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Effect of Irrigating Solutions on Cyclic Fatigue Resistance of Conventional and Heat-Treated Nickel Titanium Pediatric Rotary Instruments: An In-Vitro Study

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Abstract

Background: Introduction of Nickel-titanium (NiTi) alloy files in pediatric endodontics has eased the chemo mechanical preparation. The cyclic fatigue resistance of Niti files is one of the major concerns, which is influenced by various factors including irrigating solutions. So this study aimed to evaluate the effect of irrigating solutions on cyclic fatigue resistance of conventional and heat-treated nickel titanium pediatric rotary instruments.

Methods: 24 Niti rotary files of each: ProTaper Gold; Kedo SG blue and Pro AF Baby Gold were subdivided into (n=12) and immersed in : 1) 3 % NaOCl; 2) 3% NaOCl with 17% EDTA for 10 minutes at 35°C. Cyclic fatigue resistance was assessed by determining number of cycles to fracture (NCF) in a simulated canal and surface changes using scanning electron microscope. Unpaired t-test was applied to compare each treated file with control group, and

one-way ANOVA was used for comparison among main groups and Bonferroni post-hoc test for intergroup comparison.

Results: Significant difference in NCF was seen except those between the Pro tapper gold and Pro AF (P>0.05). When 17% NaOCl was used, Kedo SG blue files showed highest fracture resistance (1878.05±66.26). ProTaper Gold (3.94±0.11) showed a significant difference in fractured fragment length.

Conclusion: Exposure of NiTi files to 3% NaOCl and 17 % EDTA affects the cyclic fatigue resistance adversely. Kedo SG Blue files exhibited the best performance among the tested groups.

Key Words: Cyclic fatigue, Niti rotary files, Sodium hypochlorite

Introduction: The fundamental goal of root canal therapy is to achieve root canal disinfection and to prevent or remove apical periodontitis. Conventionally manual endodontic files were used for pediatric endodontics which were more time consuming and a greater number of files were needed for the root canal preparation. Because of its superior qualities Nickel-titanium (NiTi) alloy has gained popularity in pediatric endodontics. Despite this NiTi instruments experience unexpected separation due to cyclic fatigue and torsional fracture. The Cyclic fatigue (CF) resistance of files is thought to be influenced by several parameters, including the radius and degree of root canal curvature, as well as the design of the instrument.[1]

Because of its unusual nanocrystalline martensitic microstructure, endodontic tools created with M alloy are projected to have more flexibility, strength, and wear resistance than equivalent instruments built with typical highly elastic NiTi wires.[2]

According to the latest study on the metallurgical characterization of M-Wire by Alapati et al, M Wire contains all 3 crystalline phases, including deformed and micro twinned martensite, R-phase, and austenite which gives it greater flexibility than traditional NiTi files and greater resistance to cyclic fatigue.[3]

When NiTi files come into contact with irrigation solutions during root canal preparation, they corrode and distort, which can lead to unexpected breakage during clinical usage. Sodium hypochlorite (NaOCl) is the most often utilised root canal irrigation solution. The physical characteristics of instruments in regions where they encounter NiTi instruments were affected by NaOCl and ethylene diamine tetra-acetic acid (EDTA) solutions, and the files broke at those sites.[4]

In addition to NaOCl, EDTA is applied to the root canal to aid root canal instrumentation. A caustic solution, such as sodium hypochlorite solution, is usually withdrawn from a root canal after it is applied in endodontic therapy, implying that sodium hypochlorite's impact may be reduced.[5] An EDTA agent, on the other hand, is usually not eliminated, and root canal instrumentation is performed while the agent is still present. This clinical circumstance suggests that the EDTA agent may have a greater impact on Ni-Ti file corrosion fatigue.

Hence, the aim of this study was to evaluate the effect of irrigating solutions on cyclic fatigue resistance of conventional and heat-treated nickel titanium pediatric rotary instruments.

The tested null hypotheses in the current study was as follows: there would be no significant effect on the cyclic fatigue resistance of the three types of heat treated NiTi rotary Pediatric endodontic files in contact with 3% NaOCl and 3% NaOCl with 17 % EDTA.

Methods

File Samples and Preparation: The current study employed three pediatric rotary file systems: ProTaper Gold (Dentsply Tulsa Dental Specialties, Tulsa, OK, USA); Kedo SG blue (Kedo files, India); and Pro AF Baby Gold (Kids -e- Dental, India). For the fatigue resistance test, 72 heat-treated NiTi rotary endodontic files were used. The size and taper of all the instruments were similar (#21, #16; 0.04). Each group was made up of 24 unused files divided into two subgroups. The first subgroup's files were immersed in 2.5 % NaOCl for 10 minutes at 35°C, whereas the second subgroup's files were immersed in 2.5 % NaOCl + 17 percent EDTA for 10 minutes at 35°C as shown in Figure 1. The files were properly cleaned with distilled water and dried after the immersion to get rid of any residual effect for the irrigant.

Cyclic Fatigue Testing: Using an artificial canal at 35°C, files were examined for cyclic fatigue resistance. The artificial canal was created from a zirconia block with an apical diameter of 0.6 mm, a radius of 6.06 mm, and a curvature angle of 60°. The curvature of the canal began at 2.5 mm from the canal tip and reached a maximum of roughly 5.5 mm. It was constructed on a pre-sintered zirconia block, which was then sintered for an hour at 1500° C in a sintering oven (Vita Zyrcomat, Vita Zahnfabrik, Germany).

The rotation was performed with a constant speed of 350 rpm utilizing a contra-angle and motorized by a torque-controlled electric motor in back-and-forth axial movements till the files fracture. The time to fracture was recorded in seconds for each instrument using a

digital chronometer and the number of cycles to fracture (NCF) for each file was calculated using the following formula: [NFC = revolutions per minute (rpm)×time to fracture (s)/60]. A digital micro caliper was used to determine the length of each fractured fragment (FL). The mean FL was recorded to evaluate the correct positioning of the tested instrument inside the canal curvature and to determine whether similar stresses were induced.

Fractographic Analysis: The cross-sectional and lateral views of the fractured files were examined under a scanning electron microscope (Carl Zeiss Ltd, 40 VP, Smart SEM, Cambridge, UK) at various magnifications (×200 to ×5,000) to observe the fracture behaviors. The fatigue signs were manifested in four areas: 1) crack initiation, where microcracks form and start to grow; 2) crack propagation, where the crack continuously grows; 3) overstressed area or overload zone a typical dimple rupture or ductile failure; 4) signs of edge wear with rounding of cross-sectional outline and loss of sharpness of the cutting edge.

Statistical Analysis: For each subgroup, the mean and standard deviation of the NCF was recorded. The collected data was entered in Microsoft excel spreadsheet. The data on continuous variable was presented as Mean ± Standard Deviation (SD). The Shapiro Wilk test for normality indicated that data were normally distributed. Unpaired t-test were used to test the significance difference between means of two groups. One way ANOVA were used to find difference between the means of three groups and Bonferroni post-hoc test was used for intergroup comparison. The entire data was statistically analyzed using Statistical Package for Social Sciences (SPSS version 20.0, IBM Corporation, USA) for MS Windows. Probabilities of greater than 0.05 considered as statistically not significant. Probabilities of less than 0.05(0.01) and 0.001 were accepted as statistically significant and highly significant respectively.

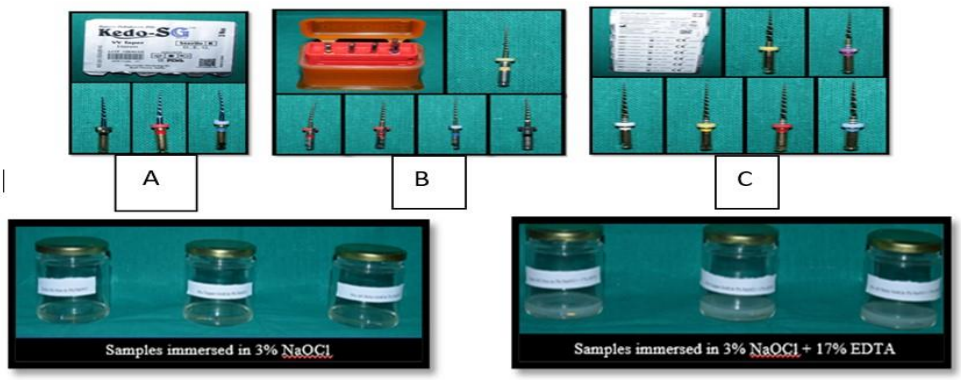

Figure 1: A) Kedo SG Blue Files; B) Pro AF Baby Gold; C) Pro Taper Gold Files.Samples immersed in 3% NaOCl and 3% NaOCl with 17 % EDTA.

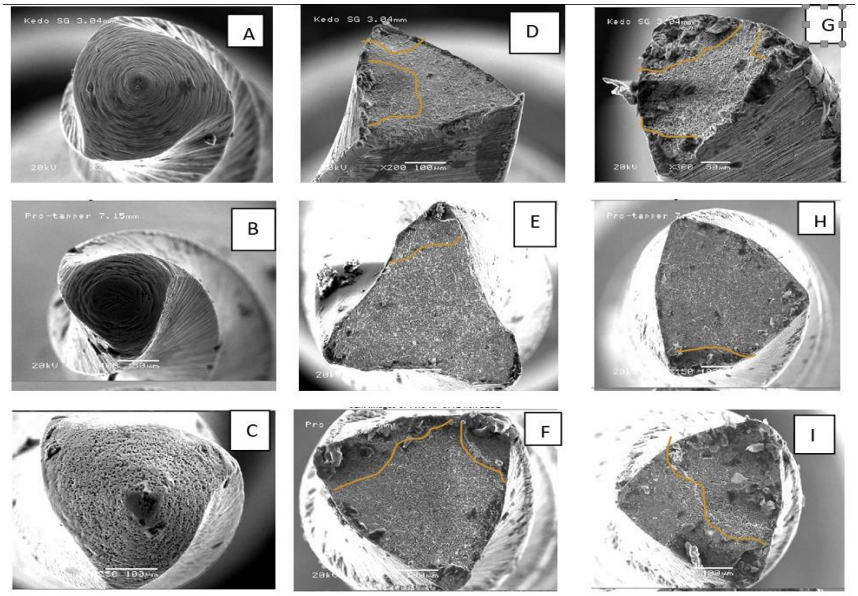

Figure 2: Scanning Electron Microscope images of (A) Original cross section of Kedo SG Blue; (B) Original cross section of Pro tapper Gold ; (C) Original cross section of Pro AF Baby Gold ; after immersion in 3 % NaOCl Fractured Files with their Cross Section: (D) Kedo SG Blue; (E) Pro Tapper Gold ; (F) Pro AF Baby Gold; after immersion in 3 % NaOCl + 17 % EDTA Fractured Files with their Cross Section: (G) Kedo SG Blue; (H) Pro Tapper Gold ; (I) Pro AF Baby Gold.

Results: The inter group comparison of the 3 file systems for NCF, in the two different irrigating solution groups showed a statistically significant difference between Pro AF files immersed in NaOCl 3% and NaOCl 3% + EDTA 17%, while no significant difference in Pro Tapper Gold and Kedo SG Blue file systems was noted. (Table 1) There was a statistically highly significant difference between groups as determined by one-way ANOVA for file treatment in NaOCl 3% and NaOCl 3%+ EDTA 17%. When tested in 3 % NaOCl, Kedo SG blue files showed highest resistance to cyclic fatigue (1903.74±44.93) followed by Pro Tapper Gold (1243.71±31.39), and least amount of cyclic fatigue resistance was shown by Pro AF Baby Gold files (1190.96±33.29). After addition of 17 % EDTA to 3% NaOCl, Kedo SG blue files showed highest resistance to cyclic fatigue (1878.05±66.26) followed by Pro Tapper Gold (1233.04±45.95), and least amount of cyclic fatigue resistance was shown by Pro AF Baby Gold files (1138.46±21.95).

The difference between the tested groups were significant except those between the Pro tapper gold and Pro AF ($P>0.05$). After adding EDTA 17%, the difference between the tested groups were statistically significant. (Table 2)

There was a statistically significant difference between the fragment length of Pro Tapper Gold of NaOCl 3% and NaOCl 3% + EDTA 17% while no significant difference was noted in Kedo SG blue and Pro AF Baby Gold. There was a statistically highly significant

difference between groups as determined by one-way ANOVA for file treatment NaOCl 3% and NaOCl 3% + EDTA 17%. (Table 3)

The difference between the tested groups were significant¸ except for those between the Kedo SG Blue and Pro AF (P>0.05) in both NaOCl 3% and NaOCl 3% + EDTA 17%. (Table 4)

The fracture surface of instruments of different design and size was similar. The appearance of the fracture surfaces, assessed by SEM, indicated that the breakage of the instruments was the result of fatigue. The fracture surface revealed a smooth, almost featureless area at the periphery of the fracture site. The fracture surface of instruments of different design and size was similar. The appearance of the fracture surfaces, assessed by SEM, indicated that the breakage of the instruments was the result of fatigue. The fracture surface revealed a smooth, almost featureless area at the periphery of the fracture site.

Figure 2 shows SEM analysis of all fractured files vs the original cross section. The fracture surface of instruments of different design and size was similar. The appearance of the fracture surfaces, assessed by SEM, indicated that the breakage of the instruments was the result of fatigue. The fracture surface revealed a smooth, almost featureless area at the periphery of the fracture face and large central irregular fibrous areas associated with final ductile breakage. Areas of crack initiation and growth exhibited small regions of nucleation and slow crack propagation, known as smooth regions, peripheral to the cross section. Crack propagation was typified by striations, each representing the progression of the crack caused by tension during the rotation of the instrument. Fractures propagated from the periphery of the instrument towards the centre.

Table 1: The Mean ± SD of the NCF of the tested files

File treatment	**Pro tapper gold**	**Kedo SG blue**	**Pro AF**	**P@ value**
NaOCl 3%	1243.71±31.39	1903.74±44.93	1190.96±33.29	<0.001*
NaOCl 3% + EDTA17%	1233.04±45.95	1878.05±66.26	1138.46±21.95	<0.001*
P$ value	>0.05	>0.05	<0.05	

$: Unpaired t-test, @: One-Way ANOVA,*: P value statistically significant

Table 2: P values of multiple comparisons by Bonferroni test for NCF of the tested file groups

File treatment	Group	Group	P# value
NaOCl 3%	Pro tapper gold	Kedosg blue	<0.001*
		Pro AF	>0.05
	Kedosg blue	Pro AF	<0.001*
NaOCl 3% + EDTA 17%	Pro tapper gold	Kedosg blue	<0.001*
		Pro AF	<0.05*
	Kedosg blue	Pro AF	<0.001*

*P value statistically significant

Table 3: The Mean ± SD of the FL of the tested files

Treatment group	**Pro Tapper Gold**	**Kedo SG blue**	**Pro AF**	**P@ value**
NaOCl 3%	3.72±0.20	3.05±0.03	3.14±0.05	<0.001*
NaOCl 3% + EDTA 17%	3.94±0.11	3.06±0.03	3.15±0.05	<0.001*
P$ value	<0.05	>0.05	>0.05	

$: Unpaired t-test, **@: One-Way ANOVA,*: P value statistically significant**

Table 4: P values of multiple comparisons by Bonferroni test for FL of the tested file groups

File treatment	Group	Group	P# value
NaOCl 3%	Pro Tapper Gold	Kedo SG Blue	<0.001*
		Pro AF	<0.001*
	Kedo SG Blue	Pro AF	>0.05
NaOCl 3%+EDTA 17%	Pro Tapper Gold	Kedo SG Blue	<0.001*
		Pro AF	<0.001*
	Kedo SG Blue	Pro AF	>0.05

#: Bonferroni post-hoc test,*: P value statistically significant

Discussion: Due to cyclic fatigue while rotating inside the curved root canals, endodontic files abruptly fail at their maximal flexure point. [6,7] During file sterilisation or canal irrigation in pediatric endodontics, advanced NiTi instruments may encounter NaOCl and EDTA. Thus, conducting cyclic fatigue studies is critical in order to provide dentists with information about the potential effects of NaOCl and EDTA on file fracture resistance of these files. In this study the cyclic fatigue of three types of heat-treated NiTi rotary endodontic files was compared before and after a 10-minute immersion in 3 % NaOCl and 3 % NaOCl with 17% EDTA. The AAPD recommends 1- 5.25 % NaOCl in its diluted forms along with 17 % EDTA to be used in primary teeth as irrigants. Hence 3 % NaOCl along with 17 % EDTA was used in this study.[8]

In previous studies various file systems: Pro Taper Gold, Pro Taper Next and Pro Taper Universal have been tested for cyclic fatigue.[9] However, to our knowledge no studies for cyclic fatigue resistance have been conducted comparing the Pediatric new generation rotary endodontic files such as Kedo SG blue and Pro AF Baby Gold.

In the present study, the zirconia artificial canal was milled on a presintered zirconia block, and then the block was sintered in a sintering oven (Vita Zyrcomat, Vita Zahnfabrik, Germany) as used similar to a recent study by Naswari et al.[10]The physical properties of Zirconia are quiet in accordance with the root dentine of primary teeth root canals.[11] This model is made up of custom made, size-matched artificial canals in a noncorrosive biomaterial. This allowed standardized evaluation of the fatigue resistance of NiTi files in the potentially corrosive environment of concentrated irrigation solutions (NaOCl and EDTA), which will mimic clinical conditions better than earlier models. In addition, in a previous study, it was reported that the trajectory of the NiTi files during the cyclic fatigue test is important to achieve a reliable result.[12] Thus, in the present study the custom-made artificial canals according to the file taper were used. It has been demonstrated that the cyclic fatigue resistances of thermomechanically treated NiTi files were affected by ambient temperature.[13] Thus, in the present study, all the NiTi files were tested at 37 °C to mimic clinical conditions.

According to the results of present study, Kedo SG Blue files have a higher cyclic fatigue resistance compared to Pro Taper Gold and Pro AF Baby Gold. And when compared in two different irrigating media the effect of EDTA causes a significant reduction in Cyclic fatigue resistance of the Kedo SG Blue files compared to Pro T/aper Gold and Pro AF.

The major factors affecting cyclic fatigue resistance of the files include file size, taper, cross-sectional design, manufacturing techniques, and materials. [12,13] The Kedo SG

Blue files and Pro Tapper Gold files have a similarity between them, they are both third Generation Rotary endodontic files which are heat treated. Dalibor (DaliborVojtech, 2010), found that all annealing temperatures result in TS reduction (stress at the onset of B2→ B19′ transformation) except for a very short annealing at 410°C. [14] The rate of TS reduction increases with increasing temperature. In Pro Taper Gol, Post heat treatment is applied after the flutes of a file have been manufactured. The temperature used is in a range of 370-510° C for a variable period of time (typically 10-60 min, depending on file size and taper) (Gao, 2011). Files exhibits 2-stage specific transformation behaviour and high Af temperature around 50 ˚C (Hieawy, 2015). [15,16] The Kedo SG Blue files are third generation of the Kedo system of pediatric rotary endodontic files. It consists of three files D1, E1, and U1.[17] The Pro AF files are manufactured by NiTi CM-Wire technology. It is flexible and has constant taper of 4% and 6%. They comprise of five files of 17mm long and mostly require only two files for preparation.[18]

The possible reason for Pro AF for having reduced cyclic fatigue resistance could be its manufacture (second generation files) which have the shape memory, raise the transformation temperatures (Af to about 50 °C) and obtain stable martensite at the body temperature (Santos, 2013).[19] Zhou et al. (Zhou, 2012), stated after energy dispersive spectroscopy (EDS) results that the composition of controlled memory (CM) and Super Elastic (SE) wires could be considered as the same.[20] Testarelli et al found that CM has a lower percent in weight of nickel (52 Ni %wt) compared to the common 54.5– 57 Ni % wt of the great majority of commercially available SE (Testarelli, 2011). CM instruments, in addition to the austenite, also contained martensite and R-phase (Pereira, 2012).[21] However, it has been reported that after thermal cycling, the martensitic transformation of NiTi alloys occurs in 2 stages (Alapati, 2009; Shen, 2011; Shen, 2013), instead of one. The 1-stage transformation (A-M) happens in Ni-rich NiTi alloys, whilst 2- stage transformation (A-R-M) happens after additional heat treatment. The heat treatment forms finely dispersed Ti3Ni4 precipitates in the austenitic matrix. Consequently, the R phase is formed in preference to martensite due to the presence of Ti3Ni4 fine particles. However, the alloy needs additional cooling to form martensite, and hence, martensitic transformation occurs in 2 steps (A-R-M) (Otsuka, 2005).[22] This process was implied to several systems by Dentsply Tulsa in its Pro Tapper Gold files.

Kedo-SG Blue files are coated with titanium, adding greater flexibility to reach even the tortuous root canal system resulting in an effective and consistently successful cleaning and shaping. The uniqueness of this rotary file system lies in its variably variable (VV) taper,

varying tip diameter (D1-0.25, E1-0.30, U1-0.40) and the titanium coat, enhancing supreme flexibility and preventing inadvertent breakage of the files in the tortuous root canals of the primary teeth.[23]

Several factors, including the type of metal alloy, the treatment with heat, the number of threads, the helical angle, the cross-sectional shape and the dimensions, affect the flexibility and cyclic lifespan of files.[24] According to Elnaghy 2014, the pro tapper gold files have a triangular cross section making it more resistance to fracture from the tip however the fact that the apical section of Kedo SG Blue files have 5 mm apical triangular cross-section and coronal cross section of 7mm in tear drop shape, contributing to its superiority and a lesser fractured tip length.[25] The 21 mm length of Pro taper Gold file compared to 17 mm and 16 mm for Pro AF and Kedo SG Blue respectively makes it more vulnerable to fracture away from the apical tip.[23,24] However, the difference in fragment lengths among the groups could also be attributed to the effect of the test condition, the properties of the alloy used, or the original internal defects within the files.

Scanning electron micrographs of the control subgroups showed signs of mechanical failure as microcracking, crack propagation, and overloaded zones. While the EDTA treated subgroups showed further wear signs such as flattened edge and rounded cross section with large pitting related to the acid immersion.

The main limitation of the present study was the effect of the cyclic and the torsional fatigue could not be calculated together.Further research methodologies should be developed to investigate the influence of both torsional and cyclic fatigue factors on the life of NiTi instruments.

Conclusion: Within the limitations of the study, it can be concluded that the use of NaOCl along with EDTA used as sterilizing agent/ root canal irrigant adversely affects the cyclic fatigue resistance of the heated-treated NiTi rotary files used for root canal treatment. The Kedo SG Blue files were the best among the tested types. Kedo SG Blue files could be safely used for root canal treatment.

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