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Effect of Sodium Hypochlorite Irrigation with and Without Surfactant on Maximum Operative Torque and Vertical Force of Nickel-Titanium Endodontic Instruments

Učinak ispiranja natrijevim hipokloritom sa i bez surfaktanta na maksimalni operativni okretni moment i vertikalnu silu endodontskih instrumenata od nikal-titanija

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Abstract
Objectives: This study aimed to evaluate the effects of root canal irrigation on maximum operative torque and vertical force of Wave One Gold Primary (WOG), Reciproc Blue R25 (RB) and Protaper Next X2 (PTN) endodontic rotary instruments during simulated root canal preparation in the presence and absence of a surfactant "benzalkonium chloride". **Material and methods:** A custom-made automated irrigation and torque/force analyzing device connected with endomotor was used for the study. Acrylic resin blocks with simulated curved root canals of 35° were randomly assigned to 6 groups for each file. The following irrigants were used during simulated root canal preparation with continuous rotation or reciprocation motion with pecking mode: 5% NaOCl and 5% NaOCl with 0.084% benzalkonium chloride. Maximum torque and vertical force values of files were recorded during preparation. **Results:** BAC addition to NaOCl did not significantly affect maximum torque values of instruments ($p>0.05$). WOG generated lowest torque value compared with PTN and RCB in both groups ($p<0.05$). RB generated higher vertical force compared with WOG and PTN instruments in NaOCl+BAC group. The surface modifier decreased the maximum force value of WOG instrument ($p<0.05$). **Discussion:** Surfactan addition to NaOCl had no negative effects on maximum torque and force of the instruments.

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Introduction

Endodontic rotary nickel-titanium (NiTi) file systems can be used safely for root canal preparation due to their increased flexibility, strength and ease of use compared with stainless steel instruments (1). Despite the advantages, Ni-Ti rotary instruments appear to have a higher risk of fracture (2). A separation of rotary NiTi instruments occurs due to torsional or flexural fatigue (3). Torsion is the most common type of failure caused by locking of the tip or another part of instrument in the root canal while the shank continues to rotate (4, 5). When the elastic limit of the metal is exceeded by the torque exerted by the handpiece, a fracture of the tip becomes inevitable (6). For reducing the risk of fracture of the instruments, a visual inspection of the damage on the file by the physician is recommended (7). Therefore, new designs, metal alloys, manufacturing techniques and movement kinetics have been introduced.

Reciprocating kinematics aims to reduce taper lock and consequently the risk of torsional failure compared with ro-

Uvod

Rotacijski endodontski nikal-titanijevi (NiTi) sustavi instrumenata mogu se sigurno koristiti za preparaciju korijenskih kanala zbog njihove povećane fleksibilnosti, čvrstoće i jednostavnosti pri upotrebi u usporedbi s instrumentima od nehrđajućeg čelika (1). Unatoč prednostima, čini se da su rotacijski NiTi instrumenti skloniji većemu riziku od puknuća (2). Naime, rotacijski NiTi instrumenti pucaju od zamora zbog torzije ili savijanja (3). Torzija je najčešći uzrok puknuća zbog zapinjanja vrha ili drugoga dijela instrumenta u korijenskome kanalu dok se držak nastavlja rotirati (4, 5). Kada se granica elastičnosti metala prekorači okretnim momentom nasadnika, puknuće vrha postaje neizbježno (6). Kako bi se smanjio rizik od puknuća instrumenata, preporučuje se da liječnik vizualno pregleda oštećenja (7). Pritom su uvedeni novi dizajni, metalne legure, proizvodne tehnike i kinetika kretanja.

Cilj recipročne kinematike jest smanjiti zapinjanja i posljedično rizik od torzijskoga puknuća u usporedbi s rotacijskom kretnjom (8). WaveOne Gold (WOG; Dentsply Ma-

tary motion (8). WaveOne Gold (WOG; Dentsply Maillefer, Ballaigues, Switzerland) and Reciproc Blue (RB; VDW GmbH, Munich, Germany) are reciprocating systems that have different cross sections and metal treatments. WOG has a new parallelogram cross section compared with Wave One instruments. Both WOG and RB instruments are heat treated after machining, which is related to improvements in the mechanical behavior of these files (9).

ProTaper Next instruments (PTN; Dentsply Maillefer, Ballaigues, Switzerland) are rotating files made of M-wire. A unique NiTi alloy manufactured by a thermal treatment process, which reportedly increased flexibility and resistance to cyclic fatigue, has higher strength and wear resistance than similar instruments made of conventional superelastic NiTi wires (10, 11)

Sodium hypochloride (NaOCl) is the most commonly used irrigation solution for chemical preparation during root canal treatment. However, despite its excellent tissue-dissolving and antimicrobial abilities, NaOCl presents a high surface tension (12). The ability of surface-active agents (surfactants) to reduce the surface tension of NaOCl solutions has been recently demonstrated (13). Benzalkonium chloride (BAC) is a cationic surfactant frequently used in dentine bonding agents and orthodontic resins (14). Addition of 0,084% BAC to NaOCl has been reported to reduce its contact angle and the surface energy, without affecting the free chloride content, cytotoxicity or antibacterial properties of the mixture (14).

The term of "operative torque" can be defined as the quantity of torque developed during instrument progression towards the apex. It is a real time measurement of dynamic forces needed to perform the shaping of the canal.

In the current literature, there is little information about the effects of irrigation solutions on torque and vertical force values during intracanal instrumentation with rotary NiTi files. In the literature, aqueous and paste type lubricants were compared during instrumentation with rotary NiTi instruments and it was reported that aqueous solutions reduced torque values of endodontic rotary files compared with paste type in simulated root canals (15, 16). However, there is no information about how NaOCl irrigation, with or without surfactant, changes the vertical force and torque values of rotary NiTi files during intracanal instrumentation. The aim of this study was to compare maximum torque and vertical force generated by WOG, RB and PTN instruments during canal irrigation with NaOCl and NaOCl mixed with BAC. For this purpose, a customized device for automated root canal instrumentation complemented with irrigation and torque/force analysis was developed.

The hypothesis of the present study was that instrument type and surfactant addition to sodium hypochlorite does not affect the torque/force values.

Material and methods

A customized device and software were designed and manufactured for this study. The device was used for instrumentation and irrigation of the simulated canals and determina-

illefer, Ballaigues, Švicarska) i Reciproc Blue (RB; VDW GmbH, München, Njemačka) recipročni su sustavi koji imaju različite presjeke i obradu metala. WOG ima novi presjek paralelograma u usporedbi s Wave One instrumentima. I WOG i RB instrumenti termički se obrađuju poslije strojne obrade, što je povezano s poboljšanjima u mehaničkom ponašanju tih datoteka (9).

ProTaper Next (PTN; Dentsply Maillefer, Ballaigues, Švicarska) rotirajući su instrumenti izrađeni od M-žice. Jedinstvena NiTi legura proizvedena postupkom termičke obrade koja je navodno povećala fleksibilnost i otpornost na ciklički zamor čvršća je i otpornija na trošenje od sličnih instrumenata izrađenih od konvencionalnih superelastičnih NiTi žica (10, 11).

Natrijev hipoklorid (NaOCl) najčešće je korištena otopina za kemijsku preparaciju tijekom instrumentacije korijenskih kanala. No unatoč izvrsnom otapanju tkiva i antimikrobnim svojstvima, visoka je površinska napetost (12). Nedavno je dokazano svojstvo površinski aktivnih tvari (tenzida) da smanjuju površinsku napetost otopine natrijeva hipoklorida (13). Benzalkonijev klorid (BAC) kationski je surfaktant koji se često upotrebljava u dentinskim adhezivima i ortodontskim smolama (14). Dodavanje 0,084-postotnoga BAC-a natrijevu hipokloridu smanjuje njegov kontaktni kut i površinsku energiju, a ne utječe na sadržaj slobodnoga klorida, citotoksičnost ili antibakterijska svojstva otopine (14).

Pojam „operativni okretni moment" može se definirati kao količina okretnoga momenta nastala tijekom napredovanja instrumenta prema vrhu. To je mjerenje dinamičkih sila u stvarnom vremenu potrebnih za oblikovanje kanala.

U aktualnoj literaturi malo je podataka o učincima otopina za ispiranje na vrijednosti okretnoga momenta i vertikalne sile tijekom intrakanalne instrumentacije rotirajućim NiTi instrumentima. U literaturi su uspoređeni vodeni i pastozni lubrikanti tijekom instrumentacije s rotacijskim NiTi instrumentima i objavljeno je da vodene otopine smanjuju vrijednosti okretnoga momenta endodontskih rotacijskih instrumenata u usporedbi s pastama u simuliranim korijenskim kanalima (15, 16). No nema informacija o tome kako ispiranje natrijevim hipokloridom, sa surfaktantom ili bez njega, mijenja vrijednosti vertikalne sile i okretnoga momenta rotacijskih NiTi instrumenata tijekom intrakanalne instrumentacije. Cilj ovog istraživanja bio je usporediti maksimalni okretni moment i vertikalnu silu koju stvaraju instrumenti WOG, RB i PTN tijekom ispiranja kanala natrijevim hipokloridom i natrijevim hipokloridom pomiješanim s BAC-om. U tu svrhu razvijen je prilagođeni uređaj za automatiziranu instrumentaciju korijenskoga kanala upotpunjen irigacijom i analizom okretnoga momenta/sile.

Hipoteza ovog istraživanja bila je da vrsta instrumenta i dodatak surfaktanta natrijevu hipokloritu ne utječu na vrijednosti okretnoga momenta/sile.

Materijali i metode

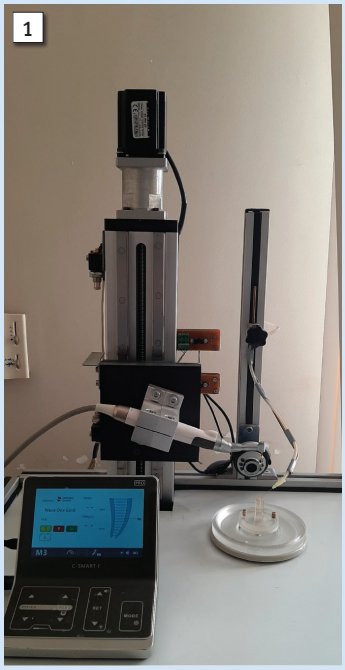
Za ovo istraživanje posebno su pripremljeni odgovarajući uređaj i softver. Uređaj je korišten za instrumentaciju i ispiranje simuliranih kanala te određivanje okretnoga momenta/

tion of the torque/vertical force during instrumentation. The device consisted of a computer (Casper, Nirvana, One PC, Turkey), an endodontic motor (C-Smart-1, COXO, Guangdong, China), a moving vertical stage which the endodontic motor head is attached to using a custom-made holder, a force measuring unit, a handle on which transparent blocks were placed, and an irrigation solution pump (Figure 1 and 2). The torque sensor of the endodontic motor was modified for measuring the torque, and apically directed forces were defined.

The device was controlled by software on the computer. When the program was run, the instant values taken from the torque and force sensors were transferred to the computer by the microcontroller.

vertikalne sile tijekom instrumentacije. Sastojao od računala (Casper, Nirvana, One PC, Turska), endodontskoga motora (C-Smart-1, COXO, Guangdong, Kina), pokretnoga vertikalnoga klipa na koji je glava endodontskoga motora pričvršćena s pomoću prilagođenoga držača, zatim jedinice za mjerenje sile te ručke na koju se postavljaju prozirni blokovi i pumpe za otopinu za ispiranje (slike 1. i 2.). Senzor endodontskoga motora modificiran je za mjerenje okretnoga momenta. Definirane su i apikalno usmjerene sile.

Uređajem je upravljao softver na računalu. Kada se program pokrenuo, trenutne vrijednosti okretnoga momenta i sile iz senzora prenošene su u računalo.



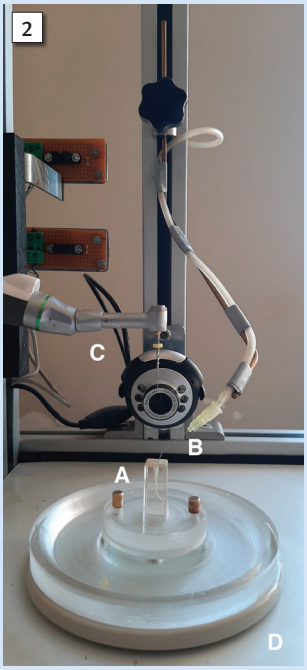


Figure 1 The root canal instrumentation, irrigation and torque/force analyzing device used in this study
Slika 1. Instrumentacija korijenskoga kanala, irigacija i uređaj za analizu okretnoga momenta/sile korišten u ovom istraživanju
Figure 2 **A:** J shaped root canal model, **B:** Irrigation tip, **C:** Endodontic motor head attached to a custom-made handle, **D:** Force measuring unit.
Slika 2. **A:** model korijenskoga kanala u obliku slova J, **B:** nastavak za ispiranje, **C:** glava na prilagođenom nastavku endodontskoga motora, **D:** jedinica za mjerenje sile

Preparation of acrylic resin blocks

Ninety acrylic resin training blocks (V04 0245; VDW, Munich, Germany) with simulated curved root canals of 35° were used in this study. Canals and apical patencies of resin blocks were checked with a #15 stainless steel hand file. In our preliminary study, we observed that most of the instruments were broken in the canal without preshaping. Therefore the canals were shaped with Protaper Next X1 file.

Preshapings were made by only one investigator (EAA), 5 ml, %5. 25 NaOCl (Werax, İzmir, Turkey) was used for irrigation between each file. After the shaping procedure, the canals were irrigated with 5 ml, %5.25 NaOCl and dried with #20 paper points (President, Allershausen, Germany).

Preparation of irrigation solutions

5.25% NaOCl and 0,084% BAC (Kim-pa, İstanbul, Turkey) mixed in 5.25% NaOCl were used in this study. During testing, solutions were heated at 37°C for mimicking body temperature.

Priprema blokova od akrilatne smole

U ovom istraživanju korišteno je 90 blokova od akirilatne smole (V04 0245; VDW, München, Njemačka) sa simuliranim zakrivljenim korijenskim kanalima od 35°. Kanali i apikalna prohodnost blokova smole provjereni su ručnim instrumentom od nehrđajućeg čelika #15. U preliminarnom istraživanju uočeno je da je većina instrumenata puknula u kanalu bez prethodnog oblikovanja. Stoga su kanali oblikovani instrumentom Protaper Next X1.

Prethodno oblikovanje učinio je samo jedan istražitelj (EAA). Za ispiranje između svakog instrumenta upotrijebljeno je 5 mL 5,25-postotnoga natrijeva hipoklorida (Werax, İzmir, Turska). Nakon postupka oblikovanja kanali su isprani s 5 mL 5,25-postotnoga natrijeva hipoklorida i osušeni papirnatim štapićima #20 (President, Allershausen, Njemačka).

Priprema otopina za ispiranje

U ovom istraživanju korišteni su 5,25-postotni NaOCl i 0,084-postotni BAC (Kim-pa, Istanbul, Turska) pomiješani u 5,25-postotnom NaOCl-u. Tijekom testiranja otopine su zagrijavane na 37 °C radi oponašanja tjelesne temperature.

Groups were designed as (n=15):

NaOCl group;

Group 1: WaveOne Gold Primary irrigated with 5. 25% NaOCl

Group 2: Reciproc Blue R25 irrigated with 5. 25% NaOCl,

Group 3: Protaper next X2, irrigated with %5. 25 NaOCl (Werax, İzmir, Turkey)

NaOCl+BAC group;

Group 4: Wave One Gold Primary irrigated with 0,084% BAC mixed in 5.25 % NaOCl

Group 5: Reciproc Blue R25 irrigated with 0,084% BAC mixed in 5. 25 % NaOCl

Group 6: Protaper next X2 irrigated with 0,084% BAC mixed in 5. 25 % NaOCl

Endodontic motor was set to rotate in "Wave One" mode for WOG; "Reciproc All" mode for RB R25, "Protaper next" mode for PTN X2. NaOCl or NaOCl mixed with BAC were transferred to root canal orifice of the acrylic blocks during instrumentation 2 mm inward from the canal orifice with a 30 gauge needle tip attached to the solution pump. 0.2ml irrigant per second was delivered through the canal orifice during the experiment. The handpiece was programmed to move in a simulated pecking motion, that is downwards for 2 s and upwards for 1s to reach the working length (16mm) of the transparent blocks.

The software recorded and plotted the values of the torque and vertical force per millisecond. The maximum torque and vertical load values were also recorded.

Statistical analysis

The data were analyzed using the Kruskal-Wallis test with Dunn-Bonferroni correction. For all tests, the alpha-type error was set at <0.05.

Results

The median, 25th percentile, 75th percentile, minimum and maximum torque and vertical force values of each groups are presented in Table 1 and Table 2.

In NaOCl group, WOG instruments generated lower torque than RB and PTN instruments ($p<0.05$). In NaOCl+BAC group, PTN generated higher torque than WOG and RCB ($p<0.05$). BAC addition to NaOCl did not significantly change the torque values of each instrument ($p<0.05$).

No significant difference was found between instruments in NaOCl group in terms of maximum vertical force ($p<0.05$). Nevertheless, in NaOCl+BAC group, RB showed higher force than WOG and PTN ($p<0.05$). The vertical force generation of WOG instruments decreased in NaOCl+BAC group compared to NaOCl group ($p<0.05$).

Discussion

In this study, we aimed to evaluate the effects of NaOCl, with or without surface modifiers, on the maximum operative torque and maximum vertical force values of PTN F2,

Grupe su podijeljene na sljedeći način (n = 15):

NaOCl skupina

Skupina 1: WaveOne Gold Primary ispiran 5,25-postotnim NaOCl-om

Skupina 2: Reciproc Blue R25 ispiran 5,25-postotnim NaOCl-om

Skupina 3: Protaper Next X2, natopljen 5,25-postotnim NaOCl-om (Werax, Izmir, Turska)

NaOCl + BAC skupina

Skupina 4: WaveOne Gold Primary ispiran 0,084-postotnim BAC-om pomiješanimu 5,25-postotni NaOCl

Skupina 5: Reciproc Blue R25 ispiran 0,084-postotnim BAC-om pomiješanim u 5,25-postotni NaOCl

Skupina 6: Protaper Next X2 ispiran 0,084-postotnim BAC-om pomiješanim u 5,25-postotni NaOCl

Endodontski motor postavljen je da se okreće u načinu rada "Wave One" za WOG; "Reciproc All" za RB R25, "Protaper Next" za PTN X2. NaOCl ili NaOCl pomiješan s BAC-om stavljeni su u otvor korijenskoga kanala akrilatnih blokova tijekom instrumentacije 2 mm prema unutra od otvora kanala s vrhom igle od 30 G pričvršćenim na pumpu za otopinu. Tijekom eksperimenta kroz otvor kanala uliveno je 0,2 mL otopine u sekundi. Ručni dio programiran je da se pomiče simuliranim pokretom prema dolje 2 sekunde i prema gore jednu sekundu da bi se postigla radna duljina (16 mm) u prozirnim blokovima.

Softver je zabilježio i iscrtao vrijednosti okretnoga momenta i vertikalne sile po milisekundi. Također su zabilježene vrijednosti maksimalnoga okretnoga momenta i vertikalnoga opterećenja.

Statistička analiza

Podatci su analizirani Kruskal-Wallisovim testom s Dunn-Bonferronijevim korekcijom. Za sve testove pogreška alfa bila je postavljena na < 0,05.

Rezultati

Vrijednosti medijana, 25. percentila, 75. percentila, minimalnoga i maksimalnoga okretnoga momenta i vertikalne sile svake skupine prikazane su u tablicama 1. i i 2.

U skupini NaOCl, WOG instrumenti generirali su niži zakretni moment od RB i PTN instrumenata ($p < 0,05$). U skupini NaOCl + BAC, PTN je generirao veći okretni moment od WOG-a i RCB-a ($p < 0,05$). Dodatak BAC-a NaOCl-u nije značajno promijenio vrijednosti momenta za svaki instrument ($p < 0,05$).

Nije utvrđena značajna razlika između instrumenata u skupini NaOCl kad je riječ o maksimalnoj vertikalnoj sili ($p < 0,05$). Ipak, u skupini NaOCl + BAC, RB je pokazao veću snagu od WOG-a i PTN-a ($p < 0,05$). Generiranje vertikalne sile WOG instrumenata smanjeno je u skupini NaOCl + BAC u usporedbi sa skupinom NaOCl ($p < 0,05$).

Rasprava

U ovom istraživanju željeli smo procijeniti učinak natrijeva hipoklorida s modifikatorom površine ili bez njega na maksimalni operativni okretni moment i maksimalne vrijed-

Table 1 Maximum torque values of tested instruments (Ncm).
Tablica 1. Maksimalne vrijednosti okretnoga momenta testiranih instrumenata (Ncm)

Groups • Skupine		Median • Medijan	25th Percentile • 25. percentila	75th Percentile • 75. percentila	Min.	Max. • Max.
NaOCl	WOG	0.19 [a,b]	0.17	0.20	0.15	0.20
	RCB	0.41 [a]	0.39	0.44	0.38	0.45
	PTN	0.88 [b]	0.74	1.10	0.64	1.16
NaOCl+BAC	WOG	0.18 [c]	0.16	0.22	0.14	0.23
	RCB	0.37 [d]	0.33	0.39	0.30	0.41
	PTN	1.13 [c,d]	1.02	1.37	0.90	1.71

Same superscript letters in the same column indicate statically differences between groups by the Bonferroni test for pair-wise comparison (p<0.05). (Min: minimum, Max: Maximum) • Ista nadredna slova u istom stupcu označavaju statičke razlike među skupinama Bonferronijevim testom za usporedbu u parovima (p < 0,05). (min. – minimum; maks. – maksimum)

Table 2 Maximum vertical force values of tested instruments (gram force).
Tablica 2. Maksimalne vrijednosti vertikalne sile testiranih instrumenata (gram. sila)

Groups • Skupine		Median • Medijan	25th Percentile • 25. percentila	75th Percentile • 75. percentila	Min.	Max. • Max.
NaOCl	WOG	250.38 [x]	208.04	346.24	160.66	382.29
	RCB	260.54	196.54	350.46	147.99	373.17
	PTN	160.79	151.88	182.62	129.57	194.95
NaOCl+BAC	WOG	149.10 [x,y]	110.45	182.72	75.85	265.85
	RCB	401.39 [y,z]	353.01	430.05	289.91	506.66
	PTN	130.83 [z]	119.45	184.30	107.54	215.81

Same superscript letters in the same column indicate statically differences between groups by the Bonferroni test for pair-wise comparison (p<0.05). (Min: minimum, Max: Maximum) • Ista nadredna slova u istom stupcu označavaju statičke razlike među skupinama Bonferronijevim testom za usporedbu u parovima (p < 0,05). (min. – minimum; maks. – maksimum)

WOG Primary and RB R25 files during intracanal instrumentation using acrylic resin blocks. Peters et. al. reported that acrylic blocks with simulated canals had similar behavior as mandibular incisors when measuring the torque of rotary instruments (17). Therefore, in the study, we preferred to use acrylic resin blocks to provide standardization among samples.

Studies evaluating the torsional resistance of rotary NiTi files are generally carried out by burying the tip of 3-5 mm of the files in acrylic or composite resin, operating the file in rotation motion and recording the maximum torque value immediately before the breakage occurs. These studies are carried out according to ISO 3630-1 standards. Nevertheless, this method doesn't provide sufficient information about the torque values generated by the file and canal walls in the dynamic clinical conditions in curved canals. Furthermore, the reciprocation files are not designed to continuously rotate in one direction until fracture. In other words, there is a gap between clinical use and experimental methods. So far, different techniques have been designed and introduced for determining the torque and vertical load similar to the clinical conditions to overcome this gap (17-19).

Studies comparing aqueous and gel-type irrigants on torque and apically directed force showed that aqueous irrigants decreases torque and force compared with paste type lubricants and dry controls (15, 16). This can be explained by the fact that the use of irrigants can reduce the torsional fracture risk by decreasing the torque values.

nosti vertikalne sile instrumenata PTN F2, WOG Primary i RB R25 tijekom intrakanalne instrumentacije u blokovima od akrilatne smole. Peters i suradnici izvijestili su da se blokovi sa simuliranim kanalima ponašaju slično kao mandibularni sjekutići pri mjerenju okretnoga momenta rotirajućih instrumenata (17). Stoga smo u istraživanju radije upotrebljavali blokove od akrilatne smole kako bismo osigurali standardizaciju među uzorcima.

Istraživanja koja procjenjuju otpornost na torziju rotacijskih NiTi instrumenata općenito se provode tako da se 3 do 5 mm vrha instrumenta ukopa u akrilatnu ili kompozitnu smolu, radi se rotacijska kretnja i bilježi maksimalna vrijednost okretnoga momenta neposredno prije nego što se dogodi puknuće. Ta istraživanja obavljaju se u skladu sa standardom ISO 3630-1. Ipak, ta metoda ne daje dovoljno informacija o vrijednostima okretnoga momenta koje stvaraju instrument i stijenke kanala u dinamičkim kliničkim uvjetima u zakrivljenim kanalima. Nadalje, recipročni instrumenti nisu oblikovani tako da se neprestano rotiraju u jednom smjeru do puknuća. Drugim riječima, postoji nesklad između kliničke uporabe i eksperimentalnih metoda. Dosad su razvijene i primjenjivane različite tehnike za određivanje okretnoga momenta i vertikalnoga opterećenja slične kliničkim uvjetima za prevladavanje toga nesklada (17 – 19).

Istraživanja u kojima se uspoređivao utjecaj irigansa u obliku vodene otopine i gela na okretni moment i apikalno usmjerenu silu, pokazala su da vodeni irigansi smanjuju okretni moment i silu u usporedbi s lubrikantima pastozno-

Using the files with pecking motion has been shown to decrease the risk of fractures by reducing flexural resistance and screw-in forces (20, 21). Hence, specially designed software enabled the files to work in pecking 2 mm forward and 1 mm backward motion.

In NaOCl group, the lowest torque value was observed in Wave One Gold Primary files compared with Reciproc Blue R25 and Protaper Next X2 ($p<0,05$). Although it was not statistically significant, the highest maximum torque value was observed in the PTN group. Designs, surface treatments, production processes and working kinetics of all these files are different from each other. These properties may affect the stress generation between the file and root canal. PTN instruments work with continuous rotation movement while WOG and RCP work with the reciprocation movement. The reciprocation movement includes clockwise and reverse cycles. It is assumed that counterclockwise rotation of reciprocating motion diminishes the torsional stress exerted on the file during the active canal shaping procedure compared with continuous rotation (22). Similarly, in a study, it was shown that reciprocating motion improves the cyclic fatigue compared to continuous motion systems (23). Although both RCB and WOG are reciprocating instruments, lower torsional stress of WOG may be related to its structural properties. In a study comparing cross-section area of WOG Primary and RCB R25 at D5 level, RCB was reported to have larger core area than WOG (24) . Although, some previous studies reported that an increase in the file's core diameter would enhance its resistance to the torsional stress (25, 26), the torque values formed between dentine wall and the instrument may be affected by many factors such as design features, the presence of irrigation solution or the physician's manipulation in clinical or experimental conditions.

Boessler et. al. evaluated aqueous ve gel-type lubricants in simulated root canals using Profile 30.06. They showed that aqueous type lubricants decrease the maximum torque, full torsional load and maximum force compared with dry controls (16). Mazzoni et. al. compared saline, NaOCl, EDTA and gel-type EDTA using Edge Taper F2 files (27). They showed that irrigants decrease the mean operative torque compared with saline. The highest decrease was observed in aqueous EDTA group in their study. Since dentin discs are used in the study, EDTA may soften the dentin and reduce the torsional resistance against the file. However, in our study, we aimed to achieve standardization by eliminating the effects of the solution on dentin by using acrylic blocks.

BAC addition to NaOCl did not significantly affect maximum torque values of instruments compared with NaOCl group ($p<0.05$). Bukiet et. al. suggested that percentage of 008 BAC additions decreased the contact angle and surface energy without affecting antibacterial properties, free chloride content and cytotoxicity of NaOCl (14). Baron et. al. showed that BAC addition increased the antibacterial properties of NaOCl (28). These studies showed that adding BAC to NaOCl affects the properties of solution positively. Similar to these positive results, this study showed that addition of BAC to NaOCl had no effects on the maximum torque generated by the instruments used in the study.

ga tipa i suhim kontrolama (15, 16). Može se protumačiti da upotreba irigansa može smanjiti rizik od torzijskoga puknuća smanjenjem vrijednosti okretnoga momenta.

Pokazalo se da uporaba instrumenata recipročnom kretnjom smanjuje rizik od puknuća smanjujući otpor na savijanje i sile uvrtanja (20, 21). Tako je specijalno dizajnirani softver omogućio da instrumenti rade kretnjom od 2 mm naprijed i 1 mm natrag.

U skupini NaOCl-a najniža vrijednost okretnoga momenta opažena je pri uporabi instrumenata Wave One Gold Primary u usporedbi s Reciproc Blue R25 i Protaper Next X2 ($p < 0,05$). Iako nije statistički značajno, najveća vrijednost maksimalnoga okretnoga momenta zabilježena je u PTN skupini. Dizajn, površinska obrada, proizvodni procesi i kinetika rada svih tih instrumenata uzajamno se razlikuju. Ta svojstva mogu utjecati na stvaranje naprezanja između instrumenta i korijenskog kanala. PTN instrumenti rade s kontinuiranim rotacijskom kretnjom, a WOG i RCP rade s recipročnom kretnjom. Recipročna kretnja uključuje cikluse u smjeru kazaljke na satu i obrnuto. Pretpostavlja se da povratna rotacija u smjeru suprotnome od kazaljke na satu umanjuje torzijski napon koji djeluje na instrument tijekom postupka aktivnoga oblikovanja kanala u usporedbi s kontinuiranom rotacijom (22). U istraživanju se pokazalo da povratna rotacija djeluje povoljno na ciklički zamor u usporedbi sa sustavima kontinuiranoga gibanja (23). Iako su i RCB i WOG recipročni instrumenti, manje torzijsko naprezanje WOG-a može biti povezano s njegovim strukturnim svojstvima. U istraživanju u kojemu je uspoređena površina poprečnoga presjeka instrumenata WOG Primary i RCB R25 na razini D5, RCB ima veću površinu jezgre od WOG-a (24). Iako su autori dosadašnjih istraživanja istaknuli da bi povećanje promjera jezgre instrumenta povećalo njegovu otpornost na torzijsko naprezanje (25, 26), na vrijednosti okretnoga momenta formirane između dentinske stijenke i instrumenta mogu utjecati mnogi čimbenici kao što su značajke dizajna, otopine za ispiranje ili liječnička manipulacija u kliničkim ili eksperimentalnim uvjetima.

Boessler i suradnici ocjenjivali su tekuće lubrikante i one u obliku gela u simuliranim korijenskim kanalima koristeći se Profileom 30,06. Pokazali su da lubrikanti vodenog tipa smanjuju maksimalni okretni moment, puno torzijsko opterećenje i maksimalnu silu u usporedbi sa suhim kontrolama (16). Mazzoni i suradnici usporedili su fiziološku otopinu, NaOCl, EDTA i EDTA u obliku gela s pomoću Edge Taper F2 instrumenata(27). Pokazali su da irigansi smanjuju srednji operativni okretni moment u usporedbi s fiziološkom otopinom. Najveći pad uočen je u skupini s tekućom EDTA-om. Budući da su u tom istraživanju korišteni dentinski diskovi, EDTA je mogla omekšati dentin i smanjiti otpor na uvijanje instrumenata. No, u našem smo istraživanju željeli postići standardizaciju eliminacijom učinaka otopine na dentin korištenjem akrilatnih blokova.

Dodatak BAC-a NaOCl-u nije značajno utjecao na maksimalne vrijednosti okretnoga momenta instrumenata u usporedbi s NaOCl skupinom ($p < 0,05$). Bukiet i suradnici sugeriraju da dodatak 0,008 % BAC-a smanjuje kontaktni kut i površinsku energiju bez utjecaja na antibakterijska svojstva, sadržaj slobodnoga klorida i citotoksičnost NaOCl-a (14).

There was no statistically significant difference between files in the NaOCl group in terms of maximum force ($p<0.05$). The addition of BAC to NaOCl caused a decrease in the maximum force value of WOG files ($p<0.05$). A disadvantage of NiTi rotary instruments is the tendency to bind into the root canal. Due to the spiral configuration of the instrument, blades are bound to the root canal dentin and cause a "screw-in effect". This effect generates a force to the apical direction (19, 29). Reciprocating movements may reduce the screw-in effect because a momentary clockwise rotation may relieve the stress when the instrument is trapped in dentin during counterclockwise rotation. Although RB files also work with reciprocation motion, their s-shaped cross-section and having 8% taper 3 mm from the tip may have caused more force compared with WOG instrument's parallelogram-shaped cross section and %7 taper.

The addition of BAC to NaOCl only caused a decrease of the force for WOG instruments, but did not cause a statistically significant change for other files. The BAC solution may have facilitated the movement of the WOG files, reduced the screwing effect, or had a lubricating effect between the canal wall and file. Some more detailed studies are needed on this subject.

The instruments working with continuous rotation movement were expected to cause more force generation by screwing in to the root canal. However, reciprocating motion exhibited higher forces than continuous rotation in most studies because reciprocating instruments can be pushed into the canal during the counterclockwise rotation (30). The results of this study showed that, PTN did not cause a higher vertical force generation. Another possible reason could be that 6% taper of Protaper Next may have reduced the apical pressure required to reach the working length in previously expanded canals.

In the study, it was not possible to clean the resin chips formed during the preparation of the canals due to the design of the device. This was one of the limitations of the study.

As a result of the study, BAC addition to NaOCl has no negative effect on the maximum torque and maximum apical force of the Wave One Gold Primary, Reciproc Blue R25 and PTN X2 instruments. Vertical force generated by WOG decreased with BAC addition to NaOCl.

Conclusions

The results of this study demonstrated that the instruments working with reciprocation motion had lower operative torque compared with instruments working with continuous rotation motion in the presence and absence of surfactant. Surfactant addition to NaOCl did not cause any change in the torque values of the instruments. While there

Barun i suradnici pokazali su da dodatak BAC-a povećava antibakterijska svojstva NaOCl-a (28). U tim istraživanjima pokazano je da dodavanje BAC-a u NaOCl pozitivno utječe na svojstva otopine. Slično tim pozitivnim rezultatima, u ovom istraživanju pokazano je da dodavanje BAC-a u NaOCl ne utječe na maksimalni okretni moment koji generiraju instrumenti koji se upotrebljavaju u istraživanju.

Nije bilo statistički značajne razlike između instrumenata u skupini NaOCl u smislu maksimalne sile ($p < 0,05$). Dodavanje BAC-a u NaOCl uzrokovalo je smanjenje vrijednosti maksimalne sile WOG instrumenata ($p < 0,05$). Nedostatak NiTi rotacijskih instrumenata jest sklonost prema zapinjanju u korijenskom kanalu. Zbog spiralne konfiguracije instrumenta oštrice se urežu u dentin korijenskoga kanala i uzrokuju „efekt uvrtanja". Taj učinak stvara silu u apikalnom smjeru (19, 29). Recipročne kretnje mogu smanjiti učinak uvrtanja jer trenutna rotacija u smjeru kazaljke na satu može ublažiti naprezanje kada instrument zapne u dentinu tijekom rotacije suprotno od smjera kazaljke na satu. Iako RB instrumenti također rade s povratnom kretnjom, njihov poprečni presjek u obliku slova S i konus od 8 % 3 mm od vrha mogli su prouzročiti veću silu u usporedbi s poprečnim presjekom u obliku paralelograma WOG instrumenta i 7 % konusom.

Dodavanje BAC-a u NaOCl prouzročilo je smanjenje sile samo za WOG instrumente, ali nije izazvalo statistički značajnu promjenu pri upotrebi drugih instrumenata. Otopina BAC-a možda je olakšala kretanje WOG instrumenta, smanjila učinak uvrtanja ili imala učinak podmazivanja između stijenke kanala i instrumenta. Potrebna su detaljnija istraživanja o toj temi.

Očekivalo se da će instrumenti koji rade s kontinuiranom rotacijskom kretnjom prouzročiti veće sile uvrtanjem u korijenski kanal. Međutim, recipročno gibanje pokazalo je veće sile od kontinuirane rotacije u većini istraživanja jer se recipročni instrumenti mogu gurnuti u kanal tijekom rotacije u smjeru suprotnome od kazaljke na satu (30). Rezultati ovog istraživanja pokazali su da PTN nije prouzročio veće stvaranje vertikalne sile. Drugi mogući razlog mogao bi biti konus od 6 % Protaper Nexta koji je možda smanjio apikalni tlak potreban za postizanje radne duljine u već proširenim kanalima.

U istraživanju nije bilo moguće očistiti strugotine smole nastale tijekom preparacije kanala zbog dizajna uređaja. To je bilo jedno od ograničenja u istraživanju.

Kao rezultat istraživanja, dodatak BAC-a u NaOCl ne utječe negativno na maksimalni okretni moment i maksimalnu apikalnu silu za instrumente Wave One Gold Primary, Reciproc Blue R25 i PTN X2 a. Vertikalna sila koju stvara WOG smanjila se dodavanjem BAC-a u NaOCl.

Zaključci

Rezultati ovog istraživanja pokazali su da instrumenti koji rade s recipročnom kretnjom imaju manji operativni okretni moment u usporedbi s onima koji rade s kontinuiranom rotacijskom kretnjom sa surfaktantom ili bez njega. Dodavanje surfaktanta NaOCl-u nije prouzročilo nikakvu promjenu u vrijednostima okretnoga momenta instrumenata. Iako ni-

was no significant difference in the vertical force generated by the instruments in NaOCl group, surfactant addition reduced the vertical force generated only by WOG instruments.

je bilo značajne razlike u vertikalnoj sili koju stvaraju instrumenti u skupini NaOCl, dodavanje surfaktanta smanjilo je vertikalnu silu samo pri upotrebi WOG instrumenata.

Conflict of interest

No potential conflict of interest relevant to this article was reported.

Sukob interesa

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Doprinos autora: **E. E. A.** – osmislio i obavio analizu, prikupio i priložio podatke, pisao rad; **S. A. O.** – prikupio i priložio podatke, obavio analizu, pisao rad; **A. S.** – osmislio i obavio analizu.

Sažetak

Svrha rada: Cilj istraživanja bio je procijeniti učinak ispiranja korijenskoga kanala pri maksimalnom operativnom okretnom momentu i vertikalnu silu rotacijskih endodontskih instrumenata Wave One Gold Primary (WOG), Reciproc Blue R25 (RB) i Protaper Next X2 (PTN) tijekom simulirane preparacije korijenskoga kanala sa surfaktantom "benzalkonijeva klorida" ili bez njega. **Materijali i metode:** Za istraživanje je upotrijebljena posebno izrađena automatizirana naprava za ispiranje i analizu okretnoga momenta/sile koja je bila povezana s endomotorom. Blokovi od akrilne smole sa simuliranim zakrivljenim korijenskim kanalima od 35° nasumično su podijeljeni u šest skupina za svaki instrument. Tijekom simulirane preparacije korijenskoga kanala kontinuiranom rotacijom ili recipročnim kretnjama upotrijebljene su sljedeće otopine: 5-postotni NaOCl i 5-postotni NaOCl s 0,084-postotnoga benzalkonijeva klorida. Tijekom instrumentacije zabilježene su vrijednosti maksimalnoga okretnoga momenta i vertikalne sile instrumenata. **Rezultati:** Dodatak BAC-a u NaOCl nije značajno utjecao na vrijednosti maksimalnih okretnih momenta instrumenata ($p > 0,05$). WOG je generirao najnižu vrijednost okretnoga momenta u usporedbi s PTN-om i RCB-om u objema skupinama ($p < 0,05$). RB je generirao veću vertikalnu silu u usporedbi s WOG i PTN instrumentima u skupini NaOCl + BAC. Modifikator površine smanjio je maksimalnu vrijednost sile WOG instrumenta ($p < 0,05$). **Zaključak.** Dodatak surfaktana natrijevu hipokloridu ne utječe negativno na maksimalni okretni moment i snagu instrumenata.

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