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Changes in the Surface Area and Volume of Hyflex EDM Instruments after Multiple Uses

Promjene površine i volumena instrumenata Hyflex EDM poslije višestruke upotrebe

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Abstract

Objective: The aim of the study was to evaluate the surface areas and volumes of HyFlex EDM (HEDM) nickel-titanium (NiTi) files before and after multiple uses in mandibular molar root canal preparation. **Materials and methods:** Twelve HEDM files with sizes of 10/.05 and 25/.08 were evaluated by micro–CT before and after a single use or multiple uses in root canal preparation. The mesiobuccal and mesiolingual root canals of thirty-six human mandibular molar teeth were instrumented using twelve 10/.05 (300 rpm and 1.8 Ncm) and twelve 25/.085 Ncm) HEDM files according to the manufacturer's recommendation. HEDM files were evaluated using micro–CT at four different timelines: 1) Intact file, 2) After instrumentation of one canal, 3) After instrumentation of two canals, and 4) After instrumentation of three canals. Each group's volume and surface area were analyzed by applying Friedman's test. Each group comparison was assessed using the Wilcoxon signed-rank test with Bonferroni correction. **Results:** Intact HEDM 10/.05 and HEDM 25/.08 files showed significantly larger volumes and surface areas compared to the used instruments ($p<0.05$). **Conclusions:** A significant decrease in the volume and surface area of the NiTi files was observed as the number of uses increased regardless of the file group. These findings emphasize the importance for clinicians to understand the structural changes in HEDM files during repeated use to ensure safe instrument reuse and prevent endodontic treatment failure.

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Introduction

Nickel titanium (NiTi) rotary file systems are frequently used to prepare root canals due to their excellent cutting ability and flexibility. (1, 2) Despite these advantages, files are exposed to pressure and stress during root canal treatment. These stresses cause cyclic fatigue, thus leading to sudden breakage or distortions in the instruments (3) and negatively affecting the outcome of root canal treatment (4).

Uvod

Rotacijski sustavi instrumenata od nikla i titanija (NiTi) često se upotrebljavaju za pripremu korijenskih kanala zbog izvrsnog svojstva rezanja i fleksibilnosti (1, 2). Unatoč tim prednostima, tijekom obrade korijenskog kanala, instrumenti su izloženi pritisku i naprezanju. Ta naprezanja uzrokuju ciklički zamor, što rezultira iznenadnim puknućem ili deformacijom instrumenata (3) i negativno utječe na ishod endodontskog liječenja (4).

There are many factors that increase the susceptibility to fracture of root canal files. While fabricating files, cracks, grooves, and pits often form on the instrument surface. (5) These areas are stress-inducing and can result in instrument breakage during clinical use. (6) HyFlex EDM (HEDM; Coltene/Whaledent) is produced from a controlled memory (CM) alloy using electrical discharging machining (EDM) technology. EDM technology is based on a noncontact thermal erosion process that partially melts and evaporates a wire through high-frequency spark discharges (7). By creating a unique shape on a file surface, the file can exhibit high abrasion resistance and good mechanical properties (8). The files produced with this method are stronger and up to 700% more resistant to cyclic fatigue compared to those produced with other methods. In addition, these features reduce file usage during root canal preparation while preserving original anatomical forms.

NiTi files might be used more than once in dental practice for financial reasons; however, studies have reported that long-term clinical use of NiTi files significantly reduces cyclic fatigue resistance (9-11). Currently, it is not possible to establish a definitive guideline regarding the safe number of uses for rotary NiTi files, as this varies depending on factors such as the type of tooth, operator, and root canal anatomy. Nonetheless, there is a clear trend toward advocating for the single-use of rotary NiTi files during root canal treatments (12). HEDM files return to their original shape after sterilization. If the files do not return to their original shape after sterilization, their use is not recommended (8). The irregularities on the surface of intact HEDM files do not cause risk on file surface preservation after repeated use due to noncontact production of NiTi files with EDM technology (13). The spark-machined surface was shown to remain unaffected after multiple uses, confirming a high wear resistance in previous studies (8). However, there are no studies in the literature on the post-use changes in surface area and volume of HEDM rotary files. The aim of this study was to evaluate the surface areas and volumes of HEDM files before and after three instances of instrumental use with microcomputed tomography (micro–CT). The null hypothesis of the study was that there would be no significant changes in the volume and surface area of HEDM rotary files after repeated use compared to their pre-use measurements.

Materials and methods

Sample size calculation

The sample size for this study was calculated using software (G * Power 3.1.7 for Windows; Heinrich Heine, University of Dusseldorf, Dusseldorf, Germany), and the t test for 2 independent groups was selected with an alpha-type error of.05 and a beta power of 0.95 for all variables. A previous study was used to determine an effect size (f) of 1.71 (13). The minimum sample size required was seven specimens per group. The sample size was increased to twelve files per group after considering the potential risk of file fracture during root canal preparation and the possibility that the files would not return to their original shape after autoclaving.

Mnogo je čimbenika koji povećavaju osjetljivost na puknuće instrumenata za obradu korijenskih kanala. Tijekom izrade na površini instrumenta često se stvaraju pukotine, žljebovi i udubljenja (5). Ta područja izazivaju naprezanje i mogu potaknuti slamanje instrumenta tijekom kliničke upotrebe (6). HyFlex EDM (HEDM; Coltene/Whaledent) proizvodi se od legure s kontroliranom memorijom (CM) primjenom tehnologije elektroerozijske obrade (EDM). EDM tehnologija temelji se na beskontaktnom procesu toplinske erozije koji djelomično topi i isparava žicu putem visokofrekventnih iskri (7). Stvaranjem jedinstvenog oblika na površini instrumenta on može pokazati visoku otpornost na abraziju i dobra mehanička svojstva (8). Instrumenti proizvedeni tom metodom jači su i do 700 % otporniji na ciklički zamor u odnosu prema onima proizvedenim drugim metodama. Te značajke smanjuju trošenje instrumenata tijekom obrade korijenskog kanala, a istodobno čuvaju izvorne anatomske oblike.

NiTi instrumenti mogu se upotrijebiti više puta u stomatološkoj praksi iz financijskih razloga, no istraživanja su pokazala da njihova dugotrajna klinička primjena znatno smanjuje otpornost na ciklički zamor (9 – 11). Trenutačno nije moguće utvrditi konačne smjernice o sigurnom broju upotrebe rotacijskih NiTi instrumenata zato što to varira ovisno o čimbenicima kao što su vrsta zuba, operater i anatomija korijenskog kanala. Ipak, postoji jasan trend zagovaranja jednokratne upotrebe rotacijskih NiTi instrumenata tijekom endodontskog liječenja (12). Instrumenti HEDM vraćaju se u svoj izvorni oblik nakon sterilizacije. Ako se to ne dogodi, njihova se upotreba ne preporučuje (8). Neravnine na površini intaktnih instrumenata HEDM nisu rizične za očuvanje njihove površine poslije ponovljene upotrebe zbog beskontaktne proizvodnje NiTi instrumenata EDM tehnologijom (13). Pokazalo se da površina obrađena iskrom ostaje nepromijenjena nakon višestruke upotrebe, što u prethodnim istraživanjima potvrđuje visoku otpornost na trošenje (8). No u literaturi nema istraživanja o promjenama površine i u volumenu rotacijskih instrumenata HEDM nakon upotrebe. Cilj ovog istraživanja bio je mikroračunalnom tomografijom (mikro-CT) procijeniti površine i volumene instrumenata HEDM prije i poslije triju upotreba. Nulta hipoteza istraživanja bila je da neće biti znatnih promjena volumena i površine rotacijskih instrumenata HEDM poslije ponovljene upotrebe u usporedbi s njihovim mjerenjima prije upotrebe.

Materijali i metode

Izračun veličine uzorka

Veličina uzorka za ovo istraživanje izračunata je s pomoću softvera (G * Power 3.1.7 za Windows; Heinrich Heine, Sveučilište Düsseldorf, Düsseldorf, Njemačka), a t-test za dvije neovisne skupine odabran je s alfa-tipom pogreške od 0,05 i beta snagom od 0,95 za sve varijable. Prethodno istraživanje korišteno je za određivanje veličine učinka (f) od 1,71 (13). Minimalna potrebna veličina uzorka bila je sedam uzoraka po skupini. Veličina uzorka povećana je na dvanaest instrumenata po skupini nakon što se uzeo u obzir potencijalni rizik od puknuća instrumenata tijekom obrade korijenskog kanala i mogućnost da se nakon autoklaviranja instrumenti neće vratiti u prvotni oblik.

Sample selection

After the study received ethical approval by the Ankara Yıldırım Beyazıt University IRB Committee (2019-336), 36 mandibular molar teeth featuring mesial roots with Vertucci's type IV(Two unique and independent canals from the orifice to the root apex) canal configurations (14) and curvature angles between 20° and 40° (15) were selected from a pool of extracted human teeth. The homogeneous distribution of the teeth and their compliance with the inclusion criteria were confirmed using digital periapical radiography and micro–CT (16). The inclusion criteria were as follows: teeth that had not undergone root canal treatment before, mature roots, no diagnoses such as root caries or internal or external resorption, and no calcification, cracks or fractures. The crowns of the teeth were removed from the enamel–cement junction with a diamond bur (Diatech, Charleston, U.S. A) by water cooling; the root length was 12±0.5 mm.

Sample preparation

The sizes of the access cavities were uniformly prepared in all samples. After access cavity preparation, the working length (WL) was determined by measuring the length of the #10 K-file (Dentsply, Maillefer, Ballaigues, Switzerland) when its tip became visible at the apical foramen. HEDM files were used with a VDW Gold (VDW, Munich, Germany) endodontic motor. The mesiobuccal and mesiolingual root canals of thirty-six human mandibular molar teeth were filed using 10/.05 (300 rpm and 1.8 Ncm) and 25/.085 Ncm) HEDM files according to the manufacturer's recommendations. The shank parts of the files were marked with an ISO 014 diamond bur (Strauss & Co, Industrial Diamonds Ltd, Ra'anana, Israel) to assess the same area in each instrument during a micro–CT analysis.

The root canals were irrigated using 5 mL of 3% sodium hypochlorite (NaOCl; CanalPro, Coltene/Whaledent, Germany) during instrumentation. In total, 20 mL of 3% NaOCl was used for each sample. The debris on the surface of the file was wiped off with alcohol-soaked gauze after each use.

One set of new HEDM files (10/.05 and 25/.08) was used to prepare two root canals (mesiolingual and mesiobuccal) on each of the three mandibular molar teeth, totaling six root canals per set of instruments. After filing the mesial canals of each mandibular molar tooth, the files were washed with 5 mL of distilled water to remove accumulated debris. They were then cleaned in an ultrasonic bath containing detergent (acetone, ethanol, and deionized water) and sterilized at 134 °C for 4 minutes at 30 psi before being used on the next canal (17). All procedures in this experiment were conducted by a single experienced endodontist to maintain consistency in technique and outcomes.

The changes in the spirals and surfaces of the files were examined at 40X magnification under a dental operating microscope (OMS 2350, Zumax, Jiangsu, China). The files with spirals that returned to their original shape during sterilization were used to prepare the root canals of the next sample.

Odabir uzorka

Nakon što je istraživanje dobilo etičko odobrenje odbora IRB-a Sveučilišta Ankara Yıldırım Beyazıt (2019.-336), među izvađenim ljudskim zubima odabrano je 36 donjih kutnjaka s mezijalnim korijenima s Vertuccijevom konfiguracijom kanala tipa IV (dva odvojena i neovisna kanala od otvora do vrha korijena) (14) i kutovima zakrivljenosti između 20° i 40° (15). Homogena raspodjela zuba i njihova usklađenost s kriterijima za uključivanje potvrđene su digitalnom periapikalnom radiografijom i mikro-CT-om (16). Kriteriji za uključivanje bili su sljedeći: zubi koji nisu bili podvrgnuti endodontskom liječenju, zreli korijeni, bez dijagnoza poput karijesa korijena ili unutarnje ili vanjske resorpcije te bez kalcifikacija, pukotina ili fraktura. Krune zuba uklonjene su na mjestu spoja cakline i cementa dijamantnim svrdlom (Diatech, Charleston, SAD) uz hlađenje vodom; duljina korijena bila je 12 ± 0,5 mm.

Priprema uzorka

Veličine pristupnih kaviteta bile su jednoliko preparirane u svim uzorcima. Nakon preparacije pristupnog kaviteta, radna duljina (WL) određena je mjerenjem duljine K-instrumentom #10 (Dentsply, Maillefer, Ballaigues, Švicarska) kada je njegov vrh postao vidljiv na apikalnom foramenu. Instrumenti HEDM korišteni su s endodontskim motorom VDW Gold (VDW, München, Njemačka). Meziobukalni i meziolingvalni korijenski kanali trideset šest ljudskih donjih kutnjaka obrađeni su instrumentima HEDM 10/.05 (300 o/min i 1,8 Ncm) i 25/.085 Ncm) prema preporuci proizvođača. Dijelovi držaka instrumenata označeni su dijamantnim svrdlom ISO 014 (Strauss & Co, Industrial Diamonds Ltd, Ra'anana, Izrael) kako bi se analizom mikro-CT-om procijenilo isto područje na svakom instrumentu.

Korijenski kanali irigirani su s 5 mL 3-postotnoga natrijeva hipoklorita (NaOCl; CanalPro, Coltene/Whaledent, Njemačka) tijekom instrumentacije. Ukupno je za svaki uzorak korišteno 20 mL 3-postotnoga NaOCl-a. Ostatci s površine instrumenta obrisani su nakon svake upotrebe gazom natopljenom alkoholom.

Jedan set novih instrumenata HEDM (10/.05 i 25/.08) korišten je za obradu dvaju korijenskih kanala (meziolingvalnoga i meziobukalnoga) na svakom od triju donjih kutnjaka, što je ukupno šest korijenskih kanala. Instrumenti su isprani s 5 mL destilirane vode da bi se uklonili nakupljeni ostatci. Zatim su očišćeni u ultrazvučnoj kupki koja je sadržavala deterdžent (aceton, etanol i deionizirana voda) i 4 minute sterilizirani na 134 °C pod tlakom od 30 psi prije upotrebe u sljedećem kanalu (17). Sve postupke u ovom eksperimentu proveo je jedan iskusni endodont kako bi se održala dosljednost u tehnici i rezultatima.

Promjene u spiralama i površinama instrumenata analizirane su pri povećanju od 40 x pod stomatološkim operacijskim mikroskopom (OMS 2350, Zumax, Jiangsu, Kina). Instrumenti sa spiralama koje su se vratile u prvotni oblik tijekom sterilizacije upotrijebljeni su za obradu korijenskih kanala sljedećeg uzorka.

Micro–CT analysis

The sizes (10/.05 and 25/.08) of each new HEDM file and those used multiple times were evaluated by micro–CT (SkyScan 1274, SkyScan, Aartselaar, Belgium) four times: when intact, after filing one canal, after filing two canals and after filing three canals. Samples were scanned with a resolution of 33 µm, exposure time of 50 ms, and rotation of 0.4°. The electrical values applied to the X-ray source during scanning were 50 kV and 800 µa. Data were reconstructed with NRecon (NRecon version 1.6.9.4; Skyscan), and transverse sections were obtained. Then, the surface properties were analyzed with CTan (CTan version 1.13.5.1; Skyscan). Three-dimensional models were created using CTvol (CTvol version 1.7.4.2; Skyscan).

Statistical Analysis

Data were first analyzed using the Shapiro–Wilk test to verify the assumption of normality; the data were not normally distributed. The volume and surface area in each file group were analyzed by applying Friedman's test. Each group comparison was assessed using the Wilcoxon signed rank test with Bonferroni correction. Statistical analyses were performed using SPSS 21.0 (IBM - SPSS Inc., Chicago, IL, USA) software, and the statistical significance level was $P < 0.05$.

Results

No fractures occurred in any HEDM files during root canal preparation. Figures 1 and 2 show the three-dimensional (3D) micro-CT superimposition of pre- and post-use images of the HEDM 10/.05 and HEDM 25/.08 files, respectively. These images show the surface alterations of the instruments after repeated clinical use. Color coding is used to differentiate the file surfaces: intact instruments are shown

Analiza mikro-CT-om

Veličine (10/.05 i 25/.08) svakoga novog instrumenta HEDM i onih korištenih više puta procijenjene su mikro-CT-om (SkyScan 1274, SkyScan, Aartselaar, Belgija) četiri puta: kada su bile intaktne, poslije instrumentacije jednog kanala, poslije instrumentacije dvaju kanala i poslije instrumentacije triju kanala. Uzorci su skenirani u rezoluciji od 33 µm, s vremenom ekspozicije od 50 ms i rotacijom od 0,4°. Električne vrijednosti primijenjene na izvor X-zraka tijekom skeniranja bile su 50 kV i 800 µa. Podatci su rekonstruirani s pomoću NRecona (NRecon verzija 1.6.9.4; Skyscan) i dobiveni su poprečni presjeci. Zatim su površinska svojstva analizirana s pomoću CTana (CTan verzija 1.13.5.1; Skyscan). Trodimenzionalni modeli izrađeni su s pomoću CTvola (CTvol verzija 1.7.4.2; Skyscan).

Statistička analiza

Podatci su najprije analizirani Shapiro-Wilkovim testom kako bi se provjerila pretpostavka normalnosti; podatci nisu bili normalno distribuirani. Volumen i površina u svakoj skupini instrumenata analizirani su primjenom Friedmanova testa. Svaka usporedba skupina procijenjena je Wilcoxonovim testom rangova s Bonferronijevom korekcijom. Statističke analize provedene su u SPSS-u 21.0 (IBM - SPSS Inc., Chicago, IL, SAD) softvera, a razina statističke značajnosti bila je $P < 0,05$.

Rezultati

Nisu zabilježene frakture ni na jednom instrumentu HEDM tijekom obrade korijenskih kanala. Na slikama 1. i 2. trodimenzionalna (3D) je mikro-CT superpozicija slika prije i poslije upotrebe instrumenta HEDM 10/.05 i HEDM 25/.08. Ove slike pokazuju promjene na površini instrumenata nakon ponovljene kliničke upotrebe. Kodiranje bojama korišteno je za razlikovanje površina instrumenta: intaktni

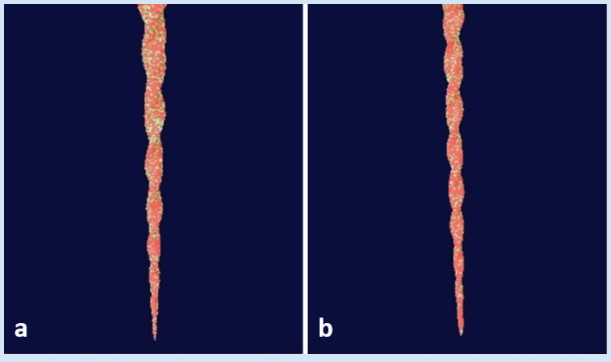

Figure 1 Representative three-dimensional (3D) micro-CT reconstructions of HEDM 10/.05 instrument. Color-coded instrument surface indicates a) Intact (green) and after single-use (red) b) After second-use (green) and after third-use (red) of the instrument.

Slika 1. Reprezentativne trodimenzionalne (3D) mikro-CT rekonstrukcije instrumenta HEDM 10/.05; površina instrumenta označena bojama označava a) intaktno (zeleno) i poslije jedne upotrebe (crveno) b) poslije druge upotrebe (zeleno) i poslije treće upotrebe (crveno) instrumenta

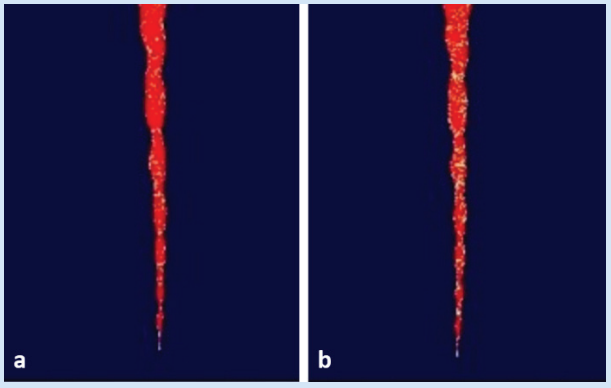

Figure 2 Representative three-dimensional (3D) micro-CT reconstructions of HEDM 25/.08 instrument. Color-coded instrument surface indicates a) Intact (green) and after single-use (red) b) After second-use (green) and after third-use (red) of the instrument.

Slika 2. Reprezentativne trodimenzionalne (3D) mikro-CT rekonstrukcije instrumenta HEDM 25/.08.; površina instrumenta označena bojama označava a) intaktno (zeleno) i poslije jedne upotrebe (crveno) b) poslije druge upotrebe (zeleno) i poslije treće upotrebe (crveno) instrumenta

in green, while the surfaces after each usage are depicted in red (1x, 2x, and 3x).

In Figure 1, the 3D reconstruction of the HEDM 10/.05 instrument highlights the changes that occur after each use. The transition from the intact state to the post-use states visually represents the reduction in surface area. Similarly, Figure 2 presents the HEDM 25/.08 instrument in 3D, thus allowing for a direct comparison of its surface integrity before and after each use, providing a reference for understanding how the performance of the instrument may be affected by continued use.

The median and interquartile range (IQR) for the volume (V) and surface area (SA) values of the HEDM 10/.05 and HEDM 25/.08 files are presented in Table 1. Based on the obtained data, the effect size value was found to be 1.25, and from this, the obtained power value was 83%.

Intact HEDM 10/.05 and HEDM 25/.08 files exhibited the highest values for both volume and surface area. With an increasing number of uses, the volume and surface area values decreased significantly ($P < 0.05$ or $P = 0.000$).

instrumenti prikazani su zelenom bojom, a površine nakon svake upotrebe prikazane su crvenom bojom (1 x, 2 x i 3 x).

Na slici 1. 3D rekonstrukcija instrumenta HEDM 10/.05 ističe promjene koje se događaju poslije svake upotrebe. Prijelaz iz intaktnog stanja u stanje poslije upotrebe vizualno označuje smanjenje površine. Slično tomu, na slici 2. je instrument HEDM 25/.08 u 3D-u pa je omogućena izravna usporedbu integriteta njegove površine prije i poslije svake upotrebe, pružajući referenciju za razumijevanje kako kontinuirana primjena može utjecati na performanse instrumenta.

Medijan i interkvartilni raspon (IQR) za vrijednosti volumena (V) i površine (SA) instrumenata HEDM 10/.05 i HEDM 25/.08 prikazani su u tablici 1. Na temelju dobivenih podataka utvrđeno je da je vrijednost veličine učinka 1,25, a iz toga je izračunata postignuta vrijednost snage od 83 %.

Intaktni instrumenti HEDM 10/.05 i HEDM 25/.08 pokazali su najviše vrijednosti i za volumen i za površinu. S povećanjem broja upotreba, vrijednosti volumena i površine značajno su se smanjile ($P < 0,05$ ili $P = 0,000$).

Table 1 The surface area and volume values of HyFlex EDM 10/.05 and HyFlex EDM 25/.08 files
Tablica 1. Vrijednosti površine i volumena instrumenata HyFlex EDM 10/.05 i HyFlex EDM 25/.08

	HyFlex EDM 10.05				HyFlex EDM 25.08			
	Surface Area • Površina		Volume • Volumen		Surface Area • Površina		Volume • Volumen	
	Median • Medijan	IQR (25th-75th) • IKR (25.-75.)	Median • Medijan	IQR (25th-75th) • IKR (25.-75.)	Median • Medijan	IQR (25th-75th) • IKR (25.-75.)	Median • Medijan	IQR (25th-75th) • IKR (25.-75.)
Intact • Intaktan	27.05+0.40^{a}	26.8-27.3	2.61+0.09^{a}	2.58-2.65	31.98+0.40^{a}	31.6-32.08	3.53+0.00^{a}	3.53-3.54
First Usage • Prva upotreba	25.84+0.43^{ab}	25.4-26.2	2.53+0.07^{ab}	2.49-2.58	30.70+0.35^{ab}	30.5-30.8	3.46+0.06^{ab}	3.42-3.47
Second Usage • Druga upotreba	24.42+0.48^{bc}	24.3-24.6	2.45+0.81^{bc}	2.41- 2.52	29.98+0.39^{bc}	29.8-30.08	3.31+0.07^{bc}	3.24-3.36
Third Usage • Treća upotreba	23.48+0.70^{c}	23.3-23.7	2.39+0.07^{c}	2.35-2.42	28.05+0.35^{c}	27.8-28.2	3.14+0.05^{c}	3.14-3.17
***P* value • *P*-vrijednost**	0.05							

*Different superscript letters indicate statistically significant differences between groups ($P < 0.05$) ($^{a, b, c, d}$ for intragroup comparasion, ^{x,y} for intergroup comparasion) • Različita slova u nadnaslovima označavaju statistički značajne razlike između skupina ($P < 0,05$) (a, b, c, d za usporedbu unutar skupine, x,y za usporedbu među skupinama)
EDM, electrical discharge machining method; IQR, interquartile range • EDM – metoda elektroerozijske obrade; IKR – interkvartilni raspon

Discussion

The changes in the surface properties of files after clinical use affect their cyclic and torsional fatigue resistance and cutting efficiency (18). Surface irregularities and blunt cutting edge can affect the cutting ability of NiTi rotary files and contribute to corrosion and material fatigue (3). Additionally, exposure to chemicals during use, as well as presterilization cleaning and multiple sterilization cycles, can deteriorate these instruments and increase their corrosion rate (19). Therefore, evaluating the surface characteristics of NiTi rotary files is essential to assess their susceptibility to damage. Some clinicians may reuse the same file while treating another tooth of the same patient out of convenience or for financial reasons (20). Scholars have reported different results regarding the maximum number of canals that can be treated with NiTi rotary files before they need to be replaced with new files (8). The recommended number of uses can

Rasprava

Promjene u svojstvima površine instrumenata poslije kliničke upotrebe utječu na njihovu otpornost na ciklički i torzijski zamor te učinkovitost rezanja (18). Neravnine površine i tupi rezni rub mogu utjecati na to kako NiTi rotacijski instrumenti režu te pridonijeti koroziji i zamoru materijala (3). Uz to, izloženost kemikalijama tijekom upotrebe i čišćenje prije sterilizacije te višestruki ciklusi sterilizacije, mogu pogoršati svojstva instrumenata i povećati njihovu stopu korozije (19). Zato je procjena površinskih značajki NiTi rotacijskih instrumenata ključna za procjenu njihove osjetljivosti na oštećenja. Neki kliničari mogu ponovno upotrijebiti isti instrument za instrumentaciju drugog zuba istog pacijenta iz praktičnih ili financijskih razloga (20). Znanstvenici su izvijestili o različitim rezultatima u vezi s maksimalnim brojem kanala koji se mogu obraditi NiTi rotacijskim instrumentima prije nego što ih je potrebno zamijeniti novima (8). Pre-

vary depending on the complexity of the root canal system being treated and the operator's technique. This research is the first study to examine changes in surface area and volume of HEDM files after multiple uses on natural teeth, using micro-CT, thus providing valuable insights into the practical implications of reusing these instruments in clinical practice. According to the results of this study, after the use of HEDM 10/.05 and HEDM 25/.08 files in root canal preparation, a decrease in volume and surface areas was observed (P <0.05). Therefore, the null hypothesis of the study was rejected.

The HEDM instruments demonstrated greater flexibility and improved resistance to cyclic fatigue when compared to the HyFlex CM, Twisted File, and K3 files in a recent study. (21) Similarly it exhibited higher cyclic fatigue resistance than Protaper Gold and K3XF (22). The unwinding of the spirals compensate for stress during their clinical use. HEDM files return to their original shape with full shape recovery and the continuous functionality following high-temperature sterilization cycles (23). This allows for multiple uses of the same file, potentially increasing their lifespan in clinical applications. However, it is essential to acknowledge that this design feature does not completely prevent the risk of degradation over time. To use files safely during clinical applications, it may be important to understand the post-production conditions and how repeated use affects surface properties, which is critical for ensuring patient safety and effective treatment outcomes. This study addresses a significant gap in the existing literature, as there are currently no micro–CT studies investigating the changes in volume and surface area of HEDM rotary files before and after multiple uses. By understanding how changes to the surface affect the performance of these instruments, clinicians can make more informed decisions about reusing files, ultimately enhancing the quality of endodontic treatments.

Artificial or natural teeth have been used in studies to examine the changes in the mechanical properties of files after root canal preparation (13). Since extracted teeth better reflect real clinical conditions than artificial teeth, extracted teeth with inclined (20°-40°) mesial canals of mandibular molar teeth were used for root canal preparation in the present study.

Studies to assess the quantitative wear amount of used rotary files utilizing microscopic images and software analysis (24). However, no study has examined the volume and surface area changes that occur on the surfaces of files using micro–CT imaging. Micro-CT provides high-resolution, 3D images, allowing for detailed quantitative assessments of volume and surface characteristics. It provides precise volumetric data by assessing the entire 3D structure of the sample. The results of our study cannot be directly compared to those of other researchers.

In studies on surface roughness in the literature, surface topographies were reported to change after the clinical use of a rotary system file, and these changes were related to erosion , cutting surface deformation, plastic deformation and microcrack formation (25). In addition, as the surface roughness increased, the tendency of the files to break increased, and the cutting efficiency decreased (26). The files were used

poručen broj upotreba može varirati ovisno o složenosti sustava korijenskih kanala koji se tretira i primijenjenoj tehnici instrumentacije. Ovo istraživanje prvo je u kojemu autori ispituju promjene površine i volumena instrumenata HEDM poslije višestruke upotrebe na prirodnim zubima, korištenjem mikro-CT-a, pružajući vrijedne uvide u praktične implikacije ponovne upotrebe tih instrumenata u kliničkoj praksi. Prema rezultatima ovog istraživanja, poslije upotrebe instrumenata HEDM 10/.05 i HEDM 25/.08 u obradi korijenskog kanala, uočeno je smanjenje volumena i površine (P < 0,05). Zato je nulta hipoteza studije odbačena.

Instrumenti HEDM u nedavno provedenom istraživanju pokazali su veću fleksibilnost i poboljšanu otpornost na ciklički zamor u usporedbi s instrumentima HyFlex CM, Twisted File i K3 (21). Također, pokazali su veću otpornost na ciklički zamor od Protaper Golda i K3XF-a (22). Odmotavanje spirala kompenzira naprezanje tijekom njihove kliničke upotrebe. Instrumenti HEDM vraćaju se u svoj izvorni oblik s potpunim oporavkom oblika i kontinuiranom funkcionalnošću nakon ciklusa sterilizacije na visokim temperaturama (23). To omogućuje višestruku upotrebu istog instrumenta, što potencijalno povećava njihov vijek trajanja u kliničkoj primjeni. Međutim, bitno je napomenuti da ta značajka dizajna ne eliminira potpuno rizik od degradacije tijekom vremena. Za sigurnu upotrebu instrumenata tijekom kliničke primjene važno je razumjeti uvjete nakon proizvodnje i kako ponovljena upotreba utječe na karakteristike površine, što je ključno za sigurnost pacijenata i učinkovitih ishoda liječenja. Ovo istraživanje treba nadopuniti praznine u postojećoj literaturi, s obzirom na to da trenutačno ne postoje mikro-CT studije koje istražuju promjene volumena i površine rotacijskih instrumenata HEDM prije i poslije višestruke upotrebe. Razumijevanjem kako promjene na površini utječu na performanse tih instrumenata, kliničari mogu donositi informiranije odluke o njihovoj ponovnoj upotrebi, što u konačnici poboljšava kvalitetu endodontskog liječenja.

U istraživanjima su upotrebljeni umjetni ili prirodni zubi za ispitivanje promjena mehaničkih svojstava instrumenata poslije obrade korijenskog kanala (13). Budući da izvađeni zubi bolje odražavaju stvarne kliničke uvjete od umjetnih, u ovom istraživanju za instrumentaciju korijenskog kanala korišteni su izvađeni zubi sa zakošenim (20° – 40°) mezijalnim kanalima donjih kutnjaka.

U istraživanjima za procjenu kvantitativnog trošenja korištenih rotacijskih instrumenata primjenjuju se mikroskopske slike i softverske analize (24). No u ni jednoj studiji autori nisu ispitali promjene volumena i površine koje se pojavljuju na površinama instrumenata korištenjem mikro-CT snimanja. Mikro-CT pruža 3D slike visoke rezolucije, što omogućuje detaljnu kvantitativnu procjenu volumena i površinskih karakteristika. Daje precizne volumetrijske podatke procjenom cijele 3D strukture uzorka. Rezultati našeg istraživanja ne mogu se izravno usporediti s rezultatima drugih istraživanja.

U istraživanjima hrapavosti površine u literaturi zabilježene su promjene u topografiji površine poslije kliničke upotrebe rotacijskih instrumenata, a te su promjene bile povezane s erozijom, deformacijom površine rezanja, plastičnom

sequentially in this study, following the manufacturer's recommendations. To reduce the stress of HEDM 25/.08, it was suggested to use HEDM 10/.05 files as the first file for mesial root curvatures in mandibular molar teeth (27). Especially at the tip of the file, HEDM 10/.05 files exhibit openings in their spirals due to stress. This effect may be due to the small-diameter files being exposed to torsional stress in root canal preparation.

Pirani et al. (8) examined the surface properties of HEDM files by SEM after the preparation of 10 molar teeth, with each file having a curvature of 50°–70°. The authors reported that none of the HEDM 25/.12 and 25/.08 files were deformed, except for slight deformations on the surfaces of the HEDM 10/.05 files. Scholars have reported that the irregularities on the surfaces of new HEDM files do not pose a danger after use. Although the authors reported that both files had oxide layers on their surfaces, they also reported that EDM may be more durable than CM, which consists of B2-austenite and B19-martensite phases, because it contains a large amount of R phase (8). While these mechanical properties are closely related to the safety and efficacy of HEDM files during clinical use, small EDM files were reported to be permanently deformed due to their higher susceptibility to torsional failure than larger instruments. Caution was recommended regarding reuse of small HyFlex EDM rotary instruments (7).

Uslu et al. (13) evaluated the changes in the surface properties of HyFlex CM 25.08 and HEDM 25/.08 files before and after use with 3D optical profilometry. Although both files tested in this study were made of CM alloy, changes occurred in the surfaces of the files after use, and the preservation of surface roughness values was observed with EDM technology.

Irrigants were found to reduce the risk of torsional fractures by reducing the torque values of Ni-Ti rotary instruments. (28) However, these instruments showed a variable increase in surface roughness after being exposed to irrigants. (29) NaOCl can cause micropitting by removing nickel from the instrument surface. This can cause corrosive areas on the NiTi instrument affecting the surface roughness. (30) Therefore, NaOCl irrigation with a concentration of 3% was chosen in the present study to reduce the amount of available chlorine that would attack the alloy. In a study, immersion in NaOCl reduced the cyclic fatigue resistance of ProTaper Next, Hyflex CM, and HEDM instruments, with a greater effect observed on those made from CM wire (31).

Changes in the surface structures of EDM files might occur due to sterilisation periods (18). Repeated sterilization contributes to surface roughness and changes in mechanical characteristics. Hyflex EDM and WaveOne Gold files were reported to show similar surface changes when subjected to multiple usage and autoclaving cycles (32). In a study in which the changes on the surfaces of HEDM files during autoclave sterilization were examined with atomic force microscopy, the surface roughness of the new brand HEDM file was reported to change at a low level after the first sterilization, and the surface roughness increased significantly after the fifth sterilization (18). After being applied as in-

deformacijom i stvaranjem mikropukotina (25). Uz to, kako se hrapavost površine povećavala, tako je rasla tendencija puknuća instrumenata, a smanjivala se učinkovitost rezanja (26). Instrumenti su se u ovom istraživanju upotrebljavali sekvencijalno, prema preporukama proizvođača. Kako bi se smanjilo naprezanje HEDM-a 25/.08, predloženo je korištenje instrumenta HEDM 10/.05 kao prvog za mezijalne zakrivljenosti korijena kod donjih kutnjaka (27). Posebno na vrhu, instrumenti HEDM 10/.05 pokazuju otvore u svojim spiralama zbog naprezanja. Taj učinak može biti posljedica izloženosti instrumenta malog promjera torzijskom naprezanju tijekom obrade korijenskog kanala.

Pirani i suradnici (8) analizirali su površinska svojstva instrumenata HEDM s pomoću SEM-a poslije instrumentacije 10 kutnjaka, pri čemu je svaki instrument imao zakrivljenost od 50° do 70°. Autori su izvijestili da nijedan instrument HEDM 25/.12 i 25/.08 nije bio deformiran, osim blagih deformacija na površinama instrumenta HEDM 10/.05. Znanstvenici su izvijestili da nepravilnosti na površinama novih HEDM instrumenata ne predstavljaju opasnost nakon upotrebe. Iako su autori izvijestili da oba instrumenta imaju oksidne slojeve na svojim površinama, također su istaknuli da EDM može biti trajniji od CM-a koji se sastoji od faza B2-austenita i B19-martenzita jer sadržava veliku količinu R-faze (8). Iako su ta mehanička svojstva usko povezana sa sigurnošću i učinkovitošću instrumenata HEDM tijekom kliničke upotrebe, zabilježeno je da su mali instrumenti EDM trajno deformirani zbog njihove veće osjetljivosti na torzijsko puknuće u usporedbi s većim instrumentima. Preporučen je oprez u vezi s ponovnom upotrebom malih rotacijskih instrumenata HyFlex EDM (7).

Uslu i suradnici (13) procijenili su 3D optičkom profilometrijom promjene površinskih svojstava HyFlex CM 25.08 i instrumenata HEDM 25/.08 prije i poslije upotrebe. Iako su oba instrumenta testirana u ovom istraživanju bila izrađena od CM legure, poslije upotrebe uočena je promjena na njihovim površinama, a očuvanje vrijednosti hrapavosti površine utvrđeno je tehnologijom EDM.

Utvrđeno je da iriganti smanjuju rizik od torzijskih puknuća smanjenjem vrijednosti momenta sile rotacijskih Ni-Ti instrumenata (28). No ti instrumenti pokazali su varijabilno povećanje hrapavosti površine nakon izlaganja irigantima (29). NaOCl može prouzročiti mikrorupice uklanjanjem nikla s površine instrumenta. To može prouzročiti korozivna područja na NiTi instrumentu koja utječu na hrapavost površine (30). Stoga je u ovoj studiji odabrano ispiranje NaOCl-om u koncentraciji od 3 % kako bi se smanjila količina dostupnog klora koji bi nagrizao leguru. U jednoj studiji je uranjanje u NaOCl smanjilo otpornost na ciklički zamor instrumenata ProTaper Next, Hyflex CM i HEDM, s većim učinkom uočenim na onima izrađenim od CM žice (31).

Promjene površinske strukture instrumenta EDM mogu se pojaviti zbog sterilizacije (18). Ponovljena sterilizacija pridonosi hrapavosti površine i promjenama mehaničkih karakteristika. Istaknuto je da instrumenti Hyflex EDM i WaveOne Gold pokazuju slične promjene na površini kada su podvrgnuti višestrukoj upotrebi i ciklusima autoklaviranja (32). U studiji u kojoj su promjene na površinama instrume-

struments, heating and severe deformation in the canal, a decrease in hardness and an increase in the elastic moduli of the EDM files were observed. These results were explained by the re-dissolution of the Ni_4Ti_3 phase and the stress-induced martensitic transformation of some austenite into an additional R-phase, which is consistent with the phase changes observed in the EDM files used (23). In this study, the files were sterilized by autoclave after each use to mirror the conditions of actual clinical use as much as possible. The decreases in the surface area and volume values of the files and the effects of sterilization on the deformations on the surface can be explained in this manner.

Considering the limitations of controlled laboratory conditions, the setting may not fully replicate the complex biological and mechanical interactions present *in vivo*, thus making it difficult to directly correlate the findings to the clinical performance of the instruments. Potential biases from operator variables and the anatomical canal configuration of mandibular molars may limit the applicability of findings to other types of teeth with different canal anatomies (33). Further research considering a diverse range of operators and anatomical canal variations is needed to enhance the generalizability of these results.

Although the results of the study show that the volume and surface area changes could be analyzed using micro–CT, further studies are needed to examine how the micro-CT findings correlate with the cyclic and torsional fatigue of files in clinical use and their relationships with the incidence of fracture. SEM and mechanical testing can be further combined with micro-CT to analyze surface details, revealing micro-cracks or assessing mechanical integrity.

Conclusion

Within the limitations of the study, micro-CT analysis revealed that the surface area and volume of HEDM files decreased progressively with each repeated use, along with observable deformations on the surfaces after multiple uses. Micro-CT analysis can be utilized to assess the volume and surface area changes of rotary instruments. Clinicians should monitor the integrity of files, consider the effects of sterilization, and the risks associated with reusing files to enhance endodontic treatment outcomes, particularly in complex canal anatomies where the risk of instrument failure is higher.

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nata HEDM tijekom sterilizacije u autoklavu ispitivane mikroskopijom atomskih sila, zabilježeno je da se hrapavost površine nove marke instrumenata HEDM malo promijenila poslije prve sterilizacije, a hrapavost površine značajno se povećala poslije pete (18). Nakon instrumentacije, zagrijavanja i jake deformacije u kanalu, uočeno je smanjenje tvrdoće i povećanje modula elastičnosti instrumenata EDM. Ti rezultati objašnjeni su ponovnim otapanjem faze Ni4Ti3 i martenzitnom transformacijom dijela austenita u dodatnu R-fazu izazvanu naprezanjem, što je u skladu s faznim promjenama uočenima na korištenim instrumentima EDM (23). U ovoj studiji instrumenti su sterilizirani u autoklavu poslije svake upotrebe kako bi se postigli uvjeti što sličniji stvarnoj kliničkoj upotrebi. Smanjenje površine i volumena instrumenata, te učinci sterilizacije na deformacije površine, mogu se objasniti na ovaj način.

S obzirom na ograničenja kontroliranih laboratorijskih uvjeta, okruženje možda neće potpuno replicirati složene biološke i mehaničke interakcije prisutne *in vivo*, što otežava izravnu korelaciju nalaza s kliničkom učinkovitošću instrumenata. Potencijalne pristranosti prouzročene varijablama operatera i anatomskom konfiguracijom kanala donjih kutnjaka mogu ograničiti primjenjivost nalaza na druge vrste zuba s različitim anatomijama kanala (33). Potrebna su daljnja istraživanja u kojima će se uzeti u obzir širok raspon operatera i anatomskih varijacija kanala kako bi se poboljšala generalizacija ovih rezultata.

Iako rezultati istraživanja pokazuju da se promjene volumena i površine mogu analizirati mikro-CT-om, potrebna su daljnja istraživanja da bi se ispitalo kako nalazi mikro-CT-a koreliraju s cikličkim i torzijskim zamorom instrumenata u kliničkoj upotrebi i njihovim odnosom s učestalošću puknuća. SEM i mehaničko ispitivanje mogu se dodatno kombinirati s mikro-CT-om za analizu detalja površine, otkrivanje mikropukotina ili procjenu mehaničkog integriteta.

Zaključak

Uzimajući u obzir ograničenja istraživanja, analiza mikro-CT-om otkrila je da se površina i volumen instrumenata HEDM progresivno smanjuju sa svakom ponovljenom upotrebom, uz uočljive deformacije na površinama poslije višestruke upotrebe. Analiza mikro-CT-om može se upotrijebiti za procjenu promjena volumena i površine rotacijskih instrumenata. Kliničari bi trebali pratiti integritet instrumenata, uzeti u obzir učinke sterilizacije i rizike povezane s njihovom ponovnom upotrebom kako bi poboljšali ishode endodontskog liječenja, posebno u slučaju složenih anatomija kanala u kojem je rizik od puknuća instrumenata veći.

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Doprinos autora: **N. B. K** i **D. H. Y** – idejni koncept i pisanje teksta; **N. B.** i **Z. U.** – priprema materijala i metoda; **D. H. Y.** – priprema slika. Svi autori pregledali su tekst.

Sažetak

Svrha rada: Cilj istraživanja bio je procijeniti površine i volumene nikal-titanijevih (NiTi) instrumenata HyFlex EDM (HEDM) prije i poslije višestruke upotrebe u obradi korijenskog kanala donjeg kutnjaka. **Materijali i metode:** Dvanaest instrumenta HEDM veličina 10/.05 i 25/.08 procijenjeno je mikro-CT-om prije i poslije jednokratne ili višekratne upotrebe u obradi korijenskog kanala. Meziobukalni i meziolingvalni korijenski kanali trideset šest ljudskih donjih kutnjaka instrumentirani su s dvanaest instrumenata HEDM veličine 10/.05 (300 okretaja u minuti) i 1,8 Ncm i dvanaest 25/.085 Ncm prema preporuci proizvođača. Instrumenti HEDM procijenjeni su mikro-CT-om u četirima različitim razdobljima: 1) intaktni instrument, 2) poslije instrumentacije jednog kanala, 3) poslije instrumentacije dvaju kanala i 4) poslije instrumentacije triju kanala. Volumen i površina svake skupine analizirani su primjenom Friedmanova testa. Usporedba svake skupine procijenjena je Wilcoxonovim testom rangova s Bonferronijevom korekcijom. **Rezultati:** Intaktni instrumenti HEDM 10/.05 i HEDM 25/.08 pokazali su značajno veće volumene i površine od korištenih instrumenata ($p < 0,05$). **Zaključci:** Značajno smanjenje volumena i površine NiTi instrumenata uočeno je s povećanjem broja upotreba, bez obzira na skupinu instrumenata. Ti nalazi pokazuju koliko je važno da kliničari razumiju strukturne promjene u instrumentima HEDM tijekom ponovljene upotrebe kako bi se omogućila njihova sigurna ponovna upotreba i spriječio neuspjeh u endodontskim postupcima.

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Autorske ključne riječi: HyFlex EDM; mikro-CT; površina; volumen

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