Primljen/ Received on: 18. 2. 2023.
Revidiran / Revised on: 14. 3. 2023.
Prihvaćen/ Accepted on: 27. 3. 2023.

ORIGINALNI RAD
ORIGINAL ARTICLE
doi: 10.5937/asn2388671T

IN VITRO EVALUACIJA FRAKTURNE REZISTENCIJE ENDODONTSKI TRETIRANIH ZUBA

IN VITRO EVALUATION OF FRACTURE RESISTANCE OF ENDODONTICALLY TREATED TEETH

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Sažetak

Uvod: *Endodontski tretirani zubi imaju lošije biomehaničko stanje od intaktnih vitalnih zuba. Literatura pokazuje da se endodontskom obradom gubi zubno tkivo i smanjuje frakturna rezistencija.*
Cilj *ovog istraživanja bio je da se utvrdi da li postoji razlika u frakturnoj rezistenciji između intaktnih zuba i endodontski obrađenih i opturiranih zuba, kao i najčešći tip frakture.*
Materijali i metode: *Za potrebe ovog istraživanja korišćeno je 20 ekstrahovanih jednokorenskih intaktnih zuba. Slučajnim odabirom uzorci su podeljeni u dve grupe – G1 (negativna kontrolna grupa, n = 5): intaktni zubi, G2 (eksperimentalna grupa, n = 15): zubi obrađeni Hedstrom turpijom + opturirani gutaperkom i Endometazonom N. Uzorci su bili podvrgnuti kompresionom pritisku na Univerzalnoj mašini za potpuno automatsko CBR testiranje Profi x6 Plus, sve do trenutka lomljenja.*
Rezultati: *Prosečna vrednost pritiska ($\bar{x}$) pri kojem dolazi do frakture u G1 iznosila je 849 N, a u G2 772,33 N. Standardna devijacija (σ) vrednosti pritiska pri kojem dolazi do frakture u G1 iznosila je 246,86 N, a u G2 810,74 N. Najveći procenat uzoraka bio je sa višestrukim linijama frakture (G1: 100%, G2: 53,3%).*
Zaključak: *U svim grupama, najčešće frakture prema smeru bile su kombinovane; prema složenosti, bile su višestruke. Iako su vrednosti pritiska pri kojima dolazi do frakture u prvoj grupi bile značajno veće nego u drugoj grupi, na osnovu statističkih analiza (Studentov t-test sa vrednošću od 0,69, CI 95%; p < 0,05), zaključili smo da ne postoji značajna razlika u prosečnoj vrednosti pritiska pri kojem dolazi do frakture u obema grupama.*

Ključne reči: *intaktni zubi, endodontski obrađeni zubi, fraktura, frakturna rezistencija*

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Abstract

Introduction: *Endodontically treated teeth have a worse biomechanical condition compared to intact vital teeth. The literature shows that with endodontic treatment, tooth tissue is lost and fracture resistance is reduced. This paper presents the findings.*
Aim *of study was to determine difference in fracture resistance between intact teeth and endodontically treated and obturated teeth and which type of fracture is the most common.*
Materials and Methods: *For the purpose of this research, 20 extracted single-root intact teeth were used. By random selection, the samples were divided into 2 groups: G1 (negative control group, n = 5) - intact teeth, G2 (experimental group, n = 15) - treated with Hedstrom file + obturated with Gutta-Percha and Endomethasone N. The samples were subjected to compressive pressure on the Universal testing machine, until the moment of breaking.*
Results: *The average pressure value ($\bar{x}$) at which fracture occurred in G1 was 849 N, and in G2 it was 772.33 N. The standard deviation (σ) of the pressure value at which the fracture in G1 occurred was 246.86 N, and for G2 it is 810.74 N. The largest percentage of samples had multiple fracture lines (in 100% of G1 samples; in 53.3% of G2 samples).*
Conclusion: *In all groups, the most common fractures according to direction were combined, and according to complexity multiple. Although the pressure values at which the fractures occurred in the first group were significantly higher than in the second group, from the statistical analyses (Student's t-test with a value of 0.69, CI 95%, p < 0.05), we conclude that there is no noticeably significant difference in the average value of the pressure at which a fracture occurs in both groups.*

Key words: *intact teeth, endodontically treated teeth, fracture, fracture resistance*

Uvod

Endodontska procedura je dentalna procedura koja se primenjuje u kliničkim slučajevima u kojima je tkivo pulpe ireverzibilno oštećeno, kao posledica karijesa ili traumatske povrede. Ovaj endodontski tretman obuhvata mehaničku i hemijsku pripremu kanala korena, koja ima ulogu u dugovečnosti i životnom veku postojanosti zuba u oralnoj sredini[1].

Endodontski tretirani zubi imaju lošije biomehaničko stanje od zuba koji su intaktni i imaju očuvanu vitalnost[2]. Uz to, smatra se da endodontski tretirani zubi imaju nižu stopu preživljavanja nego vitalni zubi. Od svih vrsta fraktura, najčešća fraktura kod endodontski tretiranih zuba jeste vertikalna fraktura korena (50%), koja ima najlošiju prognozu. Druga najčešća fraktura koja dovodi do neuspeha je koronarna faktura[3,4].

Postoje različite klasifikacije povreda orofacijalnih struktura. Osnovna je podela na dve vrste povreda denticije: povrede mekih tkiva i povrede tvrdih tkiva. Fraktura zuba spada u grupu povreda tvrdih tkiva. Ovde se najčešće koristi klasifikacija Elis-Van Kot, koja uključuje promene u gleđi, dentinu i pulpi[5].

Druga podela, prema tome da li postoji vidljiva separacija između frakturiranih delova, jeste podela na kompletne i nekompletne frakture. Tu se može govoriti o izraženoj simptomatologiji, delimično izraženoj simptomatologiji ili se može odvijati kompletno asimptomatski[6,7]. Prema mišljenju pojedinih autora, češće se javljaju nekompletne frakture[8].

Kod endodontski tretiranih zuba fraktura se najčešće javlja u posteriornoj grupi zuba, tj. kod maksilarnih molara, sa 42%[9], i češće zahvata lingvalne tubere nego one vestibularne; takođe, češće se javlja ispod gingivalne linije[10].

U literaturi se za potrebe istraživanja najčešće koriste podela fraktura prema složenosti, na jednostruke i višestruke, i podela prema pravcu linije frakture, na vestibulooralne (v/o), meziodistalne (m/d) i kombinovane (k)[11].

Cilj ovog istraživanja bio je da se utvrdi razlika u frakturnoj rezistenciji između endodontski obrađenih i opturiranih zuba i intaktnih zuba. Praćen je i tip frakture koji nastaje prilikom lomljenja.

Materijali i metode

Za potrebe ovog istraživanja upotrebljeno je 20 ekstrahovanih jednokorenskih zuba koji su bili intaktni, tj. nisu bili prethodno endodontski tretirani ili restaurirani.

Introduction

The endodontic procedure is a dental procedure applied in clinical cases when the pulp tissue is irreversibly damaged as a result of caries or traumatic injury. This endodontic treatment includes mechanical and chemical preparation of the root canal that plays a role in the longevity and lifetime of the persistence of a tooth in the oral environment[1].

Endodontically treated teeth have a worse biomechanical condition compared to the teeth that are intact and have preserved vitality[2]. With this in mind, endodontically treated teeth are considered to have a lower survival rate compared to the vital teeth. Of all types of fractures, the most common fracture in endodontically treated teeth is the vertical root fracture (50%), which has the worst prognosis. Coronary fracture is the second most common fracture that leads to failure[3,4].

There are various classifications of injuries to the orofacial structures. The basic division is into 2 types of dentition injuries: soft tissue injuries and hard tissue injuries. Tooth fracture belongs to the group of hard tissue injuries. Here the most commonly used classification is Ellis-Van Cott's which includes the changes in enamel, dentine, and pulp[5].

Another division is into complete and incomplete fractures, in terms of whether there is a visible separation between the fractured parts. In this case, we may have pronounced symptomatology, partially pronounced, or it can be completely asymptomatic[6,7]. According to some authors, incomplete fractures occur more often[8].

In endodontically treated teeth, the fracture most often occurs in the posterior group of teeth, i.e., 42% of fractures occur in maxillary molars[9], the involvement of the lingual tubercles is more frequent than the vestibular ones, and the fracture occuring below the gingival line is more often[10].

For research purposes in literature, fractures are most frequently divided according to their complexity as either single or multiple. |Additionally, fractures can be divided according to the direction of the fracture line into vestibulooral (v/o), mesiodistal (m/d), and combined (c)[11].

The aim of this research was to determine the difference in fracture resistance in endodontically treated and obturated teeth compared to intact teeth. The type of fracture that occurs during breaking was also monitored.

Nakon ekstrakcije, čuvani su u medijumu destilovane vode u 100% vlažnosti i na sobnoj temperaturi. Da bi se izvršila selekcija ekstrahovanih zuba, primenjeni su selektivni inkluzioni i ekskluzioni kriterijumi koji su precizirali uzorke zuba za dalje ispitivanje. Pre primene ovih kriterijuma, zubi su prvo detaljno pregledani, a dodatno je korišćen pregled pod uvećanjem i transluminacijom.

Slučajnim izborom, zubi su podeljeni u dve grupe:

I grupa / negativna kontrolna grupa (G1) (n = 5): intaktni zubi, koji nisu trepanirani i nisu instrumentirani;

II grupa / testirana grupa 2 (G2) (n = 15): endodontski tretirani zubi.

Negativnu kontrolnu grupu (G1) činili su zubi koji su bili potpuno intaktni bez prethodne pripreme. Nisu bili ni dekoronirani, ni trepanirani, ni instrumentirani.

Testirana grupa 2 (G2) sastojala se od uzoraka u kojima su krunice endodontski obrađenih zuba uklonjene kako bi se dobila standardna dužina korena kod svakog uzorka. Da bi se postigao efekat ferule u visini, ostavljena su 2 mm od emajl-cementnog spoja prema krunici. Za dekoroniranje korišćen je dijamantski separator (Rotary Dental Instruments, NTI-Kahla GmbH, Germany).

U ovoj grupi, nakon trepanacije urađeno je depulpiranje ekstirpatorom nerva (Dentsply Maillefer, Ballaigues, Switzerland), utvrđena je prohodnost i određena je radna dužina. Prohodnost je postignuta K-turpijom veličine #10 (Dentsply Maillefer, Ballaigues, Switzerland). Radna dužina određena je umetanjem K-turpije veličine #15 (Dentsply Maillefer, Ballaigues, Switzerland) u kanal sve dok vrh instrumenta nije bio vidljiv na apikalnom otvoru, posle čega je određena radna dužina nakon što je povučena za 1 mm.

Obrada kanala korena urađena je Hedstorm turpijama do veličine #40. Irigacija je obavljena po klasičnom savremenom protokolu. Na kraju, nakon finalne irigacije NaCl 0,9%, uzorci su osušeni papirnim šiljcima i, shodno tome, ispitani pod uvećanjem.

Opturacija je izvršena Endometazonom N (Zinc oxide eugenol endodontic cement / Septodont, Saint Maur des Fosses, France) i gutaperkom, po principu tehnike jednog Potom, uzorci su smešteni u blokove materijala EKSMAL 1 (ADING AD, Skoplje), i to tako da su koronarna 2 mm ostala nepokrivena.

Da bi uzorci u G2 imali potpuno ravnu površinu, korišćena je paralelometarska glodalica sa magnetnim postoljem (Fedi F18, Mariotti, Germany).

Materials and Methods

For the purpose of this research, 20 extracted single-root intact teeth were used, i.e., they were not previously endodontically treated or restored. After their extraction, they were stored in a medium with distilled water at 100% humidity and at room temperature. In order to make a selection of the extracted teeth, selective inclusion and exclusion criteria were applied which specified the samples of teeth that were further subjected to testing. Before applying these criteria, the teeth were first examined in detail, and, in addition, examination under magnification and transil-lumination was used.

The teeth were randomly divided into two groups:

I group/negative control group (G1) (n = 5) – intact teeth that were neither trepanned nor instrumented.

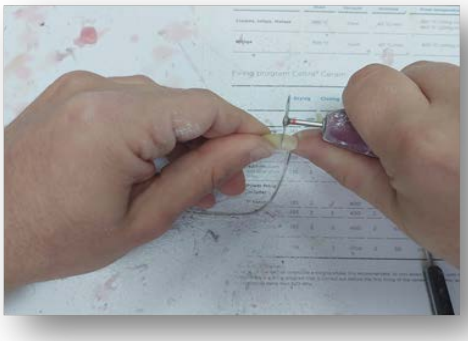
II group/experimental group 2 (G2) (n = 15) – endodontically treated teeth.

The negative control group (G1) consisted of teeth that were completely intact with no prior preparation. They were not decoronated, trepanned, or instrumented.

The experimental group 2 (G2) consisted of specimens where the crowns of endodontically treated teeth were removed to obtain a standard root length in each specimen. To achieve a ferrule effect in height, 2 mm from the enamel-cement junction towards the coronary was left. A diamond separator (Rotary Dental Instruments, NTI-Kahla GmbH, Germany) was used for decoronation. In this group, after trepanation, depulping was performed with a nerve extirpator (Dentsply Maillefer, Ballaigues, Switzerland), the glide path was established and the working length was determined. The glide path was achieved with a #10 size K-file (Dentsply Maillefer, Ballaigues, Switzerland). The working length was determined by inserting a size #15 K-file (Dentsply Maillefer, Ballaigues, Switzerland) into the canal until the tip of the instrument was visible at the apical opening, after which the working length was established by retracting it back for 1 mm.

The treatment of the root canal was done with Hedstrom files up to size #40. Irrigation was carried out according to a classic modern protocol. Finally, after the final irrigation with NaCl 0.9%, the samples were dried with paper points and examined accordingly under magnification. Obturation was performed with Endomethasone N. (Zinc oxide eugenol endodontic cement Septodont, Saint-Maur-des-Fosses, France) and Gutta-Percha according to the principle of the single cone technique with

Na ovaj način dobijena je paralelna površina bez izbočina i kosina. Zatim su uzorci na odgovarajući način premazani pomoću dva sloja laka kako bi se izolovali od vlage. Nakon toga, uzorci su držani na sobnoj temperaturi i 100% vlažnosti do vremena testiranja, kako bi se izbegla njihova dehidracija.

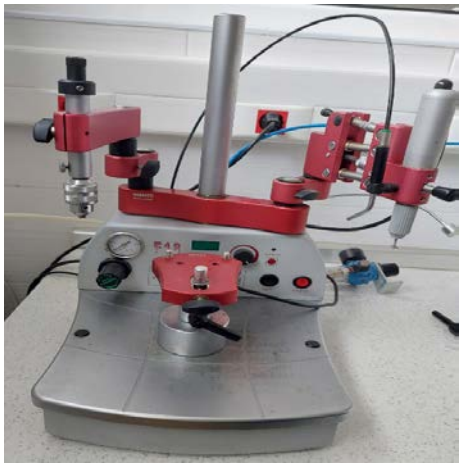


Slika 1*:* Dekoroniranje uzoraka
Figure 1: Decoronation of the samples

enabling constant conditions for all experimental samples.

After that the samples were placed in blocks mode of the EXMAL 1 (ADING AD Skopje) material, leaving 2 mm coronary uncovered.

In order to have a completely flat surface in the G2 samples, a parallelometer milling machine with a magnetic stand (Fedi F18, Mariotti, Germany) was used.In order to have a completely flat surface in the samples in G2, a parallelometer milling machine with a magnetic stand (Fedi F18, Mariotti, Germany) was used. In this way, a parallel surface was obtained without protrusions and bevels. Then the samples were properly coated with 2 layers of varnish to isolate them from humidity. After that, the samples were kept at room temperature and 100% humidity until the time of testing, in order to avoid dehydration of the samples.



Slika 2*:* Paralelometarska glodalica sa magnetnim postoljem
Figure 2: Parallelometer milling machine with a magnetic stand

Testiranje frakturne rezistencije

Uzorci su podvrgnuti kompresionom pritisku na Univerzalnoj mašini za potpuno automatsko CBR testiranje Profi x6 Plus detekcijom pritiska do 50 kN, u prostorijama „Geodizajn inženjering laboratorije" u Skoplju.

Pritisak apliciran na uzorke bio je statičan, sa vertikalnim smerom koji se postepeno povećavao manuelno, pri čemu je vizuelno i auditivno detektovan pritisak potpunog lomljenja zuba.

Testing of fracture resistance

The samples were subjected to compressive pressure using a universal testing machine fully automatic CBR testing Profi X6 Plus with pressure detection up to 50 kN in the premises of Geodesign Engineering Laboratory, Skopje. The pressure applied to the samples was static in a vertical direction, gradually increased manually, during which the pressure on the complete tooth breakage was detected, visually and auditorily. The research was conducted in such a way that each sample was individually tested, i.e., subjected to pressure.

Istraživanje je sprovedeno tako što je svaki uzorak pojedinačno testiran, tj. izlagan pritisku. Osim što je utvrđivana sila koja je dovela do lomljenja zuba, izvršena je i klasifikacija frakture prema pravcu linije frakture (vestibulooralne, meziodistalne i kombinovane), odnosno prema složenosti (jednostruke i višestruke).

Nakon dobijanja podataka urađena je statistička analiza određivanjem prosečne vrednosti ($\bar{x}$), srednje, tj. prosečnog odstupanja (So), standardne devijacije (σ), minimuma, maksimuma, modusa i medijane; takođe, korišćen je Studentov t-test.

Rezultati

Vrednost pritiska pri kojem nastaje fraktura

Prosečna vrednost pritiska ($\bar{x}$) pri kojem nastaje fraktura u G1 iznosila je 849 N; srednje, tj. prosečno odstupanje (So) vrednosti pritiska pri kojem nastaje fraktura u G1 iznosilo je 110,4 N; standardna devijacija (σ) vrednosti pritiska pri kojem nastaje fraktura u G1 iznosila je 246,86 N; medijana za G1 bila je 921 N. Prosečna vrednost pritiska ($\bar{x}$) pri kojem nastaje fraktura u G2 iznosila je 772,33 N; srednje, tj. prosečno odstupanje (So) vrednosti pritiska pri kojem nastaje fraktura u G2 iznosilo je 209,334 N; standardna devijacija (σ) vrednosti pritiska pri kojem nastaje fraktura u G2 iznosila je 810,74 N; medijana za G2 iznosila je 882 N.

Studentov t-test je za obe grupe (G1 i G2) imao vrednost 0,69 (CI 95%; $p < 0,05$), što znači da nije postojala statistički signifikantna razlika u prosečnoj vrednosti pritiska pri kojem nastaje fraktura ni u jednoj grupi.

Po složenosti linije frakture, frakture su podeljene na jednostruke i višestruke. Najčešće su bile višestruke frakture (G1: 100 %, G2: 53,3%).

Na osnovu pravca linije frakture, uzorci su podeljeni na vestibulooralne, meziodistalne i kombinovane. U obema grupama najčešće frakture bile su kombinovane (G1: 100%, G2: 33,3%).

In addition to determining the force that led to tooth breakage, a classification was also made according to the type of fracture in relation to the direction of the fracture line (vestibulooral, mesiodistal, and combined) and complexity (single and multiple).

After receiving the data, a statistical analysis was made using the average value ($\bar{x}$), mean, i.e., average deviation (So), standard deviation (σ), minimum, maximum, mode, median, and Student's t-test.

Results

Pressure value at which the fracture occurs

The average value of pressure ($\bar{x}$) at which the fracture occurred in G1 was 849 N, the mean, i.e., average deviation (So) of the pressure value at which the fracture occurred in G1 was 110.4 N, the standard deviation (σ) of the pressure value at which the fracture occurred in G1 was 246.86 N and the median for G1 was 921N. The average value of pressure ($\bar{x}$) at which the fracture occurred in G2 was 772.33 N, the mean, i.e., average deviation (So) of the pressure value at which the fracture occurred in G2 was 209.334 N, the standard deviation (σ) of the pressure value at which the fracture occurred in G2 was 810.74 N, and the median for G2 was 882 N.

The Student's t-test for both groups (G1 and G2) had a value of 0.69 (CI 95%, $p < 0.05$), which means that there was no statistically significant difference in the average pressure value at which fracture occurred in both groups.

In terms of complexity, the fracture line was divided into single and multiple. The most common were multiple fractures (100% in G1, 53.3% in G2).

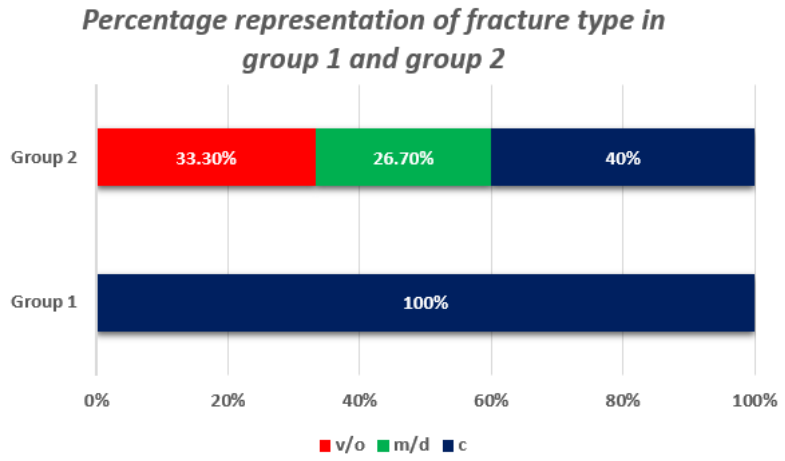
Regarding the direction of the fracture line, the samples were divided into vestibulooral, mesiodistal, and combined. The most common fracture in both groups are the combined ones. (G1 - 100%, G2 – 33,3%).

Tabela 1: Poređenje prosečne vrednosti pritiska pri kojem nastaje fraktura ($\bar{X}$), srednjeg odstupanja (So), standardne devijacije (σ), minimalnog pritiska frakture (min), maksimalnog pritiska (max) na frakturu, modusa i medijane u Grupi 1 i Grupi 2

***Table 1*:** Comparison of average fracture pressure ($\bar{X}$), mean deviation (So), standard deviation (σ), minimum fracture pressure (min), maximum fracture pressure (max), mode and median in Group 1 and Group 2

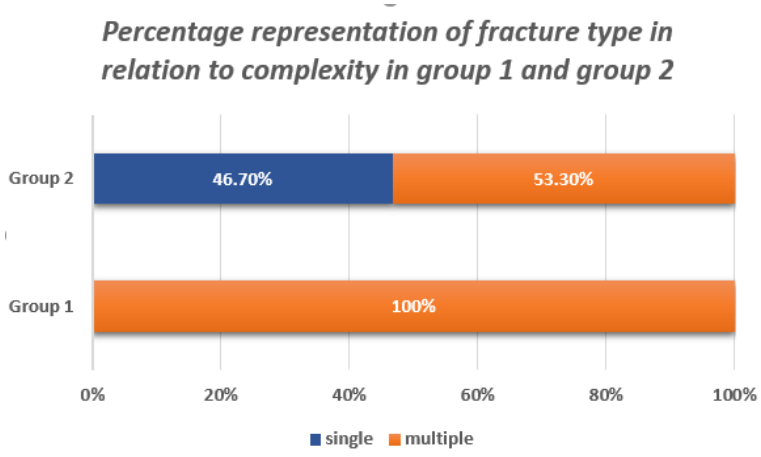
	$\bar{X}$	So	σ	Min	Max	Modus	Medijana / Median
Grupa 1 / Group 1	849	110.4	246.86	706	951	951	921
Grupa 2 / Group 2	772.33	209.334	810.74	353	1041	/	882

Lokalizacija linije frakture prema složenosti i pravcu
Localization of the fracture line in terms of complexity and direction



Slika 3: Procentualna zastupljenost vrste frakture prema pravcu u obema grupama

Figure 3: Percentage representation of fracture type in relation to direction in both groups



Slika 4: Procentualna zastupljenost vrste frakture prema složenosti u obema grupama

Figure 4: Percentage representation of fracture type in relation to complexity in both groups

Diskusija

U naše istraživanje bili su uključeni sveže izvađeni jednokorenski zubi relativno pravih i zaobljenih korena, približno slične radne dužine i sa jednim kanalom.

Irigacija je vršena po klasičnom savremenom kliničkom protokolu rada – sa irigansima i lubrikantima. Za razliku od naše studije, ima studija u kojima se in vitro uzorci irigiraju samo destilovanom vodom kako bi se izbeglo negativno dejstvo NaOCl na dentinsko tkivo[12,13]. Prado i sar. su zaključili da irigacija sa 6% NaOCl smanjuje frakturnu rezistenciju, te da je potrebna hemijska irigacija sa nižom koncentracijom[14].

Da bi se ispitala frakturna rezistencija zuba, u istraživanju se koristi dinamički ili statički pritisak na zube. U principu, dinamički pritisak na zube je odraz i u korelaciji je sa kliničkim stanjem zuba u ustima, što imitira fenomen opterećenja i pritiska u procesu žvakanja. Postoji nekoliko varijacija u simulaciji dinamičkog pritiska na zube, ali je ovo kao metod prilično teško simulirati, pa je teško i uporediti dobijene podatke; zbog toga se retko koristi u istraživanjima. U našem istraživanju izvršeno je linearno (statičko) opterećenje uzoraka, sa ciljem testiranja frakturne rezistencije. Ovo je najčešće korišćeni metod u drugim istraživanjima sa istom svrhom, pre svega zbog efikasnosti i mogućnosti poređenja dobijenih parametara[15].

U ovoj studiji, svi zubi su postavljeni vertikalno u modele napravljene od Eksmal 1 materijala, bez imitacije periodontalnog ligamenta, što je slično određenim studijama[16,17]. U nekim drugim studijama pak zubi su bili prekriveni materijalom koji imitira periodontalni ligament, kao što je plastična boja ili polistiren[13,14]. Studije Soaresa i sar.[18] i Markionatija i sar.[19] pokazale su da testiranje frakturne rezistencije neće moći da se sprovede ako se imitira periodontalni ligament. To je potvrdilo i naše istraživanje, budući da prilikom pokušaja imitacije periodontalnog ligamenta voskom, lakom ili plastikom nije bilo moguće postići pucanje ili frakturu zuba, već je zub potisnut vertikalno u model. Na ovaj način dobijeni su irelevantni podaci o frakturi zuba, tj. podaci samo o lomljenju zuba u celini. Rezultati našeg istraživanja dobijeni su mehaničkom ručnom instrumentacijom sa Hedstrom turpijom, sa 2% konusnosti endodontski tretiranog prostora.

Ako se koristi ručna instrumentacija sa #50, kod mandibularnih premolara i kanina dobija se za 30% manja otpornost nego ako nisu instrumentirani[16].

Discussion

Our research included freshly extracted single-rooted teeth with relatively straight and rounded roots of approximately similar working length and having one canal.

Irrigation was performed with irrigants and lubricants according to a classic modern clinical work protocol. Unlike our study, some studies irrigate the in vitro samples only with distilled water in order to avoid the negative effect of NaOCl on the dentinal tissue[12,13]. Prado et al. concluded that irrigation with 6% NaOCl reduces fracture resistance, recommending chemical irrigation with a lower concentration[14].

In order to investigate the fracture resistance of teeth, dynamic or static tooth pressure was used in research. In principle, the dynamic pressure on the teeth is a reflection and is correlated with the clinical condition of the teeth in the mouth, which imitates the phenomenon of stress and pressure in the process of chewing. So, there are several variations in simulating the dynamic pressure on the teeth, but as a method it is quite difficult to simulate and then to compare the data obtained. That is why it is rarely used in research. In our research, we carried out linear (static) stress on the samples to test the fracture resistance. This is the most commonly used method in other research with the same goal, primarily due to its efficiency and the possibility of comparing the obtained parameters[15].

In this study, all teeth were vertically placed in models made of Eksmal 1 material, without simulating the periodontal ligament, similar to some studies[16,17]. In other studies, the teeth were covered with a periodontal ligament-imitating material such as plastic paint or polystyrene[13,14]. The studies by Soares et al.[18] and Marchionatti et al.[19] show that the fracture resistance test will not be possible to conduct if the periodontal ligament is imitated. This was confirmed in our research, where during the attempts to imitate the periodontal ligament with wax, varnish, or plastic, it was not possible to achieve a cracking or a fracture of the tooth, but the tooth in the model was pushed vertically. This resulted in irrelevant data on the fracture of the tooth, i.e., data only for the breaking of the model in its entirety.

The results of our research were obtained using mechanical manual instrumentation with a Hedstrom file, with a 2% conicity of the endodontically treated space.

To potvrđuje i naše istraživanje – dobili smo podatke o instrumentiranim uzorcima koji su oslabljeni za 9% u odnosu na intaktne zube.

Vilkoks i sar. su u studiji dokazali da je fraktura zuba direktno povezana sa debljinom dentinskog zida, tj. da uklanjanje veće količine dentinskog tkiva dovodi do veće mogućnosti frakture[20]. Prado i sar.[14] su, nadovezavši se na ovo, naglasili da je smanjenje debljine zida dentina samo jedan od faktora rizika koji utiče na frakturnu otpornost zuba. Međutim, postoje i drugi faktori, kao što su konusnost i glatkoća endoprostora. U istraživanju su došli do podataka da jednokorenski zubi koji su tretirani ručnim instrumentima 45/0,02 imaju veću frakturnu rezistenciju (povećanu za 43,7%) nego ostale grupe; pritom, frakturna rezistencija bila je veoma slična otpornosti na lomljenje u kontrolnoj grupi zuba.

Neki autori su dokazali da manja konusnost endoprostora povećava frakturnu rezistenciju, u poređenju sa zubima instrumentiranim sa većom konusnošću[21,22,23]; u nekim drugim studijama pak zaključeno je da ne postoji korelacija između stepena konusnosti i frakturne rezistencije[12,24].

Prilikom analize pravca nastale linije frakture, u uzorcima u ovom istraživanju najčešće su se javljale kombinovane i višestruke frakture, tj. linije frakture i u vestibulooralnom i u meziodistalnom pravcu, što se razlikuje od podataka iz literature, gde se najčešće pominju linije frakture u vestibulooralnom pravcu, bez obzira na to što je dentin u ovom pravcu znatno tanji. Ovo je najverovatnije zbog distribucije stresa koji se javlja duž korena zuba[12,25].

Tavanfar i sar.[26] su zaključili da postoji statistička razlika u eksperimentalnim grupama i kontrolnoj, tj. intaktnoj grupi, koja je pokazala vrednosti pritiska veće od onih u ostalim grupama, odnosno imala je veću otpornost na frakturu. Mogućnost frakture u svim eksperimentalnim grupama imala je sličnu frakturnu rezistenciju, bez obzira na to koji je sistem izabran (ručne K-turpije, BioRaCe, WaveOne).

Poredeći snagu, došli smo do sledećih rezultata: u studiji[12] u kojoj se obrađivalo ručnim K-turpijama #40, prosečna vrednost pri kojoj dolazi do frakture u uzorcima iznosila je 1339 N, dok je u našoj studiji prosečna vrednost bila 849 N; dakle, bila je značajno niža.

Za razliku od navedenih rezultata, u studiji Lama i sar.[27], vrednost preloma zuba obrađenih ručnim instrumentima iznosila je 1000,2 N kod mandibularnih molara.

Our findings showed that using a #50 manual instrumentation on mandibular premolars and canines resulted in 30% less resistance compared to uninstrumented teeth[16]. We also observed that instrumented samples were weakened by 9% when compared to intact teeth.

In their study, Wilcox et al. proved that tooth fracture is directly related to the thickness of the dentine wall, i.e., the removal of a greater amount of dentine tissue leads to a greater possibility of fracture[20]. Prado et al.[14] built on this research and emphasized that the reduction of the dentine wall thickness is just one of the risk factors that affect the fracture resistance of the tooth. Other factors include the conicity and smoothness of the endospace. In their study, they found that single-rooted teeth treated with manual instruments 45/0.02 had a higher fracture resistance (increased by 43.7%), compared to the other groups, and the fracture resistance was very similar to the resistance to breaking in the control group of teeth.

Some authors have proved that a smaller conicity of the endospace increases fracture resistance, compared to teeth instrumented with a larger conicity[21,22,23] while other studies have concluded that there is no correlation between the degree of conicity and fracture resistance[12,24].

When analyzing the direction of the resulting fracture line in the samples in this research, it can be seen that combined and multiple fractures occur most often, i.e., fracture lines in both the vestibulooral and mesiodistal direction, in contrast to the literature data where fracture lines in the vestibulooral direction are mostly found, regardless of the fact that the dentin is much thinner in this direction. This is probably due to the stress distribution that occurs along the root of the tooth[12,25].

Tavanfar et al.[26] concluded that there was a statistical difference in the experimental groups and the control group, i.e., the intact group showed pressure values that were higher in comparison to the other groups, i.e., it had a higher resistance to fracture. The possibility of fracture in all experimental groups had similar fracture resistance regardless of which system was chosen (manual K files, BioRaCe, WaveOne).

Comparing the force from the study[12], where manual K files #40 were used for processing, the average value at which fracture occurs in the samples was 1339 N, while our

Ova varijacija u vrednostima pritiska frakture prvenstveno je posledica izbora ručnog instrumenta, veličine, tehnike instrumentacije, ali i vrste zuba koji su izabrani kao uzorci.

Zaključak

Iako su vrednosti pritiska pri kojima dolazi do frakture u prvoj grupi bile značajno veće nego u drugoj grupi (G1 i G2), na osnovu statističkih analiza (Studentov t-test sa vrednošću 0,69, CI 95%; $p < 0,05$), zaključili smo da nema značajne razlike u prosečnoj vrednosti pritiska pri kojem dolazi do frakture u obema grupama.

Ipak, potrebna su dodatna dalja istraživanja u ovoj oblasti, koja će uzeti u obzir i grupu zuba sa različitim tipovima anatomskih varijacija.

***Zahvalnica*:** Nema.

***Sukob interesa*:** Nema.

***Finansijska podrška*:** Nema.

average value was 849 N, which means it is significantly lower. In contrast to these results, in the study by Lam et al.[27], the value of teeth breaking treated with manual instruments is 1000, 2 N in mandibular molars. This variation in fracture pressure values is primarily due to the choice of the manual instrument, size, instrumentation technique, but also to the type of teeth that are selected for samples.

Conclusion

From this research we can conclude that although the pressure values at which a fracture occurs in the first group are significantly higher than in the second group (G1 and G2), from the statistical analysis (Student's t-test with a value of 0.69, CI 95%, $p < 0.05$) we conclude that there is no noticeably significant difference in the average value of the pressure at which a fracture occurs in both groups.

However, additional further research is needed in the area where the group of teeth with different types of anatomical variations will be considered.

Acknowledgement: Nil.

Conflicts of interest: Nil.

Financial Support: Nil.

LITERATURA / REFERENCES

1. Soares CJ, Rodrigues MP, Faria-E-Silva AL, Santos-Filho PCF, Veríssimo C, Kim HC, Versluis A. How biomechanics can affect the endodontic treated teeth and their restorative procedures? Braz Oral Res. 2018 Oct 18;32(suppl 1):e76
2. Mergulhão, V. A., de Mendonça, L. S., de Albuquerque, M. S., & Braz, R. (2019). Fracture Resistance of Endodontically Treated Maxillary Premolars Restored With Different Methods. Operative dentistry. 44(1): E1–E11.
3. Vire, D.E. Failure of endodontically treated teeth: Classification and evaluation. J. Endod. 1991; 17: 338– 342.
4. Ellis SG, McCord JF, Burke FJ. Predisposing and contributing factors for complete and incomplete tooth fractures. Dent Update 1999; 26: 150–2, 6–8.
5. Soares CJ, Rodrigues MP, Faria-E-Silva AL, Santos-Filho PCF, Veríssimo C, Kim HC, Versluis A. How biomechanics can affect the endodontic treated teeth and their restorative procedures? Braz Oral Res. 2018 Oct 18;32(suppl 1):e76
6. Diangelis, A. J., Andreasen, J. O., Ebeleseder, K. A., Kenny, D. J., Trope, M., Sigurdsson, A., Andersson, L., Bourguignon, C., Flores, M. T., Hicks, M. L., Lenzi, A. R., Malmgren, B., Moule, A. J., Pohl, Y., Tsukiboshi, M., & International Association of Dental Traumatology. International Association of Dental Traumatology guidelines for the management of traumatic dental injuries: 1. Fractures and luxations of permanent teeth. Dental traumatology : official publication of International Association for Dental Traumatology, 2012., 28(1):, 2–12.
7. Vire DE. Failure of endodontically treated teeth: classification and evaluation. J Endod. 1991 Jul;17(7):338-42.
8. Braly BV, Maxwell EH. Potential for tooth fracture in restorative dentistry. J Prosthet Dent. 1981 Apr;45(4):411-4.
9. Braly BV, Maxwell EH. Potential for tooth fracture in restorative dentistry. J Prosthet Dent 1981; 45: 411–4.
10. Gher ME Jr, Dunlap RM, Anderson MH, Kuhl LV. Clinical survey of fractured teeth. J Am Dent Assoc 1987; 114: 174– 7.
11. Lagouvardos P, Sourai P, Douvitsas G. Coronal fractures in posterior teeth. Oper Dent 1989; 14: 28–32.
12. Tian SY, Bai W, Jiang WR, Liang YH. Fracture Resistance of Roots in Mandibular Premolars Following Root Canal Instrumentation of Different Sizes. Chin J Dent Res. 2019;22(3):197-202.
13. Souza EM, Calixto AM, Lima CN, Pappen FG, De-Deus G. Similar influence of stabilized alkaline and neutral spdium hypochlorite solutions on the fracture resistance of root canal-treated bovine teeth. J Endod 2014; 40:1600-1603.
14. Prado M, de Lima NRB, de Lima CO, Gusman H, Simão RA. Resistance of vertical root fracture of root filled teeth using different conceptual approaches to canal preparation. Int Endod J 2016;49:898-904.
15. Naumann M, Metzdorf G, Fokkinga W, et al. Influence of test parameters on in vitro fracture resistance of post-endodontic restorations: a streuctured review. J Oral Rehabil 2009; 36: 299-312.
16. Wu Mk, van der Sluis LW, Wesselink PR. Comparison of mandibular premolars and canines with respect to their resistance to vertical root fracture. J Dent 2004;32:265-268.
17. Capar ID, Altunsoy M, Arslan H, Erstas H, Aydinbelge HA. Fracture straight of root instrumented with self-adjusting file and Pro Taper Rotary systems. J Endod 2014;40:5511-554.
18. Soares, C. J., Pizi, E. C., Fonseca, R. B., & Martins, L. R. (2005). Influence of root embedment material and periodontal ligament simulation on fracture resistance tests. Brazilian oral research. 19(1), 11–16.
19. Marchionatti AM, Wandscher VF, Broch J, Bergoli CD, Maier J, Valandro LF, Kaizer OB. Influence of periodontal ligament simulation on bond strength and fracture resistance of roots restored with fiber posts. J Appl Oral Sci. 2014 Sep-Oct;22(5):450-8.
20. Wilcox LR, Roskelley C, Sutton T. The relationship of root canal enlargement to finger-spreader induced vertical root fracture. J Endod. 1997 Aug;23(8):533-4.
21. Kılıç, Y., Karata¸slıo ˘glu, E.; Kaval, M.E. The Effect of Root Canal Preparation Size and Taper of Middle Mesial Canals on Fracture Resistance of the Mandibular Molar Teeth: An In Vitro Study. J. Endod. 2021, 47, 1467–1471.
22. Yıldız. E.D., Fidan, M,E., Sakarya, R.E., Dinçer. B. The effect of taper and apical preparation size on fracture resistance of roots. Aust. Endod. J. 2020,(47):67–72.
23. Munari, L.S.; Bowles, W.R.; Fok, A.S. Relationship between Canal Enlargement and Fracture Load of Root Dentin Sections. Dent. Mater. 2019, 35, 818–824.
24. Zogheib, C.; Sfeir, G.; Plotino, G.; De Deus, G.; Daou, M.; Khalil, I. Impact of minimal root canal taper on the fracture resistance of endodontically treated bicuspids. J. Int. Soc. Prev. Community Dent. 2018, 8, 179–183.
25. Lertchirakarn V, Palamara JE, Messer HH. Load and strain during lateral condensation and vertical root fracture. J Endod. 1999 Feb;25(2):99-104.
26. Tavanafar S, Karimpour A, Karimpour H, Mohammed Saleh A, Hamed Saeed M. Effect of Different Instrumentation Techniques on Vertical Root Fracture Resistance of Endodontically Treated Teeth. J Dent (Shiraz). 2015 Mar;16(1 Suppl):50-5.
27. Lam PP, Palamara JE, Messer HH. Fracture strength of tooth roots following canal preparation by hand and rotary instrumentation. J Endod. 2005 Jul;31(7):529-32.