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Research Article

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Effect of number of uses and sterilization on the instrumented area and resistance of reciprocating instruments

Victor de Ornelas Peraça [1], **Samantha Rodrigues Xavier** [1], **Fabio de Almeida Gomes** [2], **Luciane Geanini Pena dos Santos** [1], **Erick Miranda Souza** [3], **Fernanda Geraldo Pappen** [1*]

[1]Graduation Program in Dentistry, Federal University of Pelotas, Pelotas, RS, Brazil
[2]Department of Endodontics, Universidade de Fortaleza, CE, Brazil
[3]Department of Endodontics, Federal University of Maranhão, São Luiz, MA, Brazil

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Peraça VO, Xavier SR, Almeida Gomes F, Santos LGP, Souza EM, Pappen FG

***Correspondence to**
Fernanda Geraldo Pappen, PhD
Associate Professor, Graduate Program in Dentistry, Faculty of Dentistry, Federal University of Pelotas, Gonçalves Chaves, 457/507, Pelotas, RS 96015-560 Brazil.
E-mail: ferpappen@yahoo.com.br

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

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ABSTRACT

Objectives: This study evaluated the effect of repeated uses and autoclaving in the instrumented area, fracture resistance, and time of instrumentation of thermally treated nickel-titanium reciprocating systems.
Materials and Methods: Two hundred simulated canals were instrumented using Reciproc Blue and WaveOne Gold. Each file was used up to 10 times or until fracture. The instrumented area was measured in pre- and post-operative images, using ImageJ software. Kaplan-Meier survival analysis evaluated the number of uses of instruments before fracture. Instrumented area and time of instrumentation were analyzed by Mann-Whitney U test and Kruskal-Wallis. Correlations among the number of uses and instrumented area were measured. The level of statistical significance was set at $p < 0.05$.
Results: Reciproc Blue presented a higher estimated number of uses in comparison with WaveOne Gold ($p = 0.026$), but autoclaving did not affect the resistance to fracture of instruments ($p > 0.05$). The instrumented area was different among the evaluated groups ($p = 0.039$), and the instrumented area along the uses of both tested instruments was reduced. With the time of instrumentation, there was also a significant difference among the evaluated groups; the groups without sterilization cycles were faster, in comparison to those submitted to autoclaving ($p = 0.010$).
Conclusions: Reciproc Blue was more resistant than WaveOne Gold, suffering later fracture. Additionally, the sterilization cycles did not influence the estimated number of uses of thermally treated reciprocating instruments, but the instrumented area of root canals was reduced along with the repeated uses of both instruments.

Keywords: Instrument fracture; Instrumentation; Sterilization; Reciproc Blue; WaveOne Gold

INTRODUCTION

The development of nickel-titanium (NiTi) instruments has enhanced root canal shaping, making it more effective, easier, and faster [1]. Despite these advantages, NiTi instruments are susceptible to deformations and/or fractures, which may affect the treatment prognosis

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ORCID iDs
Victor de Ornelas Peraça
https://orcid.org/0000-0001-7172-4530
Samantha Rodrigues Xavier
https://orcid.org/0000-0002-2296-0550
Fabio de Almeida Gomes
https://orcid.org/0000-0003-0066-6729
Luciane Geanini Pena dos Santos
https://orcid.org/0000-0003-0531-0828
Erick Miranda Souza
https://orcid.org/0000-0003-2074-0834
Fernanda Geraldo Pappen
https://orcid.org/0000-0002-8483-455X

[2]. To control these difficulties, new NiTi alloys and different cross-sectional designs have been proposed, optimizing the characteristics of endodontic instruments [3,4].

Thermal processing of NiTi alloys has improved fatigue resistance, flexibility, cutting efficiency, and canal-centering ability of instruments [4]. In addition to the thermal treatment modifications, the reciprocating motion kinematic has already been shown to extend the life span of NiTi instruments and the resistance to fatigue in comparison with continuous rotation movement [5]. Reciproc Blue (VDW, Munich, Germany), as well as WaveOne Gold (Dentsply Mailefer, Ballaigues, Switzerland) instruments, are produced from a metal alloy treated with a complex heating-cooling proper treatment, presenting improvements in the resistance and flexibility of instruments [6]. The movement of clockwise-relief and the heat treatment of the reciprocating instruments improve their resistance to fracture; however, manufacturers still recommend a single use of each instrument. Root canal preparation may damage NiTi instruments resulting in wear and deformation [7], especially because one single reciprocating instrument is responsible for the shaping of the root canal. Therefore, since these instruments are submitted to high mechanical stress load, it is possible that a decrease in cutting efficiency occurs after repeated uses, even though it is not evidenced in the literature. In addition, the sterilization cycles, essential for the re-use of the instrument, could also negatively affect its fracture resistance [8]. The re-use of reciprocating instruments is still a controversial issue and some studies advise to keep the protocol of a single-use, guaranteeing a margin of safety against the fracture of the instrument [9-11].

Even though Spicciarelli *et al.* [12] demonstrated that Reciproc files repeated use affected their shaping efficiency in simulated canals, other studies suggest that Reciproc system can be repeatedly used in root canal instrumentation, without causing anatomical deformities [9,13]. In addition, a recent clinical study demonstrated that the files of the Reciproc and WaveOne systems are safe when used in endodontic treatments of up to 3 posterior teeth [9].

Considering that there is still a lack of information regarding the resistance to fracture of thermally treated NiTi reciprocating instruments, the aim of the present study was to evaluate the effect of the number of uses and cycles of sterilization in the instrumented area and fracture resistance of 2 thermally treated NiTi reciprocating systems (WaveOne Gold e Reciproc Blue) in simulated curved canals.

MATERIALS AND METHODS

Sample size calculation

Sample size was estimated using the following parameters: medium effect size = 0.30, alpha-error = 0.05 and power beta = 95% [14]. Parameters were input into an F test family of analysis of variance (ANOVA) with fixed effects and interactions. The results indicated the need for a minimum of 195 resin blocks for performing the experiment using 4 groups and 2 different files.

Sample preparation

Two hundred resin blocks (IM do Brasil Ltda, São Paulo, SP, Brazil) with simulated root canals with a curvature varying from 38° to 40°, 19 mm in length, initial size of ISO 15/0.02 taper were used in this study.

The resin blocks were numbered and individually photographed using a Nikon D40X digital camera, using 105 mm macro lens (Nikon Inc., Tokyo, Japan), with standardized conditions. The images were recorded in .TIFF format, with a resolution of 5,184 × 3,456 pixels. After recording the initial images, the blocks were randomly divided into 4 experimental groups (n = 50/group), according to the system to be tested and the sterilization cycles.

Reciproc Blue R25 (n = 10) and WaveOne Gold Primary (n = 10) instruments were selected to instrumentation of 2 experimental groups each. Prior to root canal preparation and after each use, each file was photographed using a Nikon D40X digital camera, with a 105 mm macro lens (Nikon Inc.), in standardized conditions at a 22 cm focal length. For each instrument, 2 registers were made: after the first picture, the instrument was rotated 180°, and photographed again. Each image was inspected for evaluation of morphological deformations or distortions that may have occurred after each use. The images were saved in .TIFF format, with a resolution of 5,184 × 3,456 pixels.

Root canal instrumentation

The instruments were distributed into four groups: Reciproc Blue (G1 and G2, n = 5/group) and WaveOne Gold (G3 and G4 n = 5/group). Groups 1 and 3 were composed of instruments used up to ten times and not submitted to sterilization cycles; while groups 2 and 4 were composed of instruments used up to 10 times, with cycles of sterilization between each use.

Each simulated root canal was instrumented once, and pre-instrumentation images were used as control. The canal patency was confirmed with a size 10 precurved K-file (Dentsply Maillefer, Ballaigues, Switzerland) and the working length (WL) was set 0.5 mm short of this measurement. All instruments were used in an endodontic engine (X-smart Plus; Dentsply Maillefer) at the suggested setting for each reciprocating (reciprocating "*RECIPROC All*" mode for Reciproc Blue instruments; reciprocating "*WAVEONE gold*" mode for WaveOne Gold instruments). The blocks were instrumented using the pecking motion kinematics with slight apical pressure. Each pecking depth was limited to less than 2 mm. After every 3 strokes, the debris was removed from the flutes of the NiTi file, and the artificial canal was irrigated with 2.5% sodium hypochlorite solution, followed by aspiration using the Capillary Tips system (0.48 mm and 0.35 mm, Ultradent Products Inc., Salt Lake City, UT, USA). The apical patency was maintained along the instrumentation using a size 10.02 K-file (Dentsply Maillefer). When the working length was reached, the root canal was irrigated with 2.5% sodium hypochlorite and then dried using absorbent paper points. The debris was removed from the flutes of the NiTi file, and a new sequence of photographs was achieved. These procedures were repeated until some deformation or fracture of the instruments was identified, or until the preparation of 10 simulated root canals. In groups G2 and G4, after each block instrumentation, the instruments were submitted to an autoclaving cycle. Autoclave cycles were performed at a temperature of 121°C for 30 minutes by using saturated steam under 15 psi of pressure.

For each simulated root canal, the stopwatch was triggered when the instrument had its first contact within the root canal and it was interrupted when the pre-set working length was reached.

Analysis of images

Post-instrumentation images were obtained from the simulated root canals, using the standardized conditions used in the achievement of initial photographs. The images of each block, before and after instrumentation were saved in TIFF format and transferred to the ImageJ software (version 1.43; National Institutes of Health, Bethesda, MD, USA). Software

calibration was performed using a standard image of a known measure. All the images had a standardized size, with the image of the simulated root canal centralized. The image of the root canal before and after instrumentation was selected, the number of pixels per millimeter was registered through the measure tool. The difference between pre- and postoperative values was calculated for each sample, allowing the group comparisons. **Figure 1** illustrates the area measurement performed.

Additionally, the images of the instruments before each use or until they showed some kind of fracture were evaluated in order to locate morphological alterations before eventual fractures (**Figure 2**).

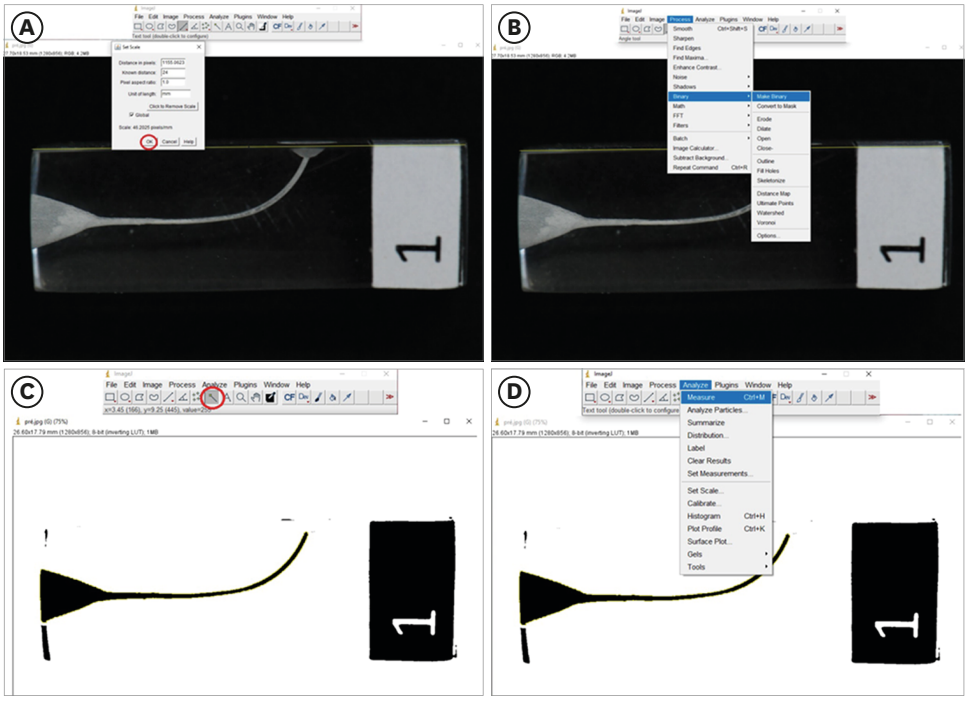

Figure 1. Example of a pre-instrumentation image achieved, and transferred to ImageJ software (version 1.43; National Institutes of Health). The image of the root canal before and after instrumentation was selected and the number of pixels per millimeter was registered through the measure tool.

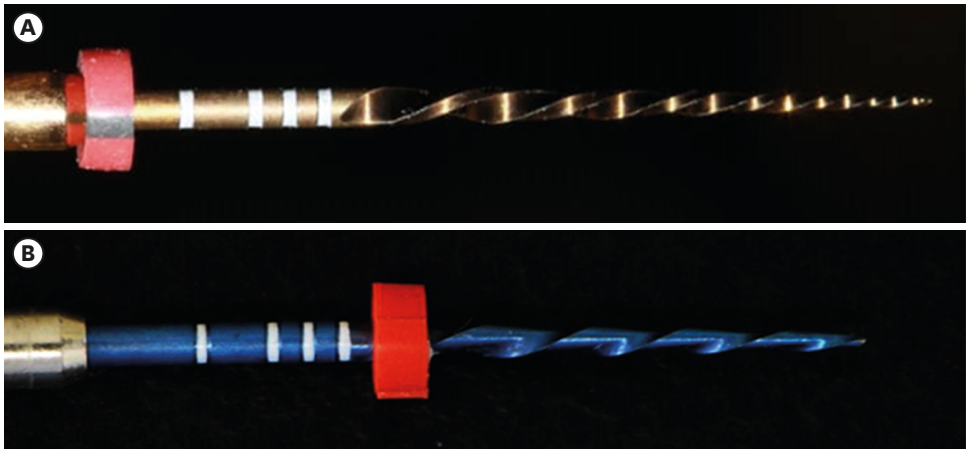

Figure 2. Image of the instruments achieved to illustrate fracture and locate morphological alterations before eventual fractures. (A) WaveOne Gold with no deformation or fracture; (B) Reciproc Blue after fracture.

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Statistical analysis

The results were tabulated and analyzed in IBM Statistics SPSS software version 20.0 for Windows. The number of instrumented samples before the occurrence of fracture of the instruments was analyzed using the Kaplan-Meier survival analysis.

The analysis of the data regarding the preparation time and the post-instrumentation areas resulting from the use of the different instruments was performed through the Mann Whitney and Kruskal Wallis tests since they did not present normal distribution. The Spearman correlation test was also applied, in order to evaluate the correlation between the number of uses of each instrument with the dependent variables: preparation time and prepared area of the simulated canals. The level of statistical significance was set at $p < 0.05$.

RESULTS

There was no evidence of morphologic alterations in the design of instruments before fracture. Reciproc Blue was able to instrument more simulated canals before fracture, in comparison to WaveOne Gold ($p = 0.026$). According to the Kaplan-Meier survival analysis, the sterilization cycles did not influence the estimated number of uses of Reciproc Blue ($p = 0.085$) and WaveOne Gold ($p = 0.853$). The estimated number of uses before fracture, for each evaluated group, is described in **Figure 3**.

The instrumented area was different among the evaluated groups ($p = 0.039$), and the smallest area was observed in the canals instrumented with Reciproc Blue with sterilization cycles (**Table 1**). According to the correlation test, there was a reduction in the instrumented area along the uses of both instruments, WaveOne Gold (r = −0,731, $p = 0,001$ and Reciproc Blue (r = −0.923, $p < 0,001$).

Figure 4 illustrates the reduction in the instrumented area along with the uses, using instruments with and without sterilization cycles. In relation to the time elapsed to the

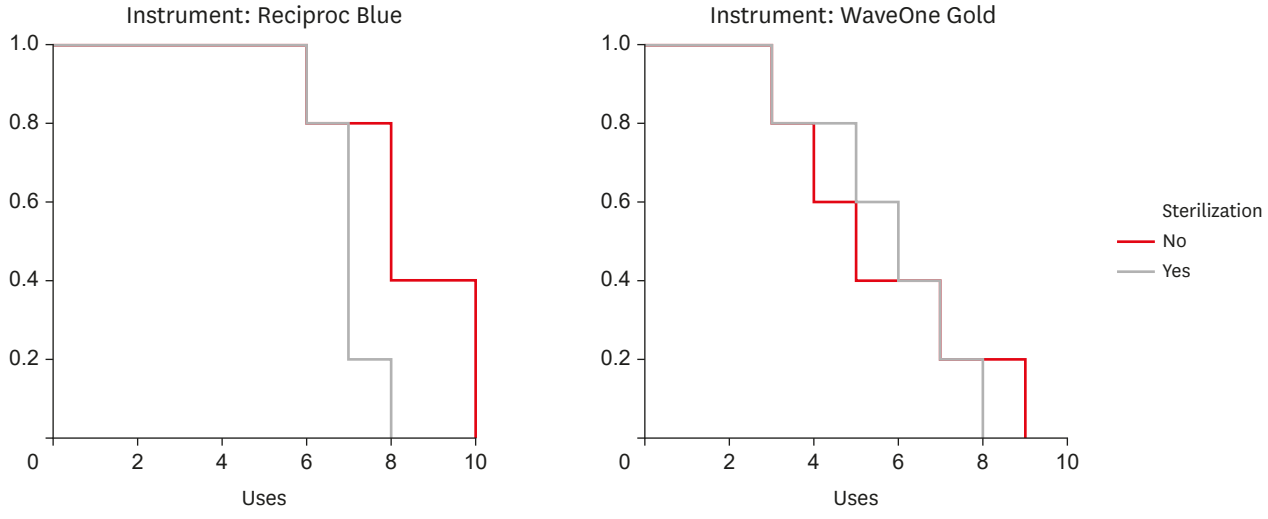

Figure 3. Graphic representation of Kaplan-Meier survival analysis. The estimated survival (number of uses to fracture) of Reciproc Blue was 8.88 uses without sterilization, and 8.36 uses when autoclaved between the uses ($p = 0.085$); while WaveOne Gold presented an estimated survival of 7.05 without autoclaving, and 6.88 when submitted to sterilization ($p = 0.853$).

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Table 1. Instrumented area of simulated root canals (pixels per mm²), within the different evaluated groups

Instrument	Sterilization cycle	Instrumented area	*p* value*
Reciproc Blue	No	1,479.81 ± 1,130.91[b]	0.039
	Yes	791.75 ± 610.26[a]	
WaveOne Gold	No	1,144.38 ± 915.81[ab]	
	Yes	1,270.27 ± 770.59[ab]	

Values are expressed as mean ± standard deviation.
[a,b]Different superscript letters indicate statistically significant differences. *Kruskal-Wallis test.

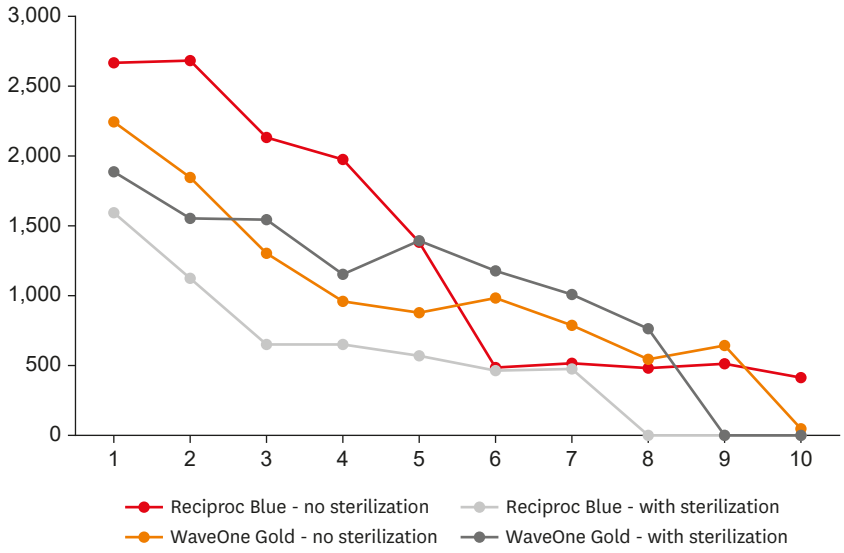

Figure 4. Graphic illustrating the reduction in the instrumented area (pixels per mm²) along the uses within the evaluated groups (WaveOne Gold and Reciproc Blue, with and without sterilization cycles).

instrument to reach the root canal length, there was also a significant difference among the evaluated groups ($p = 0.010$). Data described in **Table 2** demonstrate that the groups without sterilization cycles were faster, in comparison to those submitted to autoclaving.

DISCUSSION

In the present study, 2 thermally treated NiTi reciprocating systems were compared regarding their fracture resistance, instrumented area and time elapsed to instrumentation, as well as the effect of the number of uses and cycles of sterilization on these properties. Cyclic fatigue tests are the most important methods for endodontic instrument resistance analysis, and there are few variations applied to this test. However, the option of using standardized simulated canals, using the same file in up to ten standardized simulated canals, and after several cycles of sterilization, allows inferences closer to the clinical reality.

Table 2. Time to reach the working length with Reciproc Blue and WaveOne Gold, with and without sterilization cycles

Instrument	Sterilization cycle	Preparation time (seg.)	*p* value*
Reciproc Blue	No	109.66 ± 21.17[ab]	0.010
	Yes	123.21 ± 23.33[b]	
WaveOne Gold	No	108.89 ± 21.23[a]	
	Yes	116.35 ± 15.67[ab]	

Values are expressed as mean ± standard deviation.
[a,b]Different superscript letters indicate statistically significant differences. *Kruskal-Wallis test.

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Research involving the reuse of reciprocating files has the potential to influence the safety, effectiveness and quality of endodontic treatment, since the reuse of instruments results in the reduction of treatment cost, making instrumentation techniques more accessible.

Our main results demonstrated that the sterilization cycles did not influence the estimated number of uses of Reciproc Blue and WaveOne Gold. Nevertheless, in general, the fracture occurred later for Reciproc Blue instruments compared to WaveOne Gold instruments. The correlation test showed that there was a reduction in the instrumented area along the uses of both instruments, WaveOne Gold and Reciproc Blue.

In this study, acrylic resin simulated canals were used due to the need for anatomic standardization, which could hardly be obtained if natural teeth were used. Although simulated canals are widely used in studies related to root canal instrumentation [15-18] this method has limitations. These limitations are mainly related to the difference in microhardness of the resin and dentin, and to the effect of heat generation from the movement of the instruments in these canals, which favors the cutting of the material [19,20]. Due to these structural differences between resin specimens and dentin walls, the results of the present study should be interpreted with caution.

According to the manufacturers, WaveOne Gold and Reciproc Blue files are designed to be used in only one clinical case. The manufacturers alert to the risks that the reuse of files could cause in the resistance of the instruments. In addition, it has been demonstrated the mechanical effects of the reuse of reciprocating instruments [21]. In response to these recommendations, recent studies have indicated that the use of these instruments in multiple cases can be safe and efficient [9,22].

Even though there have been suggestions that the files manufactured from M-Wire alloy are not influenced by the sterilization process [5,23], this is the first study evaluating the effect of the sterilization process and the multiple uses of second generation reciprocating instruments. In agreement with previous results [23], where the cyclic fatigue resistance of conventional Reciproc files was not affected by up to 10 sterilization cycles, our study showed that sterilization did not affect the estimated number of canals instrumented by Reciproc Blue system and WaveOne Gold. However, in general, the fracture occurred later for Reciproc Blue instruments compared to WaveOne Gold instruments. This result can be explained by the higher torsional strength of Reciproc Blue files in relation to WaveOne Gold files [6,24].

Several producers have developed special thermomechanical treatments in order to produce NiTi alloys, which mainly contain a stable martensitic phase under clinical conditions. Thus, numerous thermomechanical treatments have been suggested, such as the Control Memory (CM; Coltene, Cuyahoga Falls, OH, USA), the Blue Technology (Dentsply Tulsa Dental Specialties, Tulsa, OK, USA), and the Gold Technology (Dentsply Tulsa Dental Specialties). The present results demonstrate a high frequency of fracture of thermally treated instruments after repeated uses, with or without cycles of sterilization. Even though NiTi properties are usually reported as extremely influenced by thermomechanical processing, the effects of heat retreatment achieved during autoclaving procedures did not significantly affect the cyclic fatigue strength of NiTi instruments [14,25-27].

Regarding the instrumented area, after repeated uses, WaveOne Gold and Reciproc Blue instruments resulted in diminished instrumented area. Our results are in agreement with

those reported by Kowalczuck *et al.* [28] who demonstrated the loss of cutting ability of Reciproc R25 file, and significant reduction of the instrumented area within the repeated uses. Nevertheless, the present study is the first one to evaluate the instrumented area achieved after repeated uses of Reciproc Blue and WaveOne Gold files taking into account the sterilization cycles. Our study also demonstrated that the smallest instrumented area was observed in the canals instrumented with Reciproc Blue with sterilization cycles, however, comparison between instruments should take into account that instruments with different tip taper and design will reflect in the different bidimensional image of preparation. NiTi properties are usually reported as extremely influenced by thermomechanical processing, consequently, the heat retreatment achieved during autoclaving procedures could significantly affect the cyclic fatigue strength of NiTi instruments, or the cutting ability of these instruments. This hypothesis was then, tested in the present study. Our results demonstrated, as described in **Table 1**, that WaveOne Gold had similar instrumented area in both groups, with or without sterilization cycles, demonstrating that it was not negatively affected by thermal changes during autoclaving. Reciproc Blue, however, showed less instrumented area after the same cycles.

The instrumentation time is dependent on several factors such as the applied technique and the operator's experience [29]. In this study, this adversity was overcome since a single operator instrumented all the canals. The literature had shown that the conventional Reciproc system produced significantly faster root canal preparation than WaveOne Gold [30]. However, Bürklein *et al.* [31] demonstrated that the preparation time using Reciproc Blue and WaveOne Gold are similar; and this statement was confirmed by our results. Nevertheless, the present study showed that the sterilization cycles seemed to interfere in the ability of instruments to reach the root canal length, probably because the heat achieved during autoclaving may diminish the cutting capacity of instruments.

CONCLUSIONS

In conclusion, our results demonstrated that Reciproc Blue was more resistant than WaveOne Gold, suffering later fracture. Additionally, the sterilization cycles did not influence the estimated number of uses of thermally treated reciprocating instruments, but the instrumented area of root canals was reduced along with the repeated uses of both instruments.

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