

# Analysis of cyclic fatigue resistance of protaper universal and protaper next rotary instruments

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## SUMMARY

**Introduction** Root canal preparation is one of the most important active phases in the treatment of infected and non-infected teeth. Nickel-titanium (NiTi) instruments are increasingly used in endodontic therapy due to their superior properties compared to those made of stainless steel. The aim of this research was to perform an analysis and comparison of cyclic fatigue in ProTaper Universal and ProTaper Next rotary NiTi instruments in full rotation in simulated canals.

**Material and methods** Twelve ProTaper Next and twelve ProTaper Universal instruments were analyzed in the study. The instruments were tested in an artificial canal stuffed in a metal block at an angle of 45° and a corner radius of 5 mm. The operating time of each instrument until fracture was measured and the number of cycles to fracture (NCF) calculated.

**Results** ProTaper Next instruments showed greater resistance to cyclic fatigue compared to ProTaper Universal. The NCF value was significantly higher in ProTaper Next (1,296.83±20.2) instruments ( $p < 0.001$ ). The average length of fractured fragments was statistically significantly higher in ProTaper Universal (4.52±0.33) instruments compared to ProTaper Next (3.82±0.27) ( $p < 0.001$ ).

**Conclusion** It was concluded that the cyclic fatigue resistance of ProTaper Next instruments was higher compared to ProTaper Universal instruments.

**Keywords:** Cyclic fatigue; NiTi, ProTaper Universal; ProTaper Next

## INTRODUCTION

Root canal preparation is one of the most important active phases in the treatment of infected and non-infected teeth. Nickel-titanium (NiTi) instruments are increasingly used in endodontic therapy due to their superior properties compared to those made of stainless steel [1, 2, 3]. The use of rotary NiTi instruments has increased the success of the treatment due to their elasticity which is necessary to clean and shape curved root canals [4]. However, in addition to all its advantages, a sudden fracture of the instrument without previous warning signs represents the highest problem and is one of the most difficult complications during endodontic therapy [5, 6]. The main causes of instrument breakage are torsional load and cyclic fatigue [7, 8, 9]. In the case when the tip of the file is stuck in the canal during the rotation of the instrument or part of the instrument is twisted into the wall of the canal, the tip of the instrument is larger than the diameter of the root canal or when excessive pressure is applied to the instrument during operation, the instrument breaks due to torsion loads [10, 11]. A much more common cause of broken instruments is cyclic fatigue that occurs due to the continuous alternating compression and stretching at each point of bent instrument in the region of the

canal curvature. This mechanism is responsible in 90% of instrument breakage cases [10, 11]. There are a number of additional factors that can affect the occurrence of fractures of NiTi instruments, such as the size, conicity and cross-sectional shape of instruments, as well as the training of the therapist [12].

The aim of this research was to analyze and compare cyclic fatigue of ProTaper Universal and ProTaper Next rotary NiTi instruments in full rotation in simulated canals.

## MATERIALS AND METHODS

The research was conducted at the Clinic for Dental Medicine, Faculty of Medicine, University of Niš. Twelve ProTaper Universal instruments and twelve ProTaper Next instruments (Dentsply Sirona, Ballaigues, Switzerland) were tested for cyclic fatigue resistance. The instruments of both groups were size 25, taper 0.04, and length 25 mm.

For the purposes of the experiment, a special metal block made of stainless steel was constructed in accordance with the research of Plotino et al. [13]. The block contained a machine-cut artificial canal 19 mm in length and 1.4 mm in internal diameter, 45-degree angle of curvature, with a corner radius of 5 mm. The center of the

curve was 5 mm away from the tip of the instrument. The block was placed on a base with feet and was enabled to move in two directions for easier placement of instruments in the canal. The canal was covered with tempered glass to allow observation of the rotating instrument and prevent the broken fragment from falling out. Glycerin was used to reduce the friction of instruments with stainless steel walls. The handpiece was fixed in a metal ring holder perpendicular to the canal. The instruments were inserted into the canal to the tip and rotated using an electric endomotor (X-smart plus, Dentsply Sirona, Ballaigues, Switzerland). All instruments were continuously rotated to the right, with constant resistance and speed as recommended by the manufacturer. A constant speed of 250 rpm and a torque of 2.5 Ncm were used for the ProTaper Universal, while a speed of 300 rpm and a torque of 2.0 Ncm were used for the ProTaper Next instruments. The rotation of the instrument was analyzed visually, and the fracture was registered visually and by sound. The rotation time until the instrument breaks was measured in seconds with a digital stopwatch. The number of cycles to fracture (NCF) was calculated according to the formula:

$$\text{NCF} = \text{rotational speed of the instrument} \times \text{time to fracture in seconds} / 60$$

The length of the fractured fragment (FL) was measured by using a Vernier caliper with an accuracy of 0.02 mm.

Statistical analysis was performed using the Mann Whitney U and Student t-test with a significance of  $p < 0.001$ .

## RESULTS

ProTaper Next instruments showed greater resistance to cyclic fatigue compared to ProTaper Universal. It was found that there is a statistically significant difference in the number of cycles to instrument fracture (NCF) between the analyzed groups ( $Z=4.163$ ;  $p < 0.001$ ) (Table 1).

**Table 1.** Number of cycles to fracture (NCF) and length of fractured fragment (FL)

**Tabela 1.** Broj ciklusa do frakture (NCF) i dužina frakturisanog fragmenta (FL)

	ProTaper Next	ProTaper Universal	p
NCF	1296,83 ± 20,21	364,23 ± 14,37	< 0,001 <sup>1</sup>
FL	3,82 ± 0,27	4,52 ± 0,33	< 0,001 <sup>2</sup>

<sup>1</sup>Mann-Whitney U test; <sup>2</sup>Student t-test

<sup>1</sup>Man-Vitnijev U test; <sup>2</sup>Studentov t-test

The average length of fractured fragments was greater in ProTaper Universal instruments compared to ProTaper Next. Statistical analysis showed that there was a significant difference in fragment length (FL) between the studied groups ( $t=5.669$ ;  $p < 0.001$ ) (Table 1).

## DISCUSSION

Root canal preparation with endodontic instruments and continuous irrigation is the most important phase of

endodontic treatment [14]. The instruments are expected to be flexible and have a high cutting efficiency, which would ensure preservation of the initial form of the canal. However, sudden fracture of instruments inside the root canal is a major concern in daily clinical practice [15]. Cyclic fatigue is the main reason of instrument fracture occurring at the point of maximum instrument flexure while rotating within curved root canals [16]. Therefore, it is of great importance to constantly perform cyclic fatigue tests on new NiTi instrument systems to provide clinicians with information on their fracture resistance [17].

In our study, the cyclic fatigue resistance of two different types of NiTi rotary instruments - ProTaper Universal and ProTaper Next - was compared in simulated root canals. The results showed extremely high resistance to cyclic fatigue in ProTaper Next instruments, compared to ProTaper Universal. This difference may be due to the continuous modification of the NiTi alloy and structure, as well as the material processing technique, which has been shown to be a factor that greatly influenced the increase in cyclic fatigue resistance. The manufacturing of ProTaper Next instruments is based on M-wire technology, which involves a series of heat treatments to which NiTi wire is exposed during the production process, which is why M-wire is much more elastic and resistant to cyclic fatigue than conventional instruments [18]. Conventional NiTi alloy is in the austenite phase at room and oral temperature. At room temperature, M-wire that has been subjected to thermal treatments is in the austenite and martensite phase. It is precisely the higher content of martensite, which is softer, in M-wire instruments that has a positive effect on the resistance to cyclic fatigue. A number of studies have reported results consistent with this claim [19, 21].

In addition to alloy differences, instrument cross-sectional differences are a significant contributing factor to the greater fatigue resistance of NiTi rotary instruments. The larger contact area of the rotating NiTi instrument in the canal leads to less flexibility and less resistance to cyclic fatigue [20]. ProTaper Universal instruments have a triangular cross-section and are manufactured using the cutting technology that is standard for conventional instruments. Such manufacturing technology leads to the appearance of microcracks and defects on the surface of the working part, which represent points of stress concentration that weakens the instrument and leads to its sudden breakage [21].

The ProTaper Next has a rectangular cross-section with an off-center position that reduces the area of contact with the root canal walls during instrumentation providing greater resistance to cyclic fatigue [20, 22]. Asymmetric movements during the rotation of the ProTaper Next instrument ensure efficiency in canal instrumentation, while the rectangular section ensures superior mechanical properties [18]. In the study by Zhang et al. [23], the cross-sectional shape and design of NiTi instruments were analyzed and it was proved that both factors significantly influence their mechanical properties during canal preparation. Uygun et al. [24] used ProTaper Universal,

ProTaper Next and ProTaper Gold in simulated canals with a curvature angle of 60 degrees to evaluate cyclic fatigue and found that ProTaper Next and ProTaper Gold showed the highest resistance to cyclic fatigue.

In the case of ProTaper Next instruments, the occurrence of fractured fragments of a significantly shorter length compared to ProTaper Universal was observed. The results of our study are correlated with the results of the study conducted by Mohamed et al. [25] who compared the cyclic fatigue resistance of five different NiTi rotary instruments. In the study by Peng et al. [15], the fragment length of ProTaper Next instruments was significantly smaller compared to ProTaper Universal when they were examined in the canal at an angle of 90 degrees. However, there was no statistically significant difference in the length of fractured fragments in canals at an angle of 45 and 60 degrees.

## CONCLUSION

ProTaper Next instruments showed greater resistance to cyclic fatigue compared to ProTaper Universal instruments. The breaking point of the ProTaper Next instruments was apically positioned compared to ProTaper Universal.

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# Analiza otpornosti na ciklični zamor rotirajućih instrumenata ProTaper Universal i ProTaper Next

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## KRATAK SADRŽAJ

**Uvod** Preparacija kanala korena predstavlja jednu od najvažnijih aktivnih faza u lečenju inficiranih i neinficiranih zuba. Nikl-titanijumski (NiTi) instrumenti se sve više koriste u endodontskoj terapiji zbog superiornijih osobina u odnosu na one od nerđajućeg čelika. Cilj ovog istraživanja je bio da se izvrši analiza i poređenje cikličnog zamora kod mašinskih NiTi instrumenata ProTaper Universal i ProTaper Next u punoj rotaciji u simuliranim kanalima.

**Materijal i metode** U studiji je bilo analizirano 12 ProTaper Next i 12 instrumenata ProTaper Universal. Instrumenti su testirani u artifičijelnom kanalu preparisanom u metalnom bloku pod uglom od 45° i radijusom ugla od 5 mm. Mereno je vreme rada svakog instrumenta do pojave frakture, a zatim je vršeno izračunavanje broja ciklusa do frakture.

**Rezultati** Instrumenti ProTaper Next su pokazali veću otpornost na ciklični zamor u odnosu na ProTaper Universal. Vrednost broja ciklusa do frakture je bila statistički značajno veća kod instrumenata ProTaper Next ( $1296,83 \pm 20,2$ ) ( $p < 0,001$ ). Prosečna dužina frakturisanih fragmenata je bila statistički značajno veća kod instrumenata ProTaper Universal ( $4,52 \pm 0,33$ ) u odnosu na ProTaper Next ( $3,82 \pm 0,27$ ) ( $p < 0,001$ ).

**Zaključak** Zaključeno je da je otpornost na ciklični zamor kod instrumenata ProTaper Next bila veća u poređenju sa instrumentima ProTaper Universal.

**Ključne reči:** ciklični zamor; NiTi, ProTaper Universal; ProTaper Next

## UVOD

Preparacija kanala korena predstavlja jednu od najvažnijih aktivnih faza u lečenju inficiranih i neinficiranih zuba. Nikl-titanijumski (NiTi) instrumenti se sve više koriste u endodontskoj terapiji zbog superiornijih osobina u odnosu na one od nerđajućeg čelika [1, 2, 3]. Upotreba mašinskih rotirajućih NiTi instrumenta je povećala uspešnost tretmana zbog njihove elastičnosti neophodne za čišćenje, širenje i oblikovanje zakrivljenih kanala korena [4]. Međutim, pored svih svojih prednosti, iznenadni prelom instrumenta bez prethodnih znakova upozorenja predstavlja najveći problem i jedna je od težih komplikacija u toku endodontske terapije [5, 6]. Glavne uzroke preloma instrumenata predstavljaju torziono opterećenje i ciklični zamor [7, 8, 9]. U slučaju kada je vrh turpije zaglavljen u kanalu tokom rotacije instrumenta, kada se deo instrumenta uvije u zid kanala, kada je vrh instrumenta veći od promera kanala korena, ili kada se vrši prekomerni pritisak na instrument u toku rada, dolazi do preloma instrumenta usled torzionog opterećenja [10, 11]. Mnogo češći uzrok preloma instrumenata je ciklični zamor koji nastaje usled neprekidnog smenjivanja kompresije i istezanja u svakoj tački savijenog instrumenta u predelu krivine kanala. Ovakav mehanizam je odgovoran u 90% slučajeva preloma instrumenata [10, 11]. Postoji veliki broj dodatnih faktora koji mogu uticati na pojavu preloma NiTi instrumenata, kao što su veličina, koničnost i oblik poprečnog preseka instrumenata, kao i obučenosť samog terapeuta [12].

Cilj ovog istraživanja je bio da se izvrši analiza i poređenje cikličnog zamora kod mašinskih NiTi instrumenata ProTaper Universal i ProTaper Next u punoj rotaciji u simuliranim kanalima.

## MATERIJAL I METODE

Istraživanje je obavljeno na Klinici za dentalnu medicinu Medicinskog fakulteta Univerziteta u Nišu. Dvanaest instrumenata ProTaper Universal i dvanaest instrumenata ProTaper Next (Dentsply Sirona, Ballaigues, Switzerland) testirano je na otpornost na ciklični zamor. Instrumenti obe grupe bili su veličine 25, stepena koničnosti 0,04, i dužine 25 mm.

Za potrebe eksperimenta konstruisan je poseban metalni blok od nerđajućeg čelika u skladu sa istraživanjem Plotina i saradnika [13]. Blok je sadržao mašinski urezan artifičijelni kanal dužine 19 mm i unutrašnjeg dijametra 1,4 mm, ugla zakrivljenosti 45 stepeni, sa radijusom ugla od 5 mm. Centar krivine je bio 5 mm udaljen od vrha instrumenta i kanala. Blok je bio postavljen na bazi sa stopama i bile su mu omogućene kretnje u dva pravca radi lakšeg postavljanja instrumenata u kanal. Kanal je bio prekriven kaljenim staklom da omogući posmatranje rotirajućeg instrumenta i spreči ispadanje polomljenog fragmenta. Za smanjenje trenja instrumenata sa zidovima od nerđajućeg čelika korišćen je glicerol. Kolenjak je bio fiksiran u metalnom prstenastom držaču upravno na kanal. Instrumenti su unošeni u kanal do vrha i rotirani korišćenjem električnog endomotora (X-smart plus, Dentsply Sirona, Ballaigues, Switzerland). Svi instrumenti su kontinuirano rotirani udesno, sa konstantnim otporom i brzinom prema preporuci proizvođača. Za ProTaper Universal je korišćena konstantna brzina od 250 rpm i tork od 2,5 Ncm, dok je kod instrumenata ProTaper Next korišćena brzina od 300 rpm i tork od 2,0 Ncm. Rotacija instrumenta je analizirana vizuelno, a prelom je registrovan vizuelno i zvukom. Vreme rotacije do preloma instrumenta mereno je u sekundama digitalnom štopericom. Broj ciklusa do frakture (NCF) računat je prema formuli:

$$\text{NCF} = \text{broj obrtaja} \times \text{vreme do frakture u sekundama} / 60$$

Dužina prelomljenog fragmenta merena je kaliperom po Vernijeru sa tačnošću 0,02 mm. Statistička analiza je izvršena pomoću Man–Vitnijičevog U i Studentovog t-testa sa pragom značajnosti od  $p < 0,001$ .

## REZULTATI

Instrumenti ProTaper Next pokazali su veću otpornost na ciklični zamor u odnosu na ProTaper Universal. Utvrđeno je da postoji statistički značajna razlika u broju ciklusa do frakture instrumenta između ispitivanih grupa ( $Z = 4,163$ ;  $p < 0,001$ ) (Tabela 1).

Prosečna dužina frakturisanih fragmenata je bila veća kod instrumenata ProTaper Universal u odnosu na ProTaper Next. Statistička analiza je pokazala da postoji značajna razlika u dužini fragmenata između ispitivanih grupa ( $t = 5,669$ ;  $p < 0,001$ ) (Tabela 1).

## DISKUSIJA

Preparacija kanala korena endodontskim instrumentima sa obilnom irigacijom predstavlja najvažniju fazu endodontskog tretmana [14]. Od instrumenata se očekuje da budu fleksibilni i da imaju visoku sečivnu efikasnost, čime bi se obezbedilo očuvanje inicijalne forme kanala. Međutim, iznenadna fraktura instrumenata unutar kanala korena predstavlja glavnu zabrinutost u svakodnevnoj kliničkoj praksi [15]. Ciklični zamor je glavni razlog preloma instrumenta, koji se javlja na tački maksimalne savijenosti instrumenta dok se slobodno okreće unutar zakrivljenih kanala korenova [16]. Zbog toga je od velike važnosti konstantno sprovođenje testove cikličnog zamora na novim sistemima NiTi instrumenata, čime bi se kliničarima obezbedile informacije o njihovoj otpornosti na prelome [17].

U ovoj studiji je izvršeno poređenje otpornosti na ciklični zamor kod dva različita tipa NiTi rotirajućih instrumenata – ProTaper Universal i ProTaper Next u simuliranim kanalima korenova. Rezultati su pokazali izuzetno visoku otpornost na ciklični zamor kod instrumenata ProTaper Next, u poređenju sa ProTaper Universal. Ova razlika može biti posledica kontinuirane modifikacije NiTi legure i strukture, kao i tehnike obrade materijala, što se pokazalo kao faktor koji u velikoj meri utiče na povećanje otpornosti na ciklični zamor. Izrada instrumenata ProTaper Next bazirana je na M-wire tehnologiji, koja podrazumeva seriju toplotnih tretmana kojima se izlaže NiTi žica u procesu proizvodnje, zbog čega je M-wire mnogo elastičniji i otporniji na ciklični zamor od konvencionalnih instrumenata [18]. Konvencionalna NiTi legura je na sobnoj i temperaturi usne duplje u fazi austenita. Na sobnoj temperaturi, M-wire koji je podvrgnut termičkim tretmanima u fazi je austenita i martenzita. Upravo veći sadržaj martenzita, koji je mekši, kod M-wire instrumenata ima pozitivan efekat na otpornost

na ciklični zamor. Brojne studije su objavile rezultate koji su u skladu sa ovom tvrdnjom [19, 21].

Pored razlika u leguri, razlike u poprečnom preseku instrumenata predstavljaju značajan faktor koji doprinosi većoj otpornosti na zamor kod NiTi rotirajućih instrumenta. Veća kontaktna površina rotirajućeg NiTi instrumenta u kanalu dovodi do manje fleksibilnosti i manje otpornosti na ciklični zamor [20]. Instrumenti ProTaper Universal imaju trougaoni poprečni presek i proizvode se tehnologijom klasičnog rezanja, koja je standardna za konvencionalne instrumente. Takva tehnologija izrade dovodi do nastanka mikropukotina i defekata na površini radnog dela koji predstavljaju tačke koncentracije stresa koje oslabljuju instrument i dovode do njegovog iznenadnog pucanja [21].

ProTaper Next ima pravougaoni poprečni presek sa necentriranim položajem koji dovodi do takvog pomeranja tokom instrumentacije da se smanjuje površina radnog dela koja je u kontaktu sa zidovima kanala korena, što obezbeđuje veću otpornost na ciklični zamor [20, 22]. Asimetrični pokreti tokom rotacije instrumenata ProTaper Next obezbeđuju efikasnost u obradi kanala, dok pravougaoni presek obezbeđuje superiorne mehaničke osobine [18]. U studiji koju su objavili Zhang i saradnici [23] analizirani su oblik i dizajn poprečnog preseka instrumenta od NiTi i dokazano je da oba faktora značajno utiču na njihove mehaničke osobine tokom preparacije kanala. Uygun i saradnici [25] za procenu cikličnog zamora koristili su ProTaper Universal, ProTaper Next i ProTaper Gold u simuliranim kanalima sa uglom zakrivljenosti od 60 stepeni i utvrdili su da su najveću otpornost na ciklični zamor pokazali ProTaper Next i ProTaper Gold.

Kod instrumenata ProTaper Next uočena je pojava frakturisanih fragmenata značajno manje dužine u odnosu na ProTaper Universal. Rezultati ove studije su u korelaciji sa rezultatima studije sprovedene od strane Mohameda i saradnika [24], koji su upoređivali rezistentnost na ciklični zamor pet različitih NiTi rotirajućih instrumenta. U studiji Penga i saradnika [15] dužina fragmenta kod instrumenata ProTaper Next bila je statistički značajno manja u poređenju sa ProTaper Universal kad su ispitivani u kanalu pod uglom od 90°. Međutim, nije bilo statistički značajne razlike u dužini prelomljenih fragmenta u kanalima pod uglom od 45° i 60°.

## ZAKLJUČAK

Instrumenti ProTaper Next su pokazali veću otpornost na ciklični zamor u poređenju sa instrumentima ProTaper Universal. Tačka preloma kod instrumenata ProTaper Next je imala apeksno pomerenu poziciju u odnosu na ProTaper Universal.

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