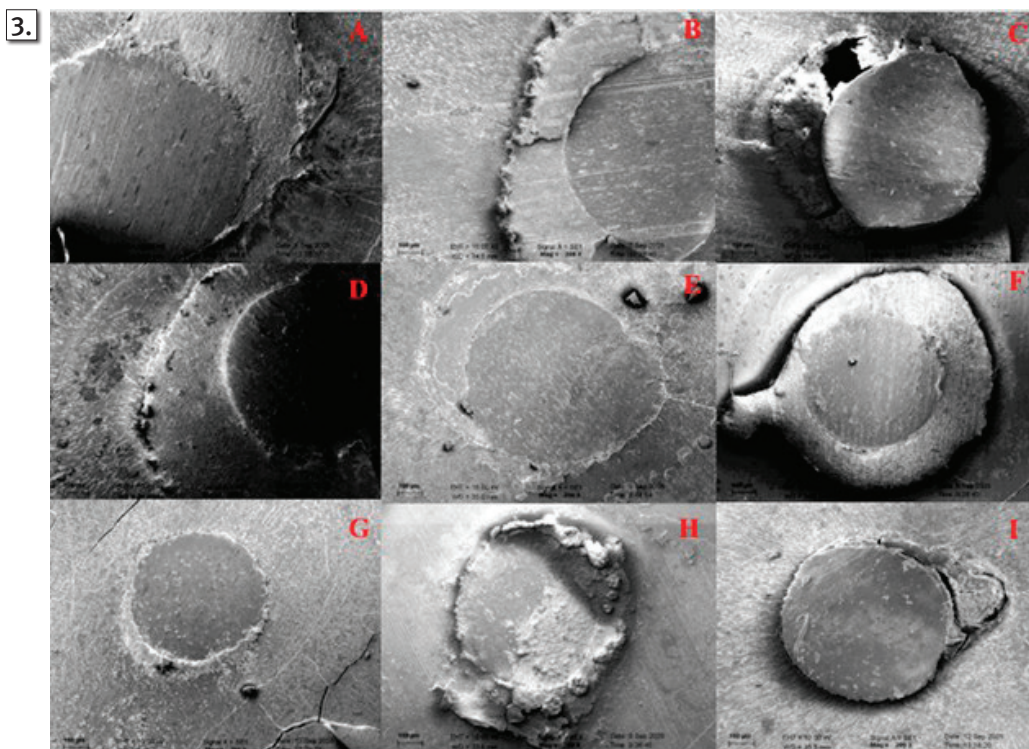


Figure 3 Representative SEM images ($\times 500$) of the dentin–sealer interface. Images labeled A–C correspond to the coronal third; D–F to the middle third; and G–I to the apical third. A, D, and G represent the Paper Point group; B, E, and H the 70% isopropyl alcohol group; and C, F, and I the Microsuction group.

Slika 3. Reprezentativne SEM slike ($\times 500$) sučelja dentina i brtvila; slike označene od A do C odgovaraju koronalnoj trećini; od D do F do srednje trećine; a od G do I do apikalne trećine. A, D i G predstavljaju skupinu s papirnatim štapićima; B, E i H skupinu sa 70-postotnim izopropilnim alkoholom; i C, F i I skupinu s mikrosukcijom.

analyzed according to the root level, no significant difference was observed among the groups (Generalized Linear Mixed Model, GLMM, $F = 1.310$; $df = 4/84$; $p = 0.273$) (Table 3).

Representative SEM images of the dentin–filling interfaces for each region (apical, middle, and coronal thirds) according to the drying protocol of each experimental group are presented in Figures 2, 3. SEM evaluation revealed that in the Alcohol and Paper Point groups, the sealer exhibited close adaptation to the root canal wall along nearly the entire interface. Particularly in the apical region, a more pronounced adhesive integrity was observed compared with other levels. In contrast, the Microsuction group demonstrated evident interfacial gaps between the filling material and the dentinal walls, as well as dentin surface areas, thus showing no contact with the sealer, especially in the coronal and middle thirds.

Discussion

This study evaluated root canal drying protocols, which represent the final stage before obturation. Previous research has investigated the effects of various drying methods on the adhesion of different types of sealers; however, the influence of moisture level on regional performance within the root has not been explored (22–24). In the present study, it was determined that drying method affected the interaction between the sealer and root dentin across different regions. In light of these findings, the null hypothesis of the study was rejected.

EndoArt Bioceramic Root Canal Sealer is a new-generation, hydrophilic, calcium silicate–based sealer that can be used either with or without gutta-percha. It is a ready-to-use, resin-free bioceramic root canal sealer composed of calcium silicate, aluminosilicate, radiopacifiers, and inert carrier substances. Similar to other calcium silicate–containing sealers, it requires moisture to set. However, there are no clear manufacturer instructions specifying the optimal level of moisture necessary for the application of calcium silicate–based sealers (25). Consequently, based on a review of the literature, various chemicals such as alcohol in different concentrations have been tested to enhance the wettability of the dentin surface (13, 14). Clinically, however, it remains unclear whether the residual moisture that persists within the dentinal tubules after conventional paper point drying adversely affects the setting reaction of these materials.

In the literature, it has been reported that the root canal drying protocol significantly influences the bond strength of calcium silicate–based sealers (12, 22, 26). Similarly, recent studies evaluating bioactive and bioglass-based root canal filling materials have demonstrated that bond strength is highly dependent on interfacial conditions and material–dentin interactions, which is consistent with the findings of the present study (27, 28). Pelozo et al. (26) demonstrated that for sealers with this composition, slightly moist canals yielded higher bond strength values compared with other drying protocols. However, some studies have found no significant differences among drying methods, or have reported that the highest bond strength values for calcium sili-

jena, nije uočena značajna razlika među skupinama (generalizirani linearni mješoviti model – GLMM, $F = 1,310$; $df = 4/84$; $p = 0,273$) (tablica 3.).

Reprezentativne SEM slike sučelja dentina i ispuna za svaku regiju (apikalna, srednja i koronarna trećina) prema protokolu sušenja za svaku eksperimentalnu skupinu nalaze se na slikama 2 i 3. Procjena SEM-om otkrila je da je u skupinama s alkoholom i papirnatim štapićima brtvilo pokazalo blisku prilagodbu stijenci korijenskog kanala duž gotovo cijele površine. Osobito je u apikalnoj regiji uočen izraženiji adhezivni integritet u usporedbi s drugim razinama. Suprotno tomu, skupina s mikrousisavanjem pokazala je evidentne međupovršinske praznine između materijala za ispune i stijenci dentina, te površine dentina koje nisu pokazivale kontakt sa sredstvom za brtvljenje, osobito u koronarnoj i srednjoj trećini.

Rasprava

U ovoj studiji procjenjivali su se protokoli sušenja korijenskog kanala za završnu fazu prije opturacije. U dosadašnjim istraživanjima analizirali su se učinci različitih metoda sušenja na prijanjanje različitih vrsta brtvila, ali utjecaj razine vlage na regionalnu izvedbu unutar korijena nije istraživano (22 – 24). U ovom je istraživanju utvrđeno da metoda sušenja utječe na interakciju između sredstva za brtvljenje i dentina korijena u različitim regijama. Na temelju tih podataka odbačena je nulta hipoteza studije.

EndoArt Bioceramic Root Canal Sealer nova je generacija hidrofilnih brtvila na bazi kalcijeva silikata koja se može koristiti s gutaperkom ili bez nje. To je biokeramičko sredstvo za brtvljenje korijenskog kanala spremno za upotrebu, bez smole je i proizvedeno od kalcijeva silikata, aluminosilikata, radiopacifikatora i inertnih nosača. Slično ostalim brtvilima koja sadržavaju kalcijev silikat, za stvrdnjavanje je potrebna vlaga. No ne postoje jasne upute proizvođača o optimalnoj razini vlage potrebne za primjenu brtvila na bazi kalcijeva silikata (25). Posljedično, razne kemikalije, kao što je alkohol u različitim koncentracijama, testirane su u literaturi kako bi se poboljšalo svojstvo vlaženja površine dentina (13, 14). No klinički ostaje nejasno utječe li zaostala vlaga koja ostaje unutar dentinskih tubula nakon konvencionalnog sušenja na papiru negativno na reakciju stvrdnjavanja tih materijala.

U literaturi je objavljeno da protokol isušivanja korijenskog kanala značajno utječe na čvrstoću veze brtvila na bazi kalcijeva silikata (12, 22, 26). Slično tomu, u nedavnim studijama u kojima se procjenjuju bioaktivni materijali i materijali za ispune korijenskih kanala na bazi biostakla, autori su pokazali da čvrstoća veze uvelike ovisi o uvjetima na površini i interakcijama između materijala i dentina, što je u skladu s nalazima u ovoj studiji (27, 28). Pelozo i suradnici (26) pokazali su da za brtvila s tim sastavom veće vrijednosti, kad je riječ o čvrstoći veze, daju blago vlažni kanali u usporedbi s drugim protokolima sušenja. Međutim, u nekim studijama autori nisu otkrili značajne razlike među metodama sušenja ili su istaknuli da su najveće vrijednosti čvrstoće veze za brtvila na bazi kalcijeva silikata dobivene nakon sušenja 70-postotnim izopropilnim alkoholom (13, 24). U literaturi se isu-

cate-based sealers were obtained after drying with 70% isopropyl alcohol (13, 24). In the literature, canal drying with paper points prior to obturation is described as producing a "normal moisture" condition, whereas solvent-based drying with isopropanol is characterized as a "dry" condition (11, 25). In addition to these two approaches, flexible silicone microcannulas were used in the present study, representing a "wet" moisture condition (11, 22). In summary, three different moisture conditions were evaluated for the EndoArt Bioceramic Root Canal Sealer, and the bond strength values obtained under each drying method were found to fall within the range reported in the literature for bioceramic sealers (29-31).

When evaluated in terms of the effect of the drying protocol on material bond strength, the specimens dried with isopropyl alcohol exhibited the highest values compared to the paper point and microsuction groups. Similar findings have been reported in previous studies, supporting these results (22, 24). It has been demonstrated in the literature that isopropyl alcohol increases dentin surface energy and facilitates more uniform penetration of the sealer into the dentinal tubules; this may partially explain higher bond strength values observed in the Alcohol group in the present study (10, 25). Although the difference between the isopropyl alcohol and paper point groups was not statistically significant, both demonstrated significantly higher bond strength than the microsuction group. In summary, the use of microcannulas during the canal drying phase did not function as an effective drying method. The inferior performance of this technique was likely due to excessive residual moisture, which may have adversely affected adhesion of the sealer.

When the bond strength values were analyzed across different root levels according to the drying methods, the highest bond strength was obtained in the apical region for all groups. Previous studies have also reported higher bond strength values in the apical third, which has been attributed to increased hydraulic pressure during obturation and the formation of a thinner, more uniform sealer layer (32). The significant differences observed among the three root regions in the Alcohol and Paper Point groups may be explained by the limited accessibility of irrigants to the apical portion and variations in dentinal tubule density (9). However, these findings are not consistent with those reported by Paula et al. (23), who observed no significant differences in bond strength among the three root regions for various sealers. The authors attributed their results to the assumption that, although dentinal tubule density differs among root levels, this variation may not be sufficient to influence the adhesion of root canal sealers. The discrepancies between the results of the two studies may be attributed to differences in the types of sealers used and the groups of teeth evaluated.

In the Paper Point group, the bond strength values in the apical slices were significantly higher than those in the middle and coronal slices, whereas in the Alcohol group, the apical slice values were significantly higher than those of the coronal slice. These findings are consistent with previous studies (21, 33). This outcome may be attributed to the improved adaptation of the gutta-percha cone in the apical re-

šivanje kanala papirnatim štapićima prije opturacije opisuje kao stvaranje uvjeta za *normalnu vlagu*, a sušenje na bazi otapala s izopropanolom smatra se *suhim* stanjem (11, 25). Uz ta dva pristupa, u ovoj studiji korištene su fleksibilne silikonske mikrokanile koje predstavljaju *mokro* stanje vlage (11, 22). Ukratko, procijenjena su tri različita uvjeta vlažnosti za *EndoArt Bioceramic Root Canal Sealer*, a utvrđeno se da vrijednosti čvrstoće veze dobivene svakom metodom sušenja nalaze unutar raspona navedenoga u literaturi za biokeramičke materijale (29 – 31).

Kada se procjenjuje, ako je riječ o učinku protokola sušenja na čvrstoću veze materijala, uzorci osušeni izopropilnim alkoholom pokazali su najviše vrijednosti u usporedbi sa skupinama s papirnatim štapićima i mikrosukcijom. Slični nalazi zabilježeni su u dosadašnjim studijama te podupiru te rezultate (22, 24). U literaturi je istaknuto da izopropilni alkohol povećava površinsku energiju dentina i olakšava ravnomjerniji prodor sredstva za brtvljenje u dentinske tubule. To može djelomično objasniti veće vrijednosti čvrstoće veze uočene u skupini s alkoholom u ovoj studiji (10, 25). Iako razlika između skupina s izopropilnim alkoholom i skupinama s papirnatim štapićima nije bila statistički značajna, obje su pokazale značajno veću čvrstoću veze od skupine s mikrosukcijom. Ukratko, korištenje mikrokanila tijekom faze sušenja kanala nije funkcioniralo kao učinkovita metoda sušenja. Inferiorna provedba te tehnike vjerojatno je bila posljedica prekomjerne zaostale vlage koja je mogla nepovoljno utjecati na prijanjanje brtvila.

Kada su vrijednosti čvrstoće veze analizirane na različitim razinama korijena prema metodama sušenja, najveća čvrstoća za sve skupine dobivena je u apeksnoj regiji. U dosadašnjim studijama također se izvješćuje o višim vrijednostima čvrstoće veze u apikalnoj trećini, što se pripisuje povećanom hidrauličnom tlaku tijekom opturacije i stvaranju tanjega, jednoličnijega sloja brtvila (32). Značajne razlike uočene među trima korijenskim regijama u skupinama s alkoholom i papirnatim štapićima mogu se objasniti ograničenom dostupnošću sredstava za ispiranje u apikalnom dijelu i varijacijama u gustoći dentinskih tubula (9). No ti nalazi nisu u skladu s onima koje su objavili Paula i suradnici (23) koji nisu uočili značajne razlike u čvrstoći veze između triju korijenskih regija za različite brtvila. Autori su svoje rezultate pripisali pretpostavki da, iako se gustoća dentinskih tubula razlikuje među razinama korijena, ta varijacija možda nije dovoljna da utječe na prijanjanje sredstava za brtvljenje korijenskih kanala. Nepodudarnosti između rezultata dviju studija mogu se pripisati razlikama u vrstama korištenih pečata i skupinama zuba koje se procjenjuju.

U skupini s papirnatim štapićima vrijednosti čvrstoće veze u apikalnim rezovima bile su značajno veće od onih u srednjim i koronalnim rezovima, a u skupini s alkoholom vrijednosti apikalnih rezova bile značajno više od onih na koronalnom rezu. Ti su nalazi u skladu su s dosadašnjim studijama (21, 33). Taj se ishod može pripisati poboljšanoj prilagodbi konusa gutaperke u apeksnoj regiji, gdje povećani hidraulični tlak olakšava učinkovitije širenje zatvarača duž stijenki kanala, što rezultira stvaranjem tanjeg sloja zatvarača (31).

gion, where increased hydraulic pressure facilitates more effective spreading of the sealer along the canal walls, resulting in the formation of a thinner sealer layer (31).

No significant difference in fracture type was observed among the different groups or root thirds evaluated in this study. Cohesive failures were the most common in both the Paper Point and Alcohol groups, while mixed failures predominated in the Microsuction group. This finding is consistent with those in previous literature (20). The low incidence of adhesive failures suggests that an adequate bond was achieved between the sealer and the dentin walls. When all groups were analyzed collectively, mixed failures were the most frequent, whereas adhesive failures were the least common. This outcome does not align with the findings of Dias et al. (9), who reported predominantly mixed failures in their study evaluating various resin-based sealers and the use of isopropyl alcohol as a final rinse. The discrepancy may be attributed to the resin-containing nature of the sealers examined in that study.

The findings obtained from the SEM analysis in this study demonstrated, in accordance with the mechanical test results, that the drying protocol directly influenced the dentin–sealer interfacial morphology. Previous studies have shown that endodontic procedures may induce surface- and microstructure-related changes in dental materials and instruments, which can indirectly influence material–substrate interactions and bonding behavior (34). The homogeneous bonding formations, continuous intimate contact along the interface, and minimal void formation observed in the Alcohol and Paper Point groups were consistent with their higher bond strength values and predominantly cohesive failure patterns (35, 36). Higher bond strength values observed particularly in the apical region were further supported by the intense adhesive penetration evident in the SEM images. In contrast, the Microsuction group exhibited irregular adhesion, large interfacial gaps, and a pronounced lack of continuity between the sealer and dentin surfaces. This morphological inadequacy corresponded to the significantly lower bond strength and the higher incidence of mixed failure modes observed in the mechanical tests. These findings indicate that an effective drying protocol not only enhances sealer adaptation but also plays a decisive role in determining the overall bonding quality.

This study stands out to address a relatively underexplored topic in the literature through a robust methodological approach. The use of the push-out test to evaluate root canal adhesion provides a simulation of shear forces similar to those encountered clinically, as the fracture occurs parallel to the bonding interface (28). Additionally, SEM imaging was employed to achieve a more comprehensive understanding of the root canal topography and the interaction between the tested factors and root dentin. However, certain limitations should be acknowledged. First, although efforts were made to simulate clinical conditions, the laboratory environment cannot fully replicate biological variables such as dynamic moisture fluctuations, tissue fluids, and temperature changes present in the oral cavity. Second, only one type of bioceramic sealer and standardized root canal morphology were used; therefore, the

Nije uočena značajna razlika u vrsti prijeloma među različitim skupinama ili trećinama korijena procijenjenima u ovoj studiji. Kohezivni neuspjesi bili su najčešći u skupinama s papirnatim štapićem i alkoholom, a mješoviti su prevladavali u skupini s mikrousisavanjem. Ovaj je nalaz u skladu s dosadašnjom literaturom (20). Niska učestalost neuspjele adhezije sugerira da je postignuta odgovarajuća veza između plombe i stijenki dentina. Kada su sve skupine analizirane zajedno, mješoviti neuspjesi bili su najčešći, a neuspjelo lijepljenje bilo je najrjeđe. Taj ishod nije u skladu s nalazima Diasa i suradnika (9) koji su izvijestili o pretežno mješovitim neuspjesima u svojoj studiji koja je procjenjivala različita brtvila na bazi smole i korištenje izopropilnog alkohola za posljednje ispiranje. Razlika se može pripisati prirodi brtvila ispitanih u toj studiji koja sadržava smolu.

Nalazi dobiveni SEM analizom u ovoj studiji pokazali su, u skladu s rezultatima mehaničkog ispitivanja, da je protokol sušenja izravno utjecao na morfologiju površine dentina i brtvila. U dosadašnjim studijama autori su pokazali da endodontski postupci mogu prouzročiti promjene povezane s površinom i mikrostrukturom dentalnih materijala i instrumenata, što može neizravno utjecati na interakcije materijal-supstrat pri vezivanju (34). Homogene formacije vezivanja, kontinuirani tijesni kontakt duž sučelja i minimalno stvaranje praznina uočeno u skupinama s alkoholom i papirnatim štapićima, bile su u skladu s njihovim višim vrijednostima čvrstoće veze i pretežno kohezivnim obrascima neuspjeha (35, 36). Veće vrijednosti čvrstoće spoja, uočene posebno u apikalnoj regiji, dodatno su potkrijepljene intenzivnim prodiranjem ljepljivosti vidljivom na SEM slikama. Suprotno tomu, skupina s mikrousisavanjem pokazala je nepravilnu adheziju, velike međupovršinske razmake i izraženi nedostatak kontinuiteta između pečata i površina dentina. Ta morfološka neadekvatnost odgovarala je značajno nižoj čvrstoći veze i većoj učestalosti mješovitih neuspjeha uočenih tijekom mehaničkih ispitivanja. Ti nalazi pokazuju da učinkoviti protokol sušenja ne samo da poboljšava prilagodbu brtvila, nego je također iznimno važan u određivanju ukupne kvalitete lijepljenja.

Ova se studija ističe po tome što se bavi razmjerno nedovoljno istraženom temom u literaturi na temelju snažnoga metodološkog pristupa. Korištenje tzv. *push-out* testa/testa istiskivanja za procjenu adhezije korijenskog kanala omogućuje simulaciju posmičnih sila sličnih onima koje se klinički susreću, zato što se prijelom događa paralelno s granicom spajanja (28). Uz to, korišteno je SEM snimanje da bi se postiglo sveobuhvatnije razumijevanje topografije korijenskog kanala i interakcije između testiranih čimbenika i korijenskog dentina. No treba priznati određena ograničenja. Prvo, iako su uloženi napor da se simuliraju klinički uvjeti, laboratorijsko okruženje ne može u cijelosti replicirati biološke varijable kao što su dinamičke fluktuacije vlage, tkivne tekućine i temperaturne promjene u usnoj šupljini. Drugo, korištena je samo jedna vrsta biokeramičkog brtvila i standardizirana morfologija korijenskog kanala; zato se nalazi ne mogu izravno generalizirati na kliničke slučajeve koji uključuju različite kemijske sastave ili složenu anatomiju korijena. Nadalje, SEM procjene provedene su na kvalitativnoj razini,

findings may not be directly generalizable to clinical cases involving different chemical compositions or complex root anatomies. Furthermore, SEM evaluations were conducted at a qualitative level, and no quantitative morphometric analysis was performed. Future studies incorporating multiple sealers and additional methods to assess long-term bonding performance, such as nanoleakage or fatigue resistance tests, are recommended to enhance the clinical relevance and generalizability of research findings.

Conclusion

Within the limitations of this *in vitro* study, it was determined that the root canal drying method influenced the bond strength of the bioceramic sealer to dentin. Higher bond strength values and superior interfacial adaptation were observed in groups dried with 70% isopropyl alcohol and paper points; whereas specimens dried using the microsuction technique exhibited markedly lower values. In conclusion, when using the bioceramic-based EndoArt sealer, the optimal moisture condition for achieving ideal push-out bond strength can be defined as a “normal or dry moisture” environment.

Conflict of Interest: The authors declare that they have no conflict of interest.

Author's contribution: I. O. – designing and creating the study, collecting, analysis and interpretation of data, critical revision of the text; N. S. E. – data analysis and interpretation, writing and critical revision of the text; B. C. – study design and data collection and interpretation, writing and critical revision of the text; H. S. O. – study design and data collection and analysis, writing and critical revision of the text. All authors have given final approval and agree to be responsible for all aspects of the work.

a kvantitativna morfometrijska analiza nije obavljena. Preporučuju se nove studije koje bi uključivale više brtvila i dodatne metode za procjenu dugotrajne učinkovitosti lijepljenja, kao što su nanopropuštanje ili testovi otpornosti na zamor, kako bi se poboljšala klinička relevantnost i mogućnost generalizacije nalaza.

Zaključak

Unutar ograničenja ove studije *in vitro* utvrđeno je da je metoda sušenja korijenskog kanala utjecala na čvrstoću veze biokeramičkog sredstva za brtvljenje dentinom. Veće vrijednosti čvrstoće veze i superiorna prilagodba međupovršine uočene su u skupinama osušenim 70-postotnim izopropilnim alkoholom i papirnatim štapićima, a uzorci osušeni tehnikom mikrousisavanja pokazali su znatno niže vrijednosti. Zaključno, kada se koristi brtvilo na bazi biokeramike EndoArt, optimalni uvjeti vlažnosti za postizanje idealne čvrstoće prijanjanja mogu se definirati kao okruženje *normalne ili suhe vlage*.

Sukob interesa: Autori nisu bili u sukobu interesa.

Doprinos autora: I. O. – koncipiranje i izrada studije, prikupljanje, analiza i interpretacija podataka, kritičko revidiranje teksta; N. S. E. – analiza i interpretacija podataka, pisanje i kritičko revidiranje teksta; B. C. – dizajn studije te prikupljanje i interpretacija podataka, pisanje i kritičko revidiranje teksta; H. S. O. – dizajn studije te prikupljanje i analiza podataka, pisanje i kritičko revidiranje teksta. Svi autori dali su konačno odobrenje i suglasni su da odgovaraju za sve aspekte rada.

Sažetak

Cilj: Željelo se procijeniti učinke sušenja papirnatim štapićem, te utjecaj mikrousisavanja i 70-postotnog izopropilnog alkohola na čvrstoću veze istiskivanjem te međupovršinska adaptacija prethodno miješanoga biokeramičkog punila. **Materijali i metode:** Trideset izvađenih maksilarnih središnjih sjekutića pripremljeno je s pomoću nikal-titanijskih (NiTi) rotacijskih instrumenata i irigirano NaOCl-om i EDTA-om. Uzorci su nasumično raspoređeni u tri skupine (n = 10): sušenje papirnatim štapićem, mikrousisavanje ili 70-postotni izopropilni alkohol. Korištenjem tehnike jednog konusa, svi su kanali opturirani biokeramičkim punilom na bazi kalcijeva silikata. Poslije jednodnevne inkubacije rezovi korijena iz koronalne, srednje i apikalne trećine (n = 90) podvrgnuti su ispitivanju čvrstoće veze istiskivanjem. Načini loma procijenjeni su stereomikroskopski, a odabrani uzorci analizirani su skenirajućom elektronskom mikroskopijom (SEM). Statistička analiza obavljena je korištenjem neparametrijskih testova ($\alpha = 0,05$). **Rezultati:** Protokol sušenja znatno je utjecao na čvrstoću veze ($p < 0,001$). Skupine s izopropilnim alkoholom (3,23 MPa) i papirnatim vrhom (2,97 MPa) pokazale su znatno veću čvrstoću veze od skupine s mikrosukcijom (1,23 MPa). Apikalni presjeci pokazali su veću čvrstoću veze od koronalnih i srednjih presjeka. Prevladavali su miješani neuspjesi, a oni kohezijski bili su češći u skupinama s alkoholom i papirnatim štapićem. SEM je u tim skupinama otkrio poboljšanu prilagodbu brtvila i dentina s manje međupovršinskih praznina. **Zaključak:** Adhezija biokeramičkog brtvila snažno je pod utjecajem metode sušenja. Sušenje papirnatim štapićem i izopropilnim alkoholom poboljšava čvrstoću veze i međupovršinsku prilagodbu, a mikrosukcijom se postižu lošije performanse.

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