RESEARCH ARTICLE

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Effect of Heated Irrigating Solutions on the Cyclic Fatigue Resistance of Reciprocating Endodontic Files

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ABSTRACT

***Objectives*: The aim of this study was to evaluate the effect of heated irrigating solutions on the cyclic fatigue resistance of reciprocating endodontic files.**

***Materials and Methods*: Reciproc Blue, ProDesign S and X1-Blue files were immersed in the irrigating solutions 5.25% NaClO and 2% chlorhexidine digluconate gel heated in oven at 37ºC for 10 min. In same conditions, saline solution was considered as control. The following groups (n=15) were considered: RSs (Reciproc Blue + saline solution); RNa (Reciproc Blue + 5.25% NaClO); RCd (Reciproc Blue + 2% Chlorhexidine digluconate gel); PSs (ProDesign S + saline solution); PNa (ProDesign S + 5.25% NaClO); PCd (ProDesign S + 2% Chlorhexidine digluconate gel; XSs (X1-Blue + Saline solution); XNa (X1-Blue + 5.25% NaClO) and XCd (X1 Blue + 2% Chlorhexidine digluconate gel). Cyclic fatigue test was performed in a device with a 60 degrees curved canal and 5 mm radius immersed in water at 37ºC. The time for file failure was recorded in seconds to calculate the number of cycles to fracture (NCF). Data were submitted to ANOVA followed by Tukey's test (α=0.05%) comparing split plots (SPSS 26.0).**

***Results*: There was no statistically significant difference for NCF between irrigating solutions and control in all file types. ProDesign S showed greater and significant difference when compared to Reciproc Blue and X1 Blue in all irrigating solutions and control.**

***Conclusions*: NCF value in each file type was not influenced by the solutions. Among file types, the NCF value was higher for ProDesign S and lower for X1-Blue in all solutions.**

***Clinical Relevance*: Heated irrigating solutions is not a relevant factor in relation to fracture resistance of reciprocating endodontic files; however, the fracture was influenced by the file types.**

Keywords: Cyclic fatigue, fracture, irrigating solution, reciprocating file, temperature.

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I. INTRODUCTION

Mechanical preparation of root canals is an important step in endodontic therapy. However, endodontic files are subjected to torsion during root canal treatment and some external factors may negatively influence the rotary instrument fatigue resistance. The file temperature can reduce the mechanical resistance to fatigue causing early fracture, and the increase of temperature from 20 to 37 °C reduced in about 85% the flexural strength of endodontic files immersed in heated water [1].

Lower flexural fatigue resistance in nickel-titanium files submitted to temperature of 35 °C was shown when compared to ambient temperature of 20 °C [2]. On the other hand, the internal temperature of the canal of 20 °C provided higher fatigue resistance value than the obtained in the temperature of 35 °C [3]. Similar result for fatigue resistance in relation to temperature was also verified with 5.25% NaOCl heated to temperature of 60 ºC, causing less fatigue cycles when compared to distilled water at temperature of 25 ºC [4]. Moreover, the protocol for file cooling with lower temperatures may also be considered an interesting strategy to improve the fatigue resistance of nickel-titanium rotary files [5].

Mechanical endodontic preparations are performed in association with irrigating chemical substances that facilitate the smear layer removal, promote lubricating effect and antimicrobial action. However, the irrigating solutions have different chemical interactions with metal alloys, condition that can change the surface relief of endodontic files [6]. It is alleged that the immersion in irrigating solutions of 17% EDTA or 5.25% NaClO can change the surface topography of nickel-titanium files, causing irregularities that concentrate mechanical stresses induced during the endodontic procedures and consequent premature failures [7].

Previous studies also showed that the 5.25% NaClO solution can decrease the cyclic fatigue resistance values of endodontic files [8]-[10]. Moreover, the 2% chlorhexidine digluconate aqueous solution (pH 5.5-6.0) has been used as an irrigating solution or intracanal medicament because it possesses wide range of antimicrobial activity and lower cytotoxicity [11]. By analogy, studies with nickel-titanium alloy used in orthodontic devices also showed some chemical reactivity effects with different antiseptic solutions [12]-[14].

According to some authors, 17% EDTA and 5.25% NaOCl solutions are preferred for root canal irrigation [2], [9], [10], [15], while temperatures of 20, 35 and 37 °C and immersion times of 5 and 10 min are commonly used. [6], [7], [16].

On the other hand, some studies showed that immersion in 5.25% NaClO solution at temperature of 37 °C for 5 and 10 min did not cause significant changes in the cyclic fatigue resistance of endodontic files [7], [15], [17]-[19], causing divergences due to different methodologies between studies [3]. However, there is no evidence that shown the existence of previous studies evaluating the effect of solutions of 2% chlorhexidine digluconate gel and 5.25% sodium hypochlorite heated on the cyclic fatigue resistance of reciprocating endodontic files.

Flexible endodontic files are recommended to prepare the root canal without causing deformation or structural deviation, mainly in accentuated root curvature. In addition, files must show proper mechanical resistance to withstand the flexural cyclic fatigue resulting from the endodontic procedures. Some divergences among studies also occur in relation to curvature of the root canal, different endodontic device formats, as well as temperature levels and irrigating solutions types. However, similar mechanical tests were made using metallic blocks with an artificial root canal with 60 degrees curvature angle, 5 mm curvature radius and central curvature distant 5 mm from the rotary instrument tip [4], [5], [10], [18].

Controversial results not completely clarified in previous investigations supported the aim of this in vitro study to verify the effect of the 5.25% sodium hypochlorite solution and 2% chlorhexidine digluconate gel heated at 37 °C on the cyclic fatigue resistance of nickel-titanium reciprocating endodontic files ProDesign S, Reciproc Blue and X1-Blue. The study hypothesis was that the heated irrigating solutions would promote similar effects on the cyclic fatigue resistance of reciprocating endodontic files.

II. Materials and Methods

A. *Reciprocating Files and* Irrigating Solutions

Commercial nickel-titanium endodontic files with reciprocating kinetics Reciproc Blue R 25.08 25 mm (VDW; Munich, Germany - batch 210817), ProDesign S 25.06 25 mm (Easy; Belo Horizonte, MG, Brazil - batch 0037/0119) and X1-Blue 25.06 25mm (MK Life; Porto Alegre, RS, Brazil -batch 20180713) with different cross-sections were evaluated (Fig. 1). The specific heat treatment procedures for each file type performed by the manufacturers are considered as trade secret. However, the file kinetic property allows rotation of 150 degrees counterclockwise and rotation of 30 degrees clockwise, being that three repetitions complete a rotation around of the file axis.

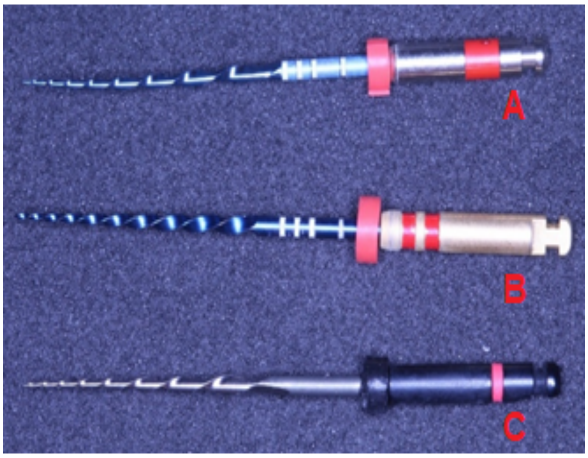

Fig. 1. Reciprocating endodontic files: A - Reciproc Blue, B - X1-Blue, C - ProDesign S.

The irrigating solutions 2% chlorhexidine digluconate gel (Maquira Dental; Maringa, PR, Brazil) and 5.25% sodium hypochlorite (Formula & Action Pharmacy; Sao Paulo, SP Brazil), as well as 0.9% saline solution (Dental Cremer; Blumenau, SC, Brazil) used as control were placed in plastic tubes used for centrifuge procedures, identified and stored in oven until reaching the temperature of 37 ºC [18]. Following, the endodontic files were individually immersed in each solution for 10 min [6], [7].

B. *Root Canal Simulator Device*

Cyclic fatigue resistance of the file was evaluated in a root canal simulator metallic device that allows the adjustment of the angle of curvature between 0 and 90 degrees and curvature radius of 5 mm. The central shaft has a metal cylinder with a movable fitting and a central guide groove for adapting the file to the cylinder, positioning it in the desired curvature. The central shaft has a metal cylinder with a movable fitting and a central guide groove for adapting the file to the cylinder, positioning it in the desired curvature. The central shaft also fixes the contra-angle preventing any negative interference during the fatique test (Fig. 2).

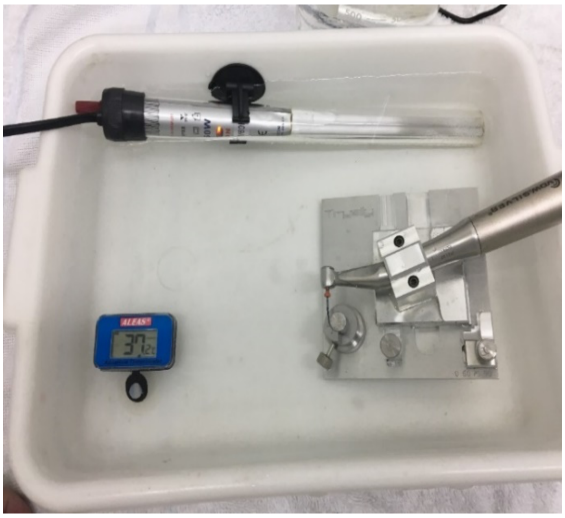
Fig. 2. Device with simulated curved root canal.

C. *Cyclic Fatigue Resistance Test*

After immersion in the irrigating solutions and control, the files were ultrasonically cleaned with distilled water (Dental Cremer) at room temperature for 10 min, dried with absorbent paper and jets of air. After, the files were positioned with 1 mm of the length beyond the curvature of the root canal simulator device [4], [5], [10], [18] and submitted to the cyclic fatigue resistance test until fracture. The test was performed with the device immersed in water at 37 ± 1 ºC to standardize the temperature and humidity conditions. For this, a portable electric heater was used to keep the water temperature at 37 ºC and checked by a digital thermometer placed near to the root canal simulator device.

The same operator properly trained evaluated the following groups associating file types and heated solutions (n=15): RSs (Reciproc Blue and saline solution - Control); RNa (Reciproc Blue and 5.25% NaClO); RCd (Reciproc Blue and 2% chlorhexidine digluconate gel); PSs (ProDesign S and saline solution - Control); PNa (ProDesign S and 5.25% NaClO); PCd (ProDesign S and 2% chlorhexidine digluconate gel); XSs (X1-Blue and saline solution - Control); XNa (X1-Blue and 5.25% NaClO) and XCd (X1-Blue and 2% chlorhexidine digluconate gel).

The reciprocating file motions in the clockwise and counterclockwise completing the rotations were driven by endodontic electric motor (VDW Silver Reciproc; Munich, Germany) with a rotation speed programmed to 350 rpm. The time elapsed to file fracture was recorded in seconds using a K30-104 digital stopwatch (Kasvi; Sao Jose dos Pinhais, PR, Brazil). The total number of cycles to fracture (NCF) was calculated for each group considering the working time versus Rpm ratio (350/60), using the equation:

NCF = Time x (350/60), where NCF= Number of cycles to fracture, Time = Test duration in seconds, and (350/60) = Electric motor rpm.

D. SEM Analysis of the Fractured File

The fractured surface of a random sample of each type of endodontic file was submitted to SEM analysis (JEOL JSM 5600 PV, Tokyo, Japan) at 120x magnification.

E. EDS Analysis of the File

The files from each commercial brand were randomly selected (n=3) and submitted to energy dispersive spectroscopy (EDS) analysis for characterization of the titanium and nickel concentrations. These metallic elements were evaluated in 3 areas of each file and the mean obtained. After, the values for titanium and nickel concentration total were obtained calculating the arithmetic mean for each file type.

F. Statistical Analysis

The data obtained were evaluated by the Pairwise test for normality and sampling force, using adjusted averages independent for solutions ($p>0.05$) or files ($p<0.05$). Following, the data were submitted to two-way ANOVA and Tukey's test ($\alpha=0.05$) comparing split plots (SPSS 26.0; Chicago, IL, USA).

III. Results

Table I shows the NCF comparing each file type among solutions and each solution among file types. There was no statistically significant difference for NCF values among solutions when each file type was considered. Significant difference among file types was observed in each solution with highest value for ProDesign S while the Reciproc Blue and X1 Blue files showed lower and similar values between them.

TABLE I: Means of the NCF Values and Standard Deviation for File and Solution Interaction

Solution	File		
	Reciproc Blue	ProDesign S	X1 Blue
2.25% NaClO	14,993 (3,301) A, a	51,983 (7,665) A, b	8,524 (5,079) A, a
2% Chlorhexidine	15,811 (3,562) A, a	49,669 (8,508) A, b	13,066 (3,229) A, a
Saline solution	14,866 (2,866) A, a	48,584 (8,191) A, b	10,856 (2,214) A, a

Means followed by the same letters (uppercase in columns and lowercase in each row) do not differ statistically by the Tukey's test ($\alpha=0.05$).

Table II shows the EDS values of the nickel and titanium concentrations (%). Reciproc Blue and ProDesign S files showed higher nickel concentrations in relation to X1-Blue file. Higher titanium concentration was verified for X1Blue file whem compared to the Reciproc Blue and ProDesign S files.

TABLE II: Means of the EDS Values And Standard Deviation For Nickel And Titanium Concentrations

File type	Concentration (%)		
	Nickel	Titanium	n
Reciproc Blue	55.16 (0.96)	44.83 (1.28)	27
ProDesign S	55.16 (1.26)	44.83 (0.98)	27
X1-Blue	30.89 (5.19)	69.10 (5.29)	27

Representative images of the EDS analysis for the nickel and titanium concentrations obtained from the reciprocating endodontic files are shown in Fig. 3 (Reciproc Blue), Fig. 4 (ProDesign S) and Fig. 5 (X1-Blue).

Representative fracture images of reciprocating files obtained by SEM are shown in Fig. 6 (Reciproc Blue, ProDesign S and X1-Blue, respectively). The nickel-titanium alloy cohesive resistance and diferent cross-section designs of the reciprocant files differently influenced the fracture pattern resulting of the cyclic fatigue test.

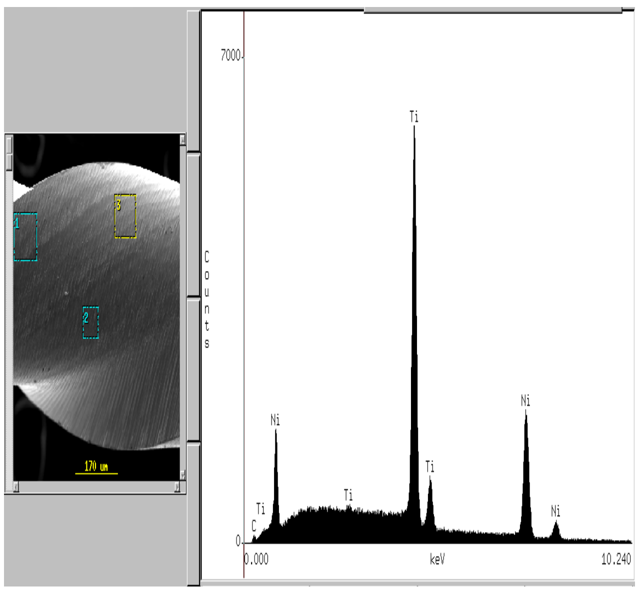

Fig. 3. Representative EDS images of the Reciproc Blue file.

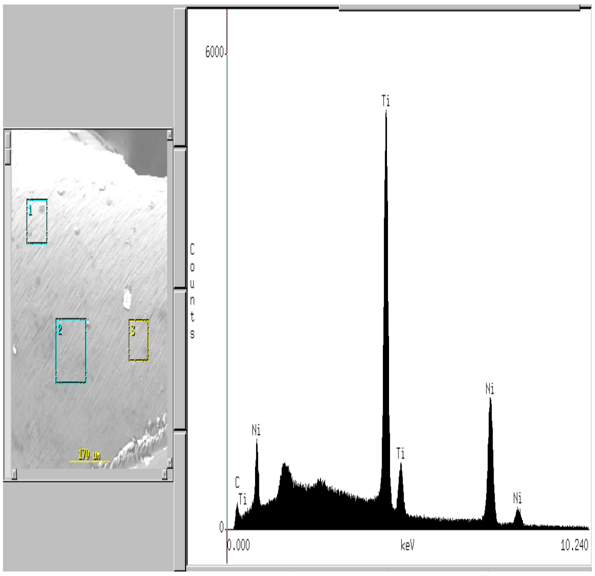

Fig. 4. Representative EDS images of the ProDesign S file.

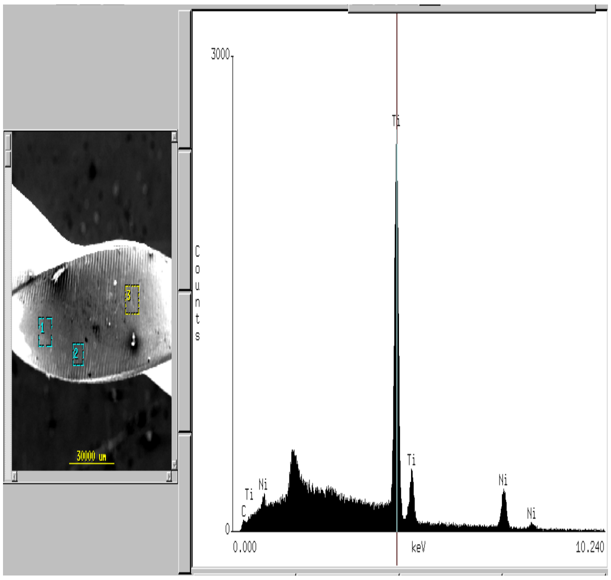

Fig. 5. Representative EDS images of the X1-Blue file.

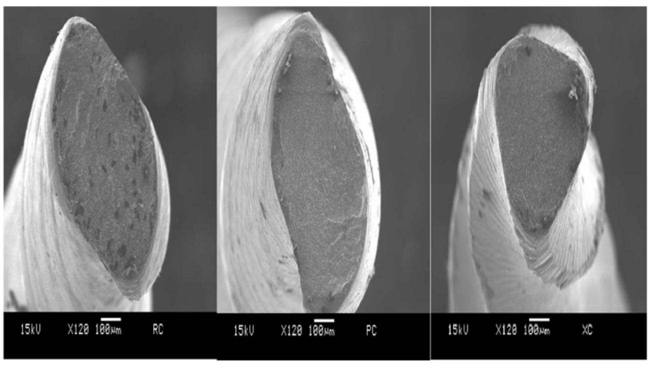

Fig. 6. Representative SEM images of the fractured file (120x).

IV. Discussion

There was no statistically significant difference for NCF values among solutions ($p>0.05$) when each file type was considered. However, statistically significant difference among file types ($p<0.05$) was observed in each solution with highest value for ProDesign S while the Reciproc Blue and X1 Blue files showed lower and similar values (Table I). Therefore, the study hypothesis suggesting that the effect of the heated solutions would be similar on the cyclic flexural resistance of the reciprocating files was rejected.

The NCF values with estatistically significant difference ($p<0.05$) among file types verified in each solution are supported by the results of a systematic review showing that different taper and cross-sections interfere on the files penetration mode into the simulated root canal, causing different file curvatures and transmitting different levels of flexural force during the test in standardized canals [20]. Moreover, the concentration of repetitive flexion stresses would be a factor that can negatively interfere in the formation and propagation of micro cracks, decreasing the cohesive strength level of metallic alloys [21].

Nickel-titanium rotary instruments show high risk of fracture, as well as the production process and the design of the files can influence the torsional resistance or flexural cyclic fatigue. Significant differences among the rotary instruments in terms of cycles number to fracture was also observed due to chemicomechanical root canal preparation, cleaning procedures, chemical disinfection, and sterilization of endodontic instruments [22]. The corrosion can occur due to metallurgical conditions of nickel-titanium instruments, by the effect of thermo-mechanical treatments in relation to instrument flexibility and cyclic fatigue, as well as by the torsion level of endodontic files when in clinical use [23].

In this sense, the differences among the files in relation to the cross-section shapes (Fig. 1) and percentual amount of titanium (Table II) were the followings: Reciproc Blue, double helix, 0.08 mm taper and 44.83% titanium; ProDesing S, double helix, 0.06 mm taper and 44.83% titanium and X1-Blue, triangular, 0.06 mm taper and 63.10% titanium. Moreover, different cross-sections with the same distances from the apical region can cause mechanical differences related to specific force distribution between the files [20].

The relationship of the cross-section distance among the files, and the conicity level of the artificial root canal were not considered in the current study, since the file design types (Fig. 1), as well as the concentration of the main constituents of the metallic alloys (Table II) are similars, except the X1 Blue file. As consequence, the same mechanical behavior pattern could be expected for the files in relation to the NCF among different irrigating solutions (Table I). This fact agrees with previous study showing that 5.25% NaOCl did not significantly affect the cyclic fatigue of nickel titanium files evaluated at 22, 37 and 60 °C [15].

Furthermore, different repeated sterilization cycles differently influence the cyclic fatigue of nickel titanium files, and the lower flexural strength was shown after application of three cycles, while the immersion in NaOCl did not significantly reduce the cyclic fatigue resistance of the heat-treated files [18]. On the other hand, irrigants during cleaning and sterilization procedures can result in corrosion and surface deformation, fact that can lead to unexpected file fracture during clinical use [7].

Table I shows that despite the NCF value be numerically lower for the X1Blue file submitted to 5.25% NaClO solution, the ANOVA did not show statistically significant difference when compared to 2% Chlorhexidine and saline solution (Control). As rotary procedure advantages, all nickel-titanium files for canal cleaning and shaping procedures are related to faster and more efficient instrumentation, decreased canal transportation and ledging, and reduced risk to file fracture [23].

It is possible that lower amount of nickel for X1 Blue file (Table II) allows that the NaClO solution promotes negative interaction with the file surface and consequent lower cyclic strength value, which did not occur with the 2% chlorhexidine digluconate in the Reciproc Blue file (Table I). Whatever the file type, it would be possible to assume that the longer the action time of the irrigating solution, the lower the NCF whatever the amount of nickel and titanium formulating the alloy.

However, Reciproc Blue and ProDesign S files showed significantly different NCF values (Table II), a result difficult to understand or explain based in the similar chemical composition of these alloys in relation to nickel (Fig. 3 and 4). For a possible understanding, further studies are needed to assess the influence of the nickel proportion in endodontic files, mainly in relation to the other constituents and their associated chemical effects.

ProDesign S under the effect of the 5.25% NaClO showed a higher NCF value when compared to the other solutions (Table I). This result can be attributed to the thermal treatment to control the alloy memory with martensitic phase predominance allowing greater elastic deformation. This condition results in more flexible files and greater resistance to cyclic and torsional fractures, both responsible for increasing the mechanical strength of metallic files [5].

It was also observed longer fatigue time for files with high flexibility driven by reciprocating movement in dynamic test models. This finding reinforce the assumption that use of reciprocating movement is a means to prolong the fatigue time of rotary nickel-titanium endodontic instruments during instrumentation of curved canals [24]. In addition, the depth of the surface grooves in the working region affects the file mechanical resistance level; therefore, the smaller the groove depth, the greater the number of cycles to fracture [25]. By analogy, different file models with variations in the depth of the grooves would also be related to the different fracture resistance levels of the files.

Based on this information, the amount of nickel in the metal alloys and its effects are significant factors for mechanical resistance of reciprocating rotary endodontic files. Therefore, similar NCF values was expected among the file types; however, this fact did not occur probably due to the different methods used in the production of endodontic files to improve the cyclic fatigue resistance, such as machining, heat treatment and surface conditioning.

Mechanical difference for cyclic fatigue and torsional resistance values were observed between reciprocating files, as well as the fractographic analysis showed different typical features between fatigue resistance and torsional failure [26]. On the other hand, ProDesign S and Reciproc Blue files show similar nickel and titanium concentration (Table II), greater cross-section area and double helix when compared to X1-Blue file (Fig. 1). It is claimed that different designs of rotary endodontic files can promote different levels of torsional strength [27], and higher number of cycles to fracture was shown in a previous study for the ProDesign S file [28], information that corroborate the results of the current study.

Representative fracture images of the reciprocating files obtained by SEM are shown in Fig. 6. Based on the different fractured surface aspects, it would be possible to assume that the failure was influenced by the different cross-section designs of the files, as well as the different levels of concentration and stresses release caused by mechanical repetitive torsion and consequent levels of cohesive resistance of the metallic alloys.

An investigation showed that the 0.2% chlorhexidine digluconate also altered the elastic modulus and surface quality of nickel-titanium orthodontic wires after immersion at 37 °C for 90 min. [29]. However, nickel ions were more released from nickel-titanium wire when compared to stainless steel wire, while the lowest rate was observed in artificial saliva [13]. Therefore, a fact significant in the endodontic therapy is that the pH level of irrigating solutions be similar to that of the oral tissues [11].

It is possible to assume that the chemical corrosion due to irrigating solutions can also cause changes in the cross-section of reciprocating files. The release of stresses concentrated is responsible by the microcracks propagation, accelerating the fatigue process and early fracture. A fact that could reduce the interaction between irrigating solution and metal alloy is the solution consistency (gel or liquid). The interaction between solution and file would be due to solution viscosity limiting or favoring the contact, the reaction speed and the reactivity level with the metallic alloy.

Other factors would also be responsible for the files mechanical resistance. There are significant differences between the types of engine-driven endodontic instruments in relation to the damage recognition; however, the propensity for caused damages was similar between instruments [30]. In addition, different rotary systems showed capacity for producing centered preparations in curved root canals with low proportion of deviations [31], while nickel-titanium files with higher flexibility driven by reciprocating movement or dynamic model showed longer fatigue life, reinforcing the assumption that the reciprocating movement is a means to prolong the fatigue of nickel-titanium endodontic files during instrumentation of curved canals [25].

Based on these considerations, further studies are opportune to verify the effect of different rotary systems, other irrigating solutions and longer application times on the mechanical properties of reciprocating endodontic files made with different metal alloys. These facts can be considered as a limitation of the current study.

V. Conclusion

Regardless of the study limitation, the NCF value for each file type was not influenced by the solutions. Among file types, the NCF value was higher for ProDesign S and lower for X1-Blue in all solutions.

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Conflict of Interest

Authors declare that they do not have any conflict of interest.

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