Deformation of Nickel-Titanium (NiTi) rotary instruments in cyclic loading – *in vitro* study

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SUMMARY

Introduction Separation of instruments in the root canal is one of the challenges in endodontic treatment. More specifically, nickel-titanium (NiTi) rotary instruments usually separate without previous deformation. The aim of this pilot study was to assess the effect of torsional stress on endodontic NiTi rotary instruments separation in simulated clinical conditions.

Materials and methods Research was conducted on a sample of 20 human teeth in laboratory conditions. Experimental procedure consisted of determining canal curvatures for each root on digital radiographs and root canal treatment using endodontic NiTi rotary instruments. Out of 20 teeth (60 canals), two groups were formed with similar root canal curvatures (10 pairs of teeth) and instrumented using NiTi rotary instrument with or without torque control.

Results Wilcoxon matched pair test showed no statistically significant difference in average number of instruments use with or without torque control ($p > 0.05$).

Conclusion Even though there is no statistical significance in instrument separation when instruments were used with or without torque, there is tendency to experience sudden fracture of instruments after work without torsional control even after only few uses in clinical work.

Keywords: nickel-titanium rotary instruments; torque; separation

INTRODUCTION

Cleaning and shaping of root canals (instrumentation and aseptic irrigation) are main preconditions for complete disinfection, which can determine the result of endodontic treatment. Root canal shaping needs to be performed respecting the initial morphology of the root canal. Ideally, a conical shape of canal from apical to coronal part should be maintained while apical foramen should remain in its anatomical and morphological position, with uninterrupted integrity [1]. Root canal systems are complex and usually more curved than roots especially if analyzed in 3D plane. Using inflexible, rigid endodontic instruments made of stainless steel can result in transportation and perforation of root canal walls, due to their characteristics to preserve initial shape after flexion [2].

Unlike endodontic instruments made of stainless steel, nickel-titanium (NiTi) rotary instruments are more present in clinical practice, primarily due to significantly faster shaping of root canals, technically simplified instrumentation, minimal errors in shaping and smaller number of instruments required. Numerous *in vitro* studies on extracted teeth showed that rotary NiTi instruments retain the original (initial) curvature of the root canal better, especially in the apical zone of the root [3, 4].

NiTi has superelastic feature - ability to restore its original shape (shape-memory effect) and high corrosion resistance. Also, nickel titanium is biocompatible material [5]. Superelastic feature of NiTi endodontic instruments

is associated with induced phase transformation of the crystal structure of the material [6]. Shape-memory effect of this alloy allows restoring the original shape and size after temperature change. Although NiTi alloy is called superelastic this material is still susceptible to fatigue and leads to its fracture after a certain number of cycles, so we call this feature pseudoelastic. Repeated loading leads to progressive accumulation of defects in the metal structure, and consequently its fracture [7].

Breakage or separation of endodontic instruments in root canal is one of complications during endodontic treatment. Unlike nickel-titanium, classic endodontic instruments made of stainless steel are visibly deformed prior to fracture; therefore dentist can discard such instruments during clinical work before they separate. Despite of increased flexibility, the occurrence of separation of nickel-titanium instruments is significant clinical problem, because the fracture of nickel-titanium instruments happens without previous deformation or macroscopically visible irregularities on instruments. Visual inspection as a method of control of nickel-titanium instruments use is not clinically reliable and cannot be used for determining the time to discard an instrument from clinical use [8].

Several factors can influence fracture of NiTi instruments, such as the size, taper and the shape of the cross-section of instruments. On the other hand, there are views that inexperienced dentist is main factor that leads to failure in NiTi instruments use [9]. Despite the low incidence,

fracture of endodontic instruments is a significant clinical problem. Stainless steel instruments usually deform before breaking, however NiTi instruments can be broken without any visible signs of deformation [10]. NiTi rotary instruments fracture during clinical use may be the result of cyclic fatigue, excessive torsional stress, or combination of both [11].

Cyclic fatigue occurs when the instrument rotates freely in a curved canal and fracture occurs at the site of its maximum curvature [12]. Maximum stress and strain are developed in the curved surface of the instrument. By cyclic rotation, the instrument is subjected to compression and stretching, and number of cycles is positively correlated with the fatigue of material. It is very difficult to determine the amount of stress that one instrument is getting during clinical use, but some estimates can be given based on the analysis of the curvature of root canals on the preliminary X-rays [10].

Torsional stress usually occurs when part of the instrument is screwed into the root canal wall, when the tip of the instrument is greater than diameter of the root canal, or when there is excessive pressure on the instrument during operation [13]. If the tip of the instrument in the root canal is blocked, and endo-motor that rotates the instrument continues to deliver torque, there is an accumulation of torsional stress within the material, which after exceeding the critical load points, consequently leads to plastic deformation and fracture of the instrument [14].

On the other hand, even if endodontic motor is used with torque control that prevents excessive torque loads and eliminates the occurrence of turning instrument in the root canal, inevitable fatigue due to repeated torsional stresses of material develops [15].

Numerous studies have shown that torsional stress is the primary cause of defects and failures of endodontic NiTi rotary instruments [11, 16, 17]. Many manufacturers recommend endo motors with torque control. While some studies indicate no statistically significant difference in the occurrence of deformation and separation of endodontic NiTi rotary instruments whether they are used at different speeds and with or without torque [18, 19, 20], manufacturers always emphasize the necessity of using endo-motor with torque control for safety reasons. On the other hand, some manufacturers have introduced endodontic reduction hand-pieces that can be used with different types of endodontic full rotation instruments. They don't have torsional control and controlled rotational speed, but due to the more favourable price compared to electric endo-motors, they are widely accepted in clinical practice.

The aim of this study is to assess the influence of torsional stress on separation of endodontic NiTi rotary instruments in simulated clinical conditions.

MATERIALS AND METHODS

The study was conducted on a sample of twenty human teeth in laboratory conditions. The sample consisted of the first, second and third molars of the upper and lower

jaw extracted at the Department of Oral Surgery Dental Clinic in Novi Sad. The period from extraction to the beginning of test was not longer than one month. After surgical removal, the crowns and roots of the teeth were washed from blood and saliva and with surgical curette soft tissue was removed. The teeth were then immersed in a bacteriostatic / bactericidal solution (0.5% chloramine), over the next seven days at a temperature of 4 degrees Celsius. The teeth were rinsed with distilled water and left in non-ionized water (ISO 3696), on the storage temperature (4 degrees Celsius). Every 48 hours, non-ionized water was replenished with fresh water.

The procedure of the experimental work involved the following steps:

1. Formation of access cavity.
2. Establishing initial patency of the root canal.
3. Determining the working length of each canal with apex locator.
4. X-ray recording with manually placed stainless steel instrument # 10 in the canal.
5. Measurement of the curvature of each root canal.
6. Root canal endodontic treatment with NiTi rotary instruments.

The entire procedure was carried out by a student of the fifth year of dentistry at the Faculty of Medicine in Novi Sad, without previous clinical experience with mechanical endodontic instruments but with previous training and ongoing supervision of accredited manager from manufacturer Dentsply / Maillefer who had years of clinical experience.

Access cavity preparation was performed with a high speed handpiece and water-cooled bur at 300 000 rpm (W & H), carbide round bur #44 and tapered fissure bur in the set Endo Access Kittm (Dentsply Maillefer, Ballaigues, Switzerland). Initial patency of the root canal was established manually with hand K expander #10, using reciprocal movement to the apical constriction. Samples were immersed with their root part in alginate (irreversible hydrocolloid) (Zermak Co., Italy), as shown in Figure 1. Working length was determined for each root canal with hand file K Expander #10 and electronic apex locator (Propex II, Dentsply Maillefer, Ballaigues, Switzerland). Periapical x-ray was taken in bucco-lingual direction individually for each tooth with K files placed into the canals (Sirona, Heliodont Vario Digital Dental Xray "2002", 70 kV, 7mA, 120V, D3350, Germany) (Figure 1).

Determination of curvature for each root canal - angle of curvature (α) and radius of curvature (R) were determined on the x-ray for each root canal using AutoCAD software (AutoCAD 2009, Autodesk Inc., San Rafael, USA) (Figure 2).

After calculating the average curvature for each of 20 teeth, two groups with 10 teeth each were established with the most similar curvature (Table 1). Before mechanical instrumentation, glide path was achieved using hand endodontic reamers K #10, #15 and #20. Shaping and cleaning of root canals was done with NiTi rotary instruments Pro-Taper Universal (Dentsply Maillefer, Ballaigues, Switzerland) driven by endo-motor (X-Smart, Endodontic Motor, Dentsply/Maillefer, Ballaigues, Switzerland: 07927988) as

Figure 1. X rays with K file #10 taken in bucco lingual projection individually for each tooth

Slika 1. Rendgenski snimak zuba sa K turpijama #10 u kanalima u oro-bukalnom pravcu

Figure 2. Determination of average curvature for each root canal
Slika 2. Određivanje prosečne zakrivljenosti kanala korena zuba

Graph 1. Average number of instruments usage in groups with and without torque control

Grafikon 1. Prosečan broj upotreba instrumenata u grupama sa torzionom kontrolom i bez nje

follows: S1, S2, F1 and F2 - a sequence of instruments recommended by the manufacturer. Throughout instrumentation copious irrigation of canals with sodium hypochlorite (1% NaOCl), lubrication Glyde File (DeTrey / Dentsply, Konstanz, Germany) and recapitulation with manual expander K #10 were done. Rotational speed of ProTaper Universal instrument was fixed at 250 rpm, as recommended by the manufacturer for using ProTaper Universal instruments in clinical conditions. The instruments were used for the root canal preparation with and without torque.

This way, two groups of teeth were formed:

First group of teeth (N = 10) was instrumented with endo-motor with set torque (3 N/cm instruments for S1, 1 N/cm for S2, 1.5 N/cm for F1 and 2 N/cm for F2 instrument, as per manufacturer recommendation.

Second group of teeth (N = 10) was treated with endo-motor without torque control; it was set to 5.2 N/cm, which is the highest adjustable value of torque.

Length of use for each tested instrument in the root canal was not longer than 10 seconds. Rotation period (10 seconds) corresponds to the time period necessary to complete the root canal instrumentation in clinical use of Ni-Ti instruments, according to researchers [21]. In both groups, instruments were used in the above sequence (S1, S2, F1, F2) and the number of usage was recorded (number of canals instrumented to the point of fracture of the instrument). After the failure of an instrument, that one was substituted with a new instrument, and others were continuously used by the time of their fracture.

Statistical analysis was carried out in two phases: in the first phase, the results presented numerical variables that were analyzed by standard procedures of descriptive statistics. Descriptive statistics were used to determine the measure of central tendency (mean, median), measures of variability (standard deviation, coefficient of variation) and the minimum and maximum values. The results are presented in tables and graphs. In the second phase, the following methods were used to compare individual characteristics, Mann-Whitney U-test to compare mean values of the two independent variables and Wilcoxon matched pairs test. Statistical analysis was performed using the software package Statistica 9.1, while the tables and graphs were done in Microsoft Office Excel 2010.

RESULTS

Table 2 presents descriptive statistic of the sample: Number of canals (N), angle and radius of curvature (Xsr), minimum and maximum value measured (min, max), standard deviation (SD) and cumulative value of average curvature of all teeth in both groups (n = 10). T-test for two paired samples determined that there was no statistically significant difference in average curvatures between the groups with and without torque control ($p > 0.05$) and they could be considered as two homogeneous groups.

Table 1. Preview of 10 pairs of two teeth with similar average curvature**Tabela 1.** Prikaz 10 parova od po dva zuba sa najsličnijim prosečnim zakrivljenostima

GROUP OF TEETH WITH TORSION CONTROL GRUPA ZUBA SA TORZIONOM KONTROLOM					GROUP OF TEETH WITHOUT TORSION CONTROL GRUPA ZUBA BEZ TORZIONE KONTROLE				
Tooth	kanal	R (mm)	U (°)	R*U prosek	Zub	kanal	R (mm)	U (°)	R*U prosek
1	1	17.37	25.86	597.96	1	1	29.81	21.22	562.15
	2	10.77	56.22			2	35.97	17.06	
	3	10.77	56.22			3	30.99	14	
2	4	50.99	6.94	666.04	2	4	51.04	7.22	651.65
	5	5.78	35.68			5	5.96	37.06	
	6	4.43	55.3			6	4.23	51.48	
3	7	85.29	5.94	828.63	3	7	69.90	10.66	807.70
	8	25.16	18.38			8	17.56	26.48	
	9	11.15	37			9	17.23	32.28	
4	10	122.20	3.36	911.97	4	10	37.81	18.42	876.54
	11	78.68	6.52			11	10.77	59.44	
	12	24.46	26.54			12	10.98	54.56	
5	13	103.25	6.14	976.114588	5	13	67.88	8.4	1305.70
	14	26.17	25.16			14	14.50	51.28	
	15	26.17	25.16			15	10.63	66.64	
6	16	278.42	0.84	2523.92	6	16	241.20	1.84	2271.58
	17	11.81	31.76			17	18.91	32.64	
	18	7.24	43.76			18	8.95	41.5	
7	19	33.17	14.34	537.04	7	19	41.52	9.54	499.13
	20	17.72	24.4			20	14.30	25.04	
	21	9.94	40.7			21	7.81	36	
8	22	37.65	11.86	682.35	8	22	26.41	16.84	685.16
	23	17.77	28.92			23	6.61	63.92	
	24	9.76	53.42			24	6.04	77.06	
9	25	25.41	14.5	419.51	9	25	18.20	12	468.68
	26	18.48	21.94			26	16.74	21.08	
	27	16.20	26.38			27	7.20	66.98	
10	28	5.02	31.48	316.64	10	28	2.32	42.7	255.88
	29	7.80	51.76			29	6.10	62.16	
	30	6.80	61.88			30	4.88	68.06	

Table 2. Descriptive statistics of both tested groups**Tabela 2.** Deskriptivna statistika obe ispitivane grupe

Variable Varijabla	N Broj	With torque control Sa torzionom kontrolom		Without torque control Bez torzione kontrole	
		Xsr ± SD	Min–Max	Xsr ± SD	Min–Max
Angle Ugao	30	28.28 ± 17.89	0.84–61.88	35.19 ± 22.26	1.84–77.06
Radius Radijus	30	36.85 ± 54.66	4.43–278.42	28.09 ± 44.08	2.33–241.2
Average curvature Prosečna povijenost	10	846.0 ± 624.9	316.64–2523.93	838.4 ± 577.4	255.89–2271.58

The table shows data of average canal curvature in the group without torque and with torque control. The obtained values do not show statistically significant difference in curvature between the groups ($p > 0.05$).

U tabeli su prikazani podaci zbirnih srednjih vrednosti povijenosti u grupi bez torzione i u grupi sa torzionom kontrolom. Dobijene vrednosti ne govore u prilog statistički značajnoj razlici ($p > 0.05$).

Test results of the instruments usage till the moment of separation are shown in Chart 1. In the group with torque control instrument S1 separated after shaping 24 root canals (during the shaping of the 24th canal); instrument S2 separated after shaping 24 root canals (during shaping of the 25th canal) (instrument S2 was not shaping 24th canal where separation of S1 occurred); instrument F1 separated after it shaped 20 root canals (during the preparation of 20th canal), instrument F2 was not separated even after shaping of all 27 root canals. Instrument F2 was not used to shape 24th canal where S1 separation

occurred, 25th canal where S2 separation occurred, or the 20th root canal where F1 separation occurred.

In the group without torque, instrument S1 separated after shaping 22 root canals (during shaping of the 22nd canal) and the new one separated after 2nd usage, during preparation of the 24th root canal. Instrument S2 separated after the 23rd usage (during the preparation of the 25th root canal). Instrument S2 did not shape the canal where S1 separation occurred (root canals number 22 and 24). Instrument F1 separated after 24 usages, during the shaping of the 27th root canal. Instrument F1 was not used for

shaping canals where S1 separation occurred (root canal number 22 and 24) and also canals where separation of S2 occurred (25th canal). Instrument F2 separated after 21 usages (during the shaping of the 21st root canal) and the second one was separated after 5 usages (during shaping of the 30th canal). The second F2 instrument was not used for shaping canals where separation of previous instruments occurred (canals number 22, 24, 25, 27).

Man-Whitney U test showed no statistically significant difference in the average usage of instruments with or without torque control ($p > 0.05$). Wilcoxon matched pair test confirmed no statistically significant difference in average usage of instruments with or without torque control ($p > 0.05$).

DISCUSSION

A young dentist who had no previous clinical experience with mechanical endodontic instruments did the experimental part of this study. In previous studies, it has been suggested that the experience of the clinician may significantly affect the quality of endodontic treatment. However, there were opposite findings where there was no significant difference in the quality of endodontic treatment based on clinical experience, if they follow clearly defined principles of modern endodontics with proper training and use of modern instruments and techniques [22–25].

In our study, the canal curvature was determined based on methodology proposed by Pruett's [10]. Geometrical analysis of the position of the instrument in each canal using digital radiography and AutoCAD application was performed [26]. After calculation of average curvature of each tooth, 10 pairs of teeth were formed with the most similar curvatures.

In experimental part of the study, all instruments were used at the speed of 250 rpm as recommended by the manufacturer. As for the torque, manufacturer emphasized the necessity of setting it to the value recommended for each individual instrument and these values were used in root canal instrumentation of group with torque control. There are findings in the literature that the value of torque has no effect on the number of shaping canals with NiTi instruments full rotation, which is applied in instrumentation of root canals in the group without torque [27].

To reduce the risk of instrument separation manufacturer's instructions for use should be followed carefully, and only a few rotational cycles of the instrument are safe when working in curved canals [28]. There is no consensus on recommended usage of NiTi instruments; the number of canals varies from 1–27, with an average of 11 canals [8]. Guettier suggested that rotary instruments could be reused, depending on the type of teeth that are treated, for example instruments used for anterior teeth can be reused higher number of times than in posterior teeth. Most authors recommend discarding the instrument after its use in highly curved, calcified and complex root canals, and in the case of occurrence of any signs of deformation [11, 16, 29, 30]. Of course, a good knowledge

of predisposing factors that lead to NiTi instruments separation is crucial in the prevention of this phenomenon.

Observing the results of this pilot study, all instruments tested with torque control were used 20 or more times until they fractured, where F2 was not separated even after 27 uses. In the group without torque control, fracture of instruments occurred after 20 or more uses, but S1 was broken after only two time use, and F2 instrument after five uses. Although there is no statistically significant difference in results between the two groups considering limitation of this pilot study, we can see a tendency that working without torque can cause unexpected breakage of instruments just after a few usage in clinical practise.

CONCLUSION

The clinical significance of this study is that when working with NiTi rotary instruments, it is important to respect manufacturer's instructions, given that there is no official recommendation on the number of use of NiTi rotary instruments. Although the analysis of the obtained data did not show statistical significance, considering the limitation of the study, it is possible to see the tendency to experience sudden fracture of instruments after work without torque control even if instruments used only few times.

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Deformacije nikl-titanijumskih mašinski pokretanih instrumenata pune rotacije u cikličnom opterećenju – *in vitro* studija

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KRATAK SADRŽAJ

Uvod Separacija ili lom endodontskih instrumenata u kanalu korena zuba je jedna od težih komplikacija u toku endodontske terapije. Separacija nikl-titanijumskih instrumenata je značajan klinički problem, jer do loma nikl-titanijumskih instrumenata dolazi bez prethodne deformacije. Cilj rada je bio da se proceni uticaj torzione kontrole na pojavu separacije endodontskih NiTi instrumenata pune rotacije u klinički simuliranim uslovima.

Materijal i metode Ispitivanje je izvršeno na uzorku od dvadeset ekstrahovanih humanih zuba u laboratorijskim uslovima. Postupak je podrazumevao merenje povijenosti kanala korena na digitalnim rendgengrafijama svakog pojedinačnog korena zuba, obradu kanala NiTi instrumentima pune rotacije. Nakon izračunavanja prosečne povijenosti svakog od 20 zuba (60 kanala), napravljeno je deset parova od po dva zuba sa najsličnijim prosečnim zakrivljenostima. Na taj način su formirane dve grupe zuba.

Rezultati Wilkoxsonovim testom parova (Wilcoxon matched pair test) potvrđeno je da ne postoji statistički značajna razlika u prosečnom broju upotreba instrumenata sa torzionom kontrolom i bez nje ($p > 0,05$).

Zaključak Iako analiza dobijenih podataka nije pokazala statističku značajnost, s obzirom na limitiranost studije može se uvideti tendencija da pri radu bez torzione kontrole može doći iznenadnog loma instrumenata posle samo nekoliko upotreba u kliničkom radu.

Ključne reči: NiTi; puna rotacija; zamor materijala; obrtni momenat; separacija

UVOD

Čišćenje i oblikovanje kanalnog prostora zuba, odnosno instrumentacija i antiseptična irigacija, ključni su preduslovi potpune dezinfekcije kanalnog prostora, od čega umnogome zavisi ishod endodontske terapije. Preoblikovanje endodontskog prostora se mora sprovesti poštujući inicijalnu morfologiju kanala korena zuba. Osnovni zahtevi oblikovanja kanalnog prostora su: konični oblik preparacije od najšireg koronarnog do najužeg apikanog dela kanala, kanalna preparacija mora zadržati inicijalni oblik kanala korena i apikalni foramen treba da ostane na svojoj anatomo-morfološkoj poziciji, nenarušenog integriteta [1]. Kanalni sistemi znatno su povijeniji od korenova zuba u kojima su smešteni i prostiru se u trodimenzionalnoj ravni. Korišćenje nefleksibilnih, krutih endodontskih instrumenata od nerđajućeg čelika u instrumentaciji kanala može rezultirati transportacijom (izmeštanjem) i perforacijom (probijanjem) kanala korena, zbog svojstva ovog instrumenta da se nakon savijanja ispravlja i vraća u svoj inicijalni oblik [2].

Za razliku od endodontskih instrumenata od nerđajućeg čelika, nikl-titanijumski instrumenti pune rotacije su sve više zastupljeni u kliničkoj praksi, prvenstveno zbog značajno bržeg oblikovanja kanala korena zuba, tehnički pojednostavljene instrumentacije, a moguće greške lekara su svedene na minimum zahvaljujući superelastičnosti nikl-titanijumskih instrumenata i manjem broju instrumenata potrebnom za oblikovanje kanala korena. Brojne *in vitro* studije na ekstrahovanim zubima, pokazale su da se upotrebom nikl-titanijumskih instrumenata pune rotacije bolje prati originalna (inicijalna) povijenost kanala korena, posebno u apikalnoj zoni korena zuba, u odnosu na endodontske instrumente izrađene od nerđajućeg čelika [3, 4].

Legura nikl-titanijuma (NiTi) poseduje svojstvo superelastičnosti, sposobnost vraćanja prvobitnog oblika (*shape-memory effect*) i visok stepen otpornosti na koroziju [5]. Superelastičnost nikl-titanijumskih endodontskih instrumenata je povezana sa indukovanom faznom transformacijom kristalne

strukture samog materijala [6]. *Memory effect* je sposobnost legure za ponovno uspostavljanje prvobitnog oblika i dimenzija nakon promene temperature. Materijal je ipak osetljiv na zamor i dolazi do njegovog loma nakon određenog broja ciklusa opterećenja, iako je NiTi legura superelastična. Naime, ponavljana opterećenja dovode do progresivne akumulacije defekata u strukturi metala, što sledstveno dovodi do njegovog loma [7].

Lom ili separacija endodontskih instrumenata u kanalu korena zuba je jedna od težih komplikacija u toku endodontske terapije. Za razliku od nikl-titanijumskih, klasični instrumenti izrađeni od nerđajućeg čelika se vidljivo deformišu pre pucaanja, tako da terapeut može da odbaci ovakve instrumente tokom kliničkog rada i spreči separaciju u toku endodontskog zahvata. Endodontski instrumenti pune rotacije izrađeni od nikl-titanijumske legure poseduju superelastična svojstva i mogu se savijati značajno više od klasičnih instrumenata od nerđajućeg čelika. Međutim, i pored povećane fleksibilnosti, pojava separacije nikl-titanijumskih instrumenata je značajan klinički problem, jer do loma nikl-titanijumskih instrumenata dolazi bez prethodne deformacije, odnosno, makroskopski uočljivih iskrivljenosti i/ili nepravilnosti instrumenta. Vizuelna inspekcija kao metod kontrole korišćenih nikl-titanijumskih instrumenata nije klinički pouzdana te se ne može koristiti u svrhu determinisanja trenutka odbacivanja instrumenta iz dalje kliničke upotrebe [8].

Više faktora može uticati na pojavu loma NiTi instrumenata, a to su veličina, koničnost i oblik poprečnog preseka instrumenata, kao i obučenosť samog terapeuta. S druge strane, postoje stavovi da je neobučeni terapeut osnovni negativni faktor koji dovodi do neuspeha pri korišćenju NiTi instrumenata [9]. Uprkos niskoj incidenciji, lom endodontskih instrumenata je značajan klinički problem. Instrumenti od nerđajućeg čelika se obično deformišu pre lomljenja, međutim NiTi instrumenti se mogu slomiti bez bilo kakvih vidljivih znakova deformacije [10]. Lom NiTi instrumenata pune rotacije tokom kliničke upo-

trebe može biti rezultat cikličnog zamora materijala, prekomernog torzionog opterećenja ili kombinacije oba [11].

Ciklični zamor nastaje kada se instrument slobodno rotira u zakrivljenom kanalu, pri čemu do loma dolazi na mestu njegove maksimalne povijenosti [12]. Maksimalno naprezanje i deformacija se razvijaju na površini povijenog instrumenta. Pri rotiranju u uslovima zakrivljenosti, instrument podleže cikličim kompresijama i istezanjima, gde je broj ciklusa u pozitivnoj korelaciji sa zamaranjem materijala. Veoma je teško odrediti količinu naprezanja koje instrument trpi tokom kliničke upotrebe, ali se mogu napraviti određene procene pri analizi povijenosti kanala korena na preliminarnom rtg snimku [10].

Torziono preopterećenje se obično događa kada se deo instrumenta uvrće u zid kanala tj. kada je vrh instrumenta veći od promera kanala korena, ili kada se vrši prekomeran pritisak na instrument u toku rada [13]. Ukoliko je vrh instrumenta blokiran u kanalu korena, a endo-motor, koji rotira instrument, nastavi da isporučuje obrtni momenat, dolazi do akumulacije torzionog stresa unutar materijala, što nakon prekoračenja kritične tačke opterećenja, dovodi prvo do plastične deformacije, a posledično i loma instrumenta [14].

S druge strane, i kada se koristi endodontski motor sa torzionom kontrolom, koji sprečava prekomerno torziona opterećenje i eliminiše pojavu ušrafljivanja instrumenta u kanalu korena, ipak dolazi do zamora materijala zbog neminovnih ponavljanih torzionih naprezanja materijala koji se javljaju pri radu instrumenta [15].

Na osnovu brojnih studija, torzioni zamor je primarni uzrok pojave defekata i lomova endodontskih NiTi instrumenata pune rotacije [11, 16, 17]. Upotreba električnih endo-motora sa torzionom kontrolom je preporučena od strane mnogih proizvođača. Iako neka istraživanja ukazuju da ne postoji statistički značajna razlika u pojavi deformacije i separacije endodontskih NiTi instrumenata pune rotacije ukoliko se koriste pri različitim brzinama i sa torzionom kontrolom ili bez nje [18, 19, 20], proizvođači uvek naglašavaju neophodnost upotrebe gorepomenutih endo-motora zbog sigurnosti u radu. S druge strane, pojedini proizvođači su predstavili endodontske redukcione kolenjake koji se mogu koristiti sa različitim tipovima endodontskih instrumenata pune rotacije. Ovi endodontski kolenjaci ne poseduju torzionu kontrolu i kontrolisanu brzinu rotiranja, ali su zbog povoljnijeg finansijskog momenta u odnosu na električne endo-motore široko zastupljeni u kliničkoj praksi.

Cilj ovog rada bio je da se ispita uticaj torzione kontrole na pojavu separacije endodontskih NiTi instrumenata pune rotacije u klinički simuliranim uslovima.

MATERIJAL I METODE

Ispitivanje je izvršeno na uzorku od dvadeset humanih zuba u laboratorijskim uslovima. Uzorak se sastojao od prvih, drugih i trećih molara gornje i donje vilice, izvađenih na odeljenju Oralne hirurgije Klinike za stomatologiju Vojvodine u Novom Sadu. Period od vađenja zuba do upotrebe u ispitivanju nije bio duži od mesec dana. Posle hirurškog vađenja, sa krunice i korena zuba isprani su krv i saliva fiziološkim rastvorom, i hirurškom kiretom uklonjeni zaostali delovi mekih tkiva. Potom su zubi potopljeni u bakterioestatični/baktericidni rastvor (0,5% hloramini), tokom narednih sedam dana na temperaturi od 4

stepena Celzijusa. Zubi su isprani destilovanom vodom i ostavljeni u nejonizovanoj vodi (ISO 3696), na temperaturi čuvanja od četiri stepena Celzijusa. Svakih 48 sati nejonizovana voda je kompletno zamenjena svežom.

Postupak eksperimentalnog rada podrazumevao je sledeće:

- formiranje pristupnog kaviteta na zubima koji su činili uzorak
- uspostavljanje inicijalne prohodnosti kanala korena zuba
- određivanje radne dužine svakog kanala apeks lokatorom
- rendgenografsko snimanje zuba sa postavljenim ručnim kanalnim proširivačima od nerđajućeg čelika #10
- merenje zakrivljenosti kanala svakog pojedinačnog korena
- obradu kanala korena zuba endodontskim NiTi instrumentima pune rotacije

Celokupan postupak je realizovan od strane stomatologa bez prethodnog kliničkog iskustva u radu sa mašinskim endodontskim instrumentima, uz prethodnu obuku i stalni nadzor akreditovanog rukovodioca endodontskih kurseva za proizvode firme Dentsply/Maillefer sa višegodišnjim kliničkim iskustvom.

Formiranje pristupnog kaviteta vršeno je visokoturažnom bušilicom sa vodenim hlađenjem 300000 o/min. (W&H), i karbidnim okruglim svrdlom #4 koničnim fisurnim borerom iz seta EndoAccess Kittm (Dentsply Maillefer, Ballaigues, Switzerland). Uspostavljanje inicijalne prohodnosti kanala korena zuba vršeno je ručnim K proširivačima #10, recipročnim pokretima do apeksnog suženja. Uzorci su korenskim delom uronjeni u ireverzibilni hidrokoloid alginat (Zermak Co., Italy). Posle toga je izvršeno određivanje radne dužine svakog kanala korena ručnim K proširivačima #10 elektronskim apeksnim lokatorom (ProPex II, Dentsply Maillefer, Ballaigues, Switzerland). Radiografsko snimanje je vršeno u vestibulo-oralnoj projekciji pojedinačno za svaki zub, za ispitivanje korišćena je rendgen jedinica za digitalnu radiografiju (Sirona, Heliodont Vario Digital Dental Xray "2002" X-ray 1 YR WARR; 70 KV, 7MA, 120V, D3350, Germany). Neposredno pre snimanja zuba u svaki kanal korena zuba je plasirana po jedna K turpija #10, na prethodno određenu radnu dužinu (Slika 1).

Određivanje povijenosti svakog kanala korena – ugao zakrivljenosti (α) i radijus zakrivljenosti (R) – urađeno je na digitalnim rendgengrafijama svakog pojedinačnog kanala korena zuba pomoću aplikacije AutoCad (AutoCAD 2009, Autodesk Inc., San Rafael, USA), što se vidi na Slici 2, odnosno matematički je određena prosečna povijenost kanala svakog zuba (Slika 2).

Posle izračunavanja prosečne povijenosti svakog od 20 zuba, napravljeno je 10 parova od po dva zuba sa najsličnijim prosečnim povijenostima (Tabela 1). Neposredno pre mašinske instrumentacije svi kanali su obrađeni ručnim endodontskim K proširivačima #10, #15 i #20. Zatim je urađena mašinska obrada kanala korena svakog zuba endodontskim NiTi instrumentima pune rotacije ProTaper Universal (Dentsply Maillefer, Ballaigues, Switzerland) pokretanih endo-motorom (X-Smart, Endodontic Motor, Dentsply/Maillefer, Ballaigues, Switzerland, sn:07927988) i to: prvo instrument S1, zatim S2, pa F1 i na kraju F2 – što predstavlja sekvencu korišćenja instrumenata po preporuci proizvođača. Brzina rotacije je fiksirana na 250 obrt/min. Celokupna instrumentacija je urađena uz obilnu irigaciju kanala rastvorom natrijum-hipohlorita (1% NaOCl), lubrikacija preparatom Glyde File (DeTrey/Dentsply, Konstanz, Germany) i rekapitulacija ručnim kanalnim proširivačem #10. Instrumenti su korišćeni za obradu kanala korena zuba sa torzionom kontrolom i bez nje.

Na taj način su formirane dve grupe zuba:

1) Grupa zuba ($N = 10$) koji su obrađivani instrumentima sa torzionom kontrolom; po preporuci proizvođača vrednost torzije, pri kojoj se blokira dalji rad endo-motora i rotiranje instrumenata u kanalu, bila je podešena na 3 Ncm za instrumente S1, 1 Ncm za instrumente S2, 1,5 Ncm za instrumente F1 i 2 Ncm za instrumente F2.

2) Grupa zuba ($N = 10$) koji su obrađivani instrumentima bez torzione kontrole; vrednost torzije za sve instrumente, pri kojoj se blokira dalji rad endo-motora i rotiranje instrumenata u kanalu, bila je podešena na 5,2 Ncm, što je i najviša podesiva vrednost korišćenog električnog aparata.

Dužina upotrebe svakog ispitivanog instrumenta pri instrumentaciji kanala korena zuba nije bila duža od 10 sekundi. Period rotacije (10 sekundi) odgovara periodu potrebnom za kompletnu instrumentaciju kanala korena zuba pri jednoj kliničkoj upotrebi Ni-Ti instrumenta, prema rezultatima istraživanja Pasqualinija i sar. [21]. U obe grupe instrumenti su korišćeni u gorepomenutoj sekvenci (S1, S2, F1, F2) i beležio se broj upotreba (broj obrađenih kanala do momenta loma instrumenta), s tim što se posle loma nekog instrumenta taj instrument zamenjivao novim, a ostali su nastavljali da se koriste do momenta njihovog loma.

Statistička analiza je sprovedena u dve faze: u prvoj fazi rezultati su prikazali numeričke varijable koje su analizirane standardnim procedurama deskriptivne statistike. Deskriptivne statistike su korišćene da se utvrdi mera centralne tendencije (srednja vrednost, medijana), mere promenljivosti (standardna devijacija, koeficijent varijacije) i minimalne i maksimalne vrednosti. Rezultati su prikazani u tabelama i grafikonima. U drugoj fazi za upoređivanje pojedinačnih karakteristika korišćeni su Mann-Whitney U-test za upoređivanje srednje vrednosti dve nezavisne varijable i Viloksonov test parova. Statistička analiza izvršena je korišćenjem softverskog paketa Statistica 9.1, a tabele i grafikoni su urađeni u programu Microsoft Office Excel 2010.

REZULTATI

U Tabeli 2 prikazana je deskriptivna statistika uzorka obe ispitivane grupe: broj kanala (N), ugao i radijus zakrivljenosti kanala (X_{sr}), minimalna i maksimalna vrednost, standardna devijacija (SD), kumulativna vrednost srednje zakrivljenosti kanala u obe grupe ($n = 10$). T-testom za dva sparena uzorka utvrđeno je da ne postoji statistički značajna razlika u prosečnim zakrivljenostima između grupa sa torzionom kontrolom i bez nje ($p > 0.05$), tj. utvrđeno je da se može smatrati da su dve grupe homogene.

Rezultati ispitivanja broja uporeba instrumenata do pojave loma prikazani su na Grafikonu 1.

U grupi sa torzionom kontrolom:

Instrument S1 – polomljen je posle 24 upotrebe (pri obradi 24. kanala korena). Instrument S2 – polomljen je posle 24 upotrebe (pri obradi 25. kanala korena). * Instrument S2 nije obrađivao 24. kanal u kome se slomio S1.

Instrument F1 – polomljen je posle 20 upotreba (pri obradi 20. kanala korena). Instrument F2 – nije polomljen ni posle 27 upotreba (obrađio je 27. kanal).

* Instrument F2 nije obrađivao kanale u kojima su se slomili instrumenti S1 (24. kanal), S2 (25. kanal) i F1 (20. kanal) zato što se oni koriste pri obradi kanala pre njega.

U grupi bez torzione kontrole:

Instrumenti S1 – prvi je polomljen posle 22 upotrebe (pri obradi 22. kanala korena), a drugi (nov) odmah posle dve upotrebe (pri obradi 24. kanala).

Instrument S2 – polomljen je posle 23 upotrebe (pri obradi 25. kanala korena).

* Instrument S2 nije obrađivao kanale u kojima su slomljeni S1 instrumenti (kanal 22 i kanal 24).

Instrument F1 – polomljen je posle 24 upotrebe (pri obradi 27. kanala korena).

* Instrument F1 nije obrađivao kanale u kojima su pukli S1 (kanal 22, kanal 24) i kanal u kome je pukao S2 (kanal 25).

Instrument F2 – prvi je polomljen posle 21 upotrebe (pri obradi 21. kanala korena), a drugi posle pet upotreba (pri obradi 30. kanala).

* Drugi instrument F2 nije obrađivao kanale u kojima su slomljeni prethodni instrumenti (kanale 22, 24, 25 i 27)

Man-Whitney U test nije pokazao statistički značajnu razliku u prosečnoj upotrebi instrumenata sa kontrolom torzionog stresa ili bez kontrole torzionog stresa ($p > 0,05$). Viloksonov test parova nije potvrdio statistički značajnu razliku u prosečnoj upotrebi instrumenata sa kontrolom ili bez kontrole torzionog stresa ($p > 0,05$).

DISKUSIJA

Eksperimentalni deo ovog rada urađen je od strane stomatologa bez prethodnog kliničkog iskustva u radu sa mašinskim endodontskim instrumentima. U dosadašnjim radovima postoje stavovi da iskustvo kliničara može značajno uticati na kvalitet endodontske terapije. Međutim, postoje i stavovi da ne postoji značajna razlika u kvalitetu sprovedenog endodontskog tretmana kada je u pitanju dužina radnog iskustva lekara, ukoliko se poštuju jasno definisani savremeni principi endodoncije uz pravilnu obuku i upotrebu savremenih instrumenata i tehnika rada [22–25].

U ovom radu je korišćen precizan metod definisanja parametara zakrivljenosti instrumenata u kanalima, kao što je predloženo od strane Prueta. [10], geometrijskom analizom položaja instrumenta u svakom kanalu, odnosno preciznim definisanjem vrednosti ugla i radijusa krivine instrumenta, aplikacijom AutoCAD na osnovu digitalnih rendgengrafija [26]. Posle izračunavanja prosečnih zakrivljenosti svakog pojedinačnog zuba formirano je 10 parova od po dva zuba sa najslabijim prosečnim zakrivljenostima, kako bi uzorak u obe grupe bio što homogeniji, odnosno kako bi nalazi instrumentacije svakog ispitivanog instrumenta (broj upotreba do pojave loma) bili uporedivi.

U eksperimentalnom delu svi ispitivani instrumenti korišćeni su pri brzinama rotiranja od 250 obrtaja u minuti, preporučenim od strane proizvođača. Što se tiče torzione kontrole, proizvođač naglašava neophodnost podešavanja njene vrednosti pri radu za svaki pojedinačni instrument i te vrednosti su korišćene u instrumentaciji kanala korena zuba kontrolne grupe (grupa sa torzionom kontrolom). Postoje stavovi da vrednost torzione kontrole nema uticaj na životni vek NiTi instrumenata pune rotacije, što je i primenjeno u instrumentaciji kanala korena zuba u eksperimentalnoj grupi (grupa bez torzione kontrole) [27].

Da bi se smanjila opasnost od loma instrumenta, uputstva proizvođača za korišćenje treba maksimalno poštovati, a samo nekoliko rotacionih ciklusa instrumenta je potpuno bezbedno pri radu u veoma zakrivljenim kanalima [28]. Ne postoji zvaničan stav o preporučenom broju korišćenja NiTi instrumenata pune rotacije; taj broj varira od 1 do 27 kanala, sa prosekom od 11 kanala [8]. Guettier [29] je predložio da se instrument može ponovno koristiti, u zavisnosti od vrste zuba koji se tretiraju, s većim brojem korišćenja kod prednjih i manjim brojem korišćenja kod bočnih zuba. Većina autora preporučuje odbacivanje instrumenta (čak i potpuno novih) nakon korišćenja u oštro zakrivljenim, kalcifikovanim i složenim kanalima korena, i u slučajevima pojave bilo kakvih znakova plastične deformacije [11, 16, 29, 30]. Naravno, dobro poznavanje predisponirajućih faktora koji dovode do frakture NiTi instrumenata pune rotacije je od presudnog značaja u prevenciji ove pojave.

Posmatrajući rezultate ove studije, svi ispitivani instrumenti u grupi sa torzionom kontrolom su upotrebljeni 20 i više puta do momenta loma, uz napomenu da instrument F2 nije polomljen ni posle 27 upotreba. U grupi bez torzione kontrole, takođe je do loma instrumenata došlo nakon 20 i više upotreba,

ali je jedan instrument S1 polomljen posle samo dve upotrebe, a jedan instrument F2 posle pet upotreba. Iako statistička obrada dobijenih rezultata nije pokazala statističku značajnost, s obzirom na limitiranost studije može se uvideti tendencija da pri radu bez torzione kontrole može doći do iznenadnog loma instrumenata posle samo nekoliko upotreba u kliničkom radu, što će biti cilj obimnijeg istraživanja koje sledi posle ove pilot studije.

ZAKLJUČAK

Klinički značaj ove studije ogleda se u tome da je pri radu sa NiTi instrumentima pune rotacije najvažnije pridržavati se uputstva proizvođača, s obzirom na to da ne postoji zvaničan stav o preporučenom broju korišćenja NiTi instrumenata pune rotacije. Iako analiza dobijenih podataka nije pokazala statističku značajnost, s obzirom na limitiranost studije može se uvideti tendencija da pri radu bez torzione kontrole može doći do iznenadnog loma instrumenata posle samo nekoliko upotreba u kliničkom radu.