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RESEARCH ARTICLE

Influence of cervical and middle preparation on the cyclic fatigue resistance of Logic 25.06 rotary instruments: Replica study

Ana L. C. Binda[1], Ana G. Limoeiro[2], Virgilio Braga[1], Michel Klymus[2], Luanna S. S. Vasconcellos[1], Augusto L. Andrade[1], Wayne M. Nascimento[1], Adriana J. Soares[3], Marilia F. V. Marceliano-Alves[4-6], Marcos Frozoni[1]

[1]Departamento de Endodontia, Faculdade São Leopoldo Mandic, Campinas, SP, Brasil
[2]Departamento de Dentística, Endodontia e Materiais Odontológicos, Faculdade de Odontologia de Bauru – USP, Bauru, SP, Brasil
[3]Departamento de Endodontia, Faculdade de Odontologia de Piracicaba – UNICAMP, Piracicaba, SP, Brasil
[4]Universidade Iguaçu, Programa de Pós-Graduação em Odontologia, Nova Iguaçu, Rio de Janeiro, Brasil
[5]Centro Universitário Maurício de Nassau (UNINASSAU), Rio de Janeiro, Brasil
[6]Department of Dental Research Cell, Dr. D. Y. Patil Vidyapeeth, Pune 411018, India

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ABSTRACT

Introduction: The aim of this study was to evaluate the influence of cervical and middle preparation on resistance to dynamic cyclic fatigue during instrumentation of mandibular molar replicas with Logic 25/.06 instruments.

Materials and Methods: Forty mandibular molar replicas were printed with 16 µm resolution from a tooth file scanned by microcomputed tomography. For the fatigue test, 40 new Logic 25/.06 nickel-titanium instruments (Bassi Endo, Belo Horizonte, Brazil) were used for mechanical preparation of the mesiobuccal canal and subjected to the dynamic cyclic fatigue test in an artificial curved metal canal with a bending angle of 45º and a bending radius of 6.6 mm. During the dynamic cyclic fatigue test, the time to fracture of the file was recorded and the number of cycles to fracture was calculated. The surfaces of the fragments were evaluated using scanning electron microscopy to verify the length of the fragment and the type of fracture that occurred. Data on time to fracture, number of cycles to fracture, and length of the fractured fragment were collected and statistically analyzed using the t-test or Mann-Whitney test with a significance level of 5%.

Results: There were no statistically significant differences between the groups with or without preparation of the cervical and middle third in relation to time to fracture ($p = 0.561$), number of cycles to fracture ($p = 0.508$), and length of the fractured fragment ($p = 0.417$).

Conclusion: Preparation of the cervical and middle thirds did not increase the resistance to fracture due to cyclic fatigue of the instruments tested.

Keywords: Cyclic fatigue; Instrumentation; Root canal preparation.

Introduction

Endodontic treatment is essential to preserve health and repair periradicular tissues[1]. Its phases involve root canal preparation, including cleaning and shaping the dentin walls, using irrigation containing an antimicrobial chemical substance[2]. Mechanical instrumentation contributes to accurate canal preparation, effective removal of bacterial contamination, facilitation of chemical debridement, and creation of the space necessary for subsequent root canal filling[2,3].

The introduction of nickel-titanium (NiTi) instruments in endodontics represented an evolution in biomechanical preparation due to the physical properties of the alloy, giving them remarkable flexibility[4-6]. Furthermore, it provided several advantages, such as reduced preparation time, cutting efficiency, and the ability to centralize the root canal when compared to manual stainless-steel instruments[7].

Despite these benefits, the preparation of curved canals presents challenges, such as risks of instrument fracture due to constant alternations of forces and tensions during preparation, which can lead to material fatigue[8,9]. Fracture of NiTi instruments can occur due to torsion or cyclic fatigue[5,10]. Torsional fracture occurs when the end or another portion of the instrument gets caught in the canal and the handle continues to rotate [11,12] Fracture of the instrument occurs when the torque exceeds the elastic limit of the metal[5].

One instrument that deserves to be highlighted are the Logic instruments (Bassi Endo, Belo Horizonte, Brazil). These instruments are found in diameters from #15 to #50, with constant tapers and modified S-shaped cross-sectional designs, variable helical angle with two cutting blades, and clockwise rotation[13,14]. Their manufacturing process is based on the heat treatment of CM-Wire.

Performing coronal preflaring has the potential to extend the cyclic fatigue life of instruments[10] Therefore, carrying out this procedure beforehand can provide greater safety when using rotating instruments. To date, there are no data available on the influence of cervical preparation prior to instrumentation with the Logic 25/.06 system.

Thus, the objective of this study was to evaluate whether cervical and middle preparation can increase the resistance to cyclic fracture of the Logic 25/.06 rotary system in an artificial canal simulating curvature in the apical third. The null hypothesis tested was that there would be no difference in resistance to cyclic fatigue with or without cervical and middle canal preparation.

Materials and Methods

SAMPLE SELECTION

The present study was approved by the local ethics and research committee (CAAE: 76207123.0.0000.5374). A total sample of 40 new heat-treated NiTi instruments (Logic 25/.06, Bassi Easy) 25 mm long were used in the study. All instruments were inspected using a stereomicroscope (Carl Zeiss, LLC, Oberkochen, Germany) at 20x magnification to observe the presence of deformities or defects. No defects were detected. The forty selected instruments were used in the two experimental phases of this study: first, the instruments were used during the preparation of root canals from 3D-printed replicas of a mandibular molar previously scanned by microcomputed tomography. Next, the instruments were subjected to the cyclic fatigue test.

3D PRINTING OF MANDIBULAR MOLAR REPLICAS AND PREPARATION OF THE STUDY MODEL

An extracted human mandibular molar was selected, with Vertucci type IV mesial canals. The tooth had no previous endodontic treatment, no fractures or resorptions, a moderate curvature angle (10º to 20º), and an anatomical diameter of the foramen compatible with a NiTi #15/.02 C-Pilot instrument (VDW, Munich, Germany). The tooth was immersed in 5.25% sodium hypochlorite (NaOCl) for one hour for disinfection, and its external surface was cleaned using periodontal curettes.

Coronal access was performed with high-speed drills (1014HL and 1558, KG Sorensen Indústria e Comércio Ltda., São Paulo, Brazil), under constant irrigation, and patency was performed with C-Pilot #10 and #15 hand files (VDW). The coronal portion of the tooth was partially removed with a diamond disc (KG Sorensen) at low speed until a length of 18 mm was obtained: 4 mm for the apical third, 4 mm for the middle third, 4 mm for the cervical third, and 6 mm for the coronal portion.

The specimen was scanned using a SkyScan 1174 (Bruker micro-CT, Kontich, Belgium) using voltage parameters of 100 kV and 100 µA current with a resolution of 26.80 µm; 360º rotation, copper and aluminum filter, 0.6º rotation, and 30-minute exposure. The images were reconstructed using the NRecon 16.9.16 program (Bruker micro-CT) and converted into Bitmap images using the following parameters: Smothing of 5, Ring artefact correction of 6, and Beam Hardening of 30%.

The data acquired after micro-CT were exported into STL files using the CTan 1.14.4.1 program (Bruker micro-CT) and 20 replicas of the lower molar were printed on a three-dimensional (3D) printer (Halot One, Creality 3D, Shenzhen, China), using a high-precision resin (3D Dental Align, 3D Cure, Betim, Brazil).

ERGONOMIC WORKING POSITION

To simulate the periodontal ligament and alveolar bone during canal preparation, the roots of the 3D replicas were wrapped with Teflon tape and placed inside heavy condensation silicone blocks (Zetaplus, Ahermack, Rovigo, Italy). This setup, comprising the replicas and the impression material, was placed on a dental mannequin to simulate clinical conditions.

The 3D replicas of the teeth were isolated using a rubber dam (Madeitex, São José dos Campos, Brazil). The dental simulator mannequin was fixed to the dental chair, positioning the lower occlusal plane perpendicular to the ground to simulate the patient's position, with the operator situated between the noon and nine o'clock positions.

ROOT CANAL PREPARATION

The canal length (CL) was measured clinically by the direct visual method using a microscope (Decius, DF Vasconcelos Valença, Brazil) at 30x magnification. A 10/.02 C-Pilot manual file (VDW) was introduced into the canal, passing 1 mm beyond the foramen, and then retracted until the tip of the file reached the edge of the apical foramen. The working length (WL) was standardized to be equal to the CL. Subsequently, tooth replicas and endodontic instruments were randomly distributed into two experimental groups (n = 20):

GROUP WITHOUT CERVICAL AND MIDDLE PREPARATION:

The 10/.02 and 15/.02 C-Pilot hand files (VDW) were introduced into the mesiobuccal canal throughout the WL (18 mm). The Logic 25/.06 instrument was activated in a rotational movement coupled to the iRoot Pro motor (Bassi/Easy). The preparation of the root canals was carried out in the crown-down direction, in an in-and-out movement with approximately 3 mm of amplitude [15]. After every movement, the instrument was cleaned with gauze and the canal was irrigated with 2.5 mL of 5.25% NaOCl.

GROUP WITH CERVICAL AND MIDDLE PREPARATION:

This group followed the same initial protocol as the group without cervical and middle preparation. However, after achieving patency with manual files, the 17/.08 Orifice Shaper file (Mklife, Porto Alegre, Brazil) was used for preflaring. The Logic 25/.06 instrument performed the mechanical preparation in the same way as described for the group without cervical and middle preparation.

A final irrigation with 2.5 mL of saline and 1 mL of 17% EDTA was performed on all replicas. Each Logic 25/.06 instrument was used only once to instrument the mesiobuccal canals of each 3D replica. All canal preparations were performed by a single previously calibrated Endodontist.

CYCLIC FATIGUE TEST

The instruments previously employed underwent testing to assess their resistance to dynamic cyclic fatigue fracture. These tests utilized an artificial root canal, as described by Al-Nasrawi et al. [16], with the following specifications: a straight cervical segment measuring 6.5 mm (from the canal entrance to the curvature's initiation), a curved section with a length of 3.0 mm, a curvature radius of 4.0 mm, an angular curvature of 45º; and a straight apical segment measuring 2.5 mm (from the curvature's end to the canal apex), featuring diameters of 1.0 mm within the cervical 5 mm, 0.7 mm in the intermediate 4 mm, and 0.5 mm within the apical 3 mm.

The tests were conducted dynamically, with the mechanical movement system being powered by a SAVOX SC-12 56T69 motor (Savox All Rights Reserved, Taichung, Taiwan), inducing back-and-forth motion of the mechanical system. This motion was guided by a linear guide under the control of an electronic processor, regulating the speed and range of the instrument's movements to replicate the axial motion seen in endodontic procedures.

The instruments were attached to the VDW Gold motor (Dentsply-Sirona) and inserted into the metal canal to a depth of 12 mm. They were activated using the "ROTATORY" setting at a speed of 900 rpm, with an in-and-out amplitude of 3 mm. These movements were standardized and repeated until fracture occurred. The stainless-steel plate containing the simulated canal was positioned on a heated plate maintained at a controlled temperature of 37°C to closely mimic clinical conditions.

To reduce the friction of the file when in contact with the walls of the artificial canal, a mineral oil (WD 40 Company, Milton Keynes, United Kingdom) was applied inside the canal for lubrication and to prevent a temperature increase [16]. Video recording of the test was performed simultaneously using a smartphone (Poco M5S), from the beginning of the file activation until its fracture. Video analysis was conducted using Microsoft Movie Maker software. The NCF of the instrument was calculated by multiplying the number of rotations per minute (RPM) by the time in seconds and dividing by 60. The same researcher who performed the canal instrumentation also conducted the cyclic fatigue tests. The fractured fragments were measured using a 150 mm digital caliper, with an accuracy of ± 0.03 mm/0.001.

SCANNING ELECTRON MICROSCOPY (SEM)

The fractured surface of each instrument subjected to the cyclic fatigue test was evaluated by SEM. The analysis was carried out in a horizontal position to detect whether there was plastic deformation and the fracture pattern among the instruments in each group [17].

STATISTICAL ANALYSIS

Data were analyzed using Mann-Whitney tests, given the non-normal distribution of the data. The SPSS 23 program (SPSS Inc., Chicago, IL, USA) was used for statistical calculations, setting the significance level at 5%.

Results

There was no significant difference between the groups without and with cervical and middle preparation with the Orifice Shaper file in relation to time to fracture (TF) ($p = 0.561$), NCF ($p = 0.508$), and the length of the instrument fragment ($p = 0.417$), as indicated in table.

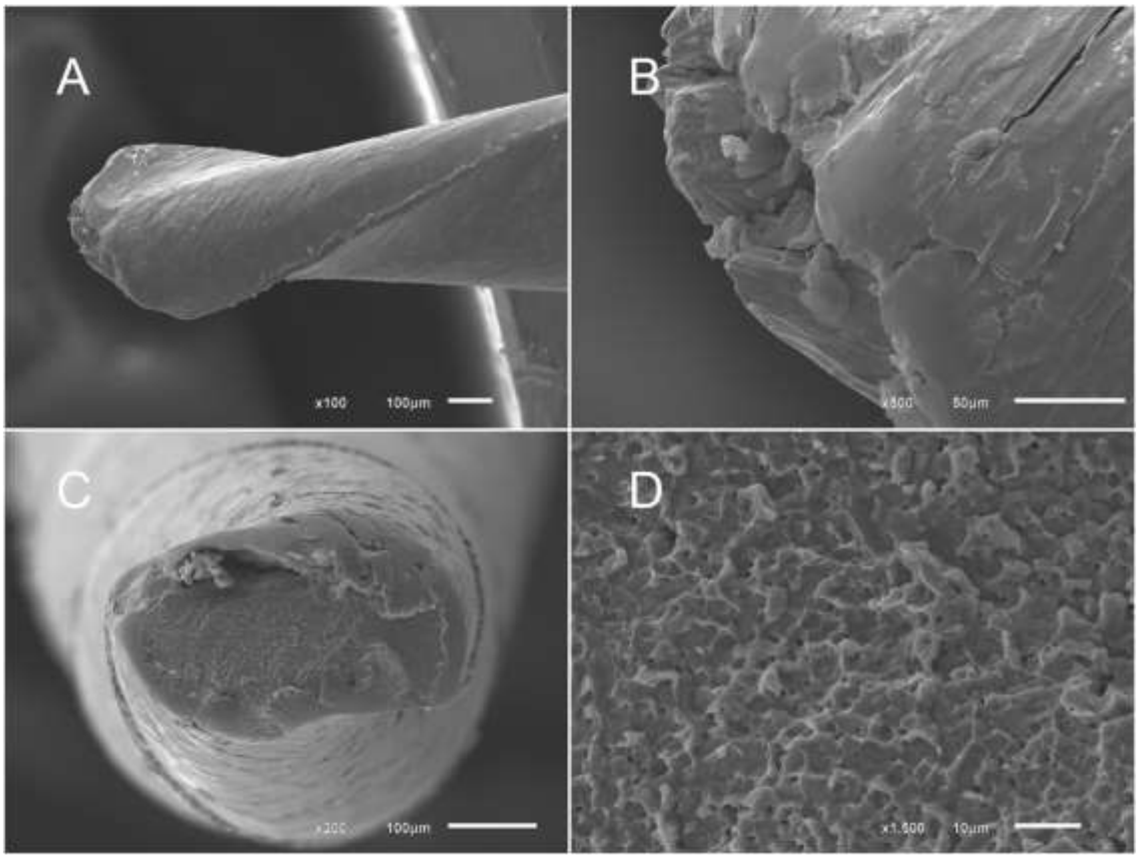
Table 1: Means and standard deviations of time and number of cycles to fracture (NCF) and fragment length of Easy Logic 25/.06 files, used in canals without and with cervical and middle preparation.

Pre-flaring	Time (seconds)	NCF	Length(mm)
Absent	166 (73) A	2803 (1325) A	1,4 (0,7) A
Present	149 (54) A	2477 (1039) A	1,4 (0,6) A

Legend: Averages followed by equal letters indicate no statistically significant difference between the groups without and with pre-widening (comparisons within each column).

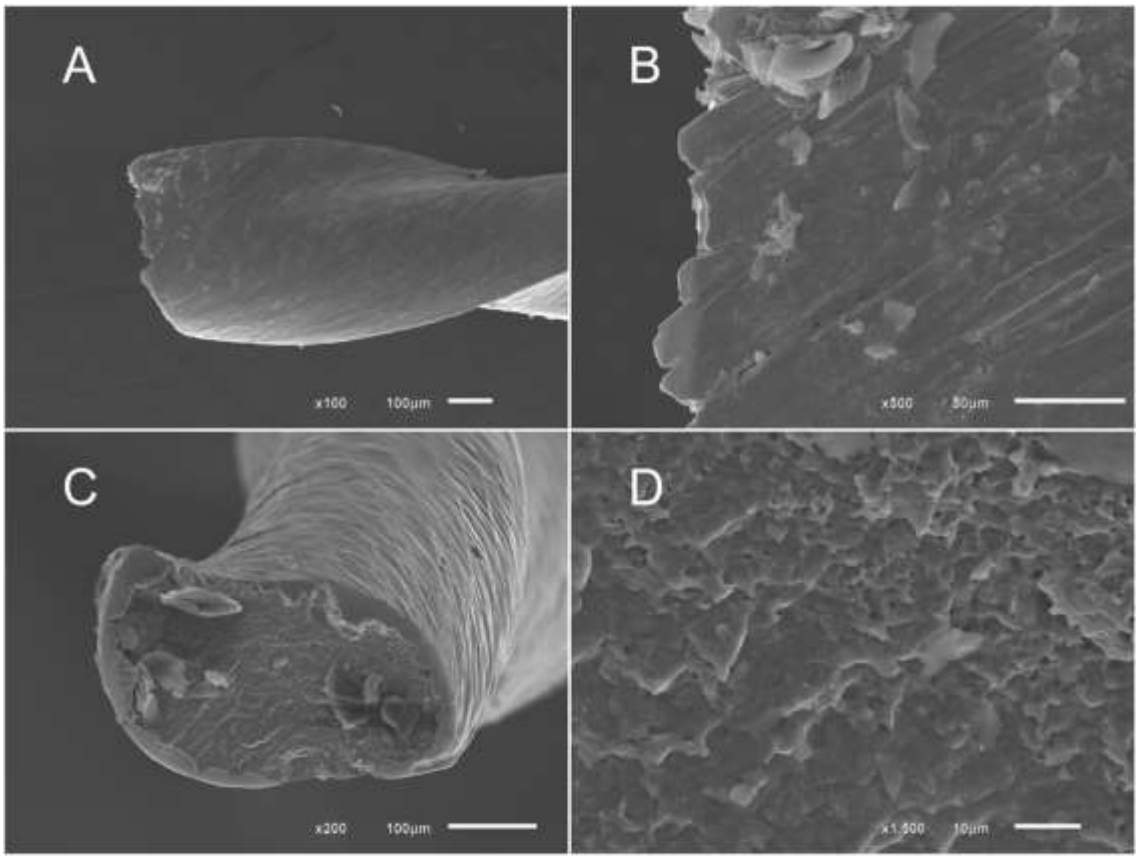
The SEM evaluation of the fractured surfaces (figures 1 and 2) showed similar and typical characteristics of cyclic fatigue for all instruments tested. The fractured surfaces demonstrated ductile-type characteristics, with areas of crack initiation and zones characteristic of rapid fractures due to overload.

Figure 1: SEM images of an instrument from the group without cervical and middle preparation after the cyclic fatigue test.



Caption: SEM - Scanning Electron Microscopy; A - magnification 100x - 100 μm; B - magnification 500x - 50μm; C - magnification 200x - 100 μm; D - magnification 1500x - 10μm.

Figure 2: SEM images of an instrument from the group with cervical and middle preparation after the cyclic fatigue test.



Caption: SEM - Scanning Electron Microscopy; A - magnification 100x - 100 µm; B - magnification 500x - 50µm; C - magnification 200x - 100 µm; D - magnification 1500x - 10µm.

Discussion

During the chemical-mechanical preparation of the root canals, preflaring aims to remove interferences, ensuring sufficient space for the penetration of mechanical instruments and allowing the free path of the files to the apical third [2]. However, current evidence is inconclusive and scarce regarding the impact of this additional preparation on the cyclic fatigue resistance of endodontic instruments in rotary movements. The objective of the present study was to investigate whether preflaring can increase the cyclic fatigue resistance of the Logic 25/.06 rotary system. The instruments were used during the preparation of root canals from a replica printed on a 3D printer and subjected to the cyclic fatigue test in an artificial curved canal.

In this study, 3D replicas from a natural tooth scanned using microcomputed tomography were used. This approach aims to overcome the limitations associated with obtaining models from extracted teeth, such as ethical difficulties and sample standardization issues[18]. Previous studies have highlighted the difficulty in standardizing samples as a significant limitation of the methodology, even when using microcomputed tomography on extracted specimens [19,20]. Thus, laboratory studies using 3D resin replicas allow control over experimental conditions, ensuring that only the variables of interest are analyzed [13].

For the cyclic fatigue test, a device already used in previous studies was employed and proved to be effective for this purpose [6,21]. A 45º curvature was adopted [16,22].

Temperature is a variable that can significantly affect the cyclic fatigue resistance of NiTi instruments [6,23,24]. La Rosa et al. [23] found that NiTi files used at room temperature showed greater resistance to cyclic fatigue compared to those used at body temperature. This is due to the nature of the NiTi alloy, characterized by two heatdependent crystalline states (martensite and austenite), and the properties of the metal vary in each of these phases. The metal is stiffer in the austenitic phase at temperatures higher than the transformation level, resulting in a decrease in resistance to cyclic fatigue [23].

In this study, NaOCl was used as an irrigating chemical substance due to its widespread use in endodontic practice and its interaction with the surface of instruments (corrosive properties), which may impact resistance to cyclic fatigue [25]. However, Pedullà et al. [26] demonstrated that immersion in NaOCl for 1 or 5 minutes does not significantly reduce the resistance of nickel-titanium instruments to cyclic fatigue. Furthermore, there are no studies in the literature that demonstrate how NaOCl can influence the physical properties of resin models. Moreover, the interplay between dentin and auxiliary chemical substances plays a critical role in the chemical-mechanical instrumentation process, affecting the cutting efficiency of the instrument as highlighted by Tanomaru et al.,[21]. This interaction's nuances are challenging to replicate accurately in resin models.

Operator experience as an independent variable is one of the most consistent and predictable parameters in instrument separation [27]. So, in this study, the tests were conducted by a trained specialist with experience in using the Logic rotary system.

The results of this research revealed that cervical and middle preparation did not interfere with the resistance to dynamic cyclic fatigue of the Logic instruments; therefore, the null hypothesis was accepted. This lack of effect can possibly be attributed to the heat treatment of the CM wire of Logic instruments during their manufacturing process. This treatment is known to produce a better arrangement of the crystal structure, resulting in greater flexibility and greater resistance to cyclic fatigue. Furthermore, this treatment is responsible for strongly influencing the martensitic/austenitic transformation behavior, allowing a greater percentage of martensitic transformation and the dissipation of the energy necessary for the formation and/or propagation of cracks during cyclic fatigue tests [28,29].

These findings contrast with another study [30] that demonstrated that coronal preflaring increased the cyclic fatigue resistance of the Reciproc and WaveOne instruments. The controversies in these results may be related to different methodologies and different thermal treatments of the alloys. In the present study, the instruments were taken out of the box, used once in resin blocks, and subjected to the cyclic fatigue test. In the study by Maniglia et al., [30] extracted human molars were used, and each file was used repeatedly until fracture occurred.

The ProDesign Logic and ProDesign R instruments tolerated a greater number of cycles to fracture (910.37 and 761.93, respectively) compared to Wave One Gold [13]. In the present study, the Logic instrument tolerated a greater number of cycles until fracture occurred (2477-2803). The discrepancies between different studies can be explained by differences in root canal curvature, instrument rotation, speeds, and torque. In this study, the speed was 3 times higher than in the study by Menezes et al.,[13].

The micrographs obtained by SEM revealed a similar pattern in the experimental groups. Both groups exhibited regions with microcracks and ripples, indicative of high stress concentration, suggesting a failure characteristic of cyclic fatigue [31]. These results contribute to the understanding of the similarity observed in the length of the fractured fragments, as the stressed areas in both groups were formed in a similar manner.

However, it is essential to exercise caution when extrapolating these results to the clinical context, given that the microhardness of resin blocks differs from that of human dentin (25 to 93.3 on the Knoop scale). This difference can compromise the cutting mechanics of the instruments and may not reliably reproduce the effects of canal instrumentation on the mechanical properties of the instrument. Therefore, future studies should compare the impact of using extracted teeth and 3D prototypes in evaluating the mechanical properties of instruments.

Conclusion

Based on the results obtained in this study and the methodology used, it is concluded that cervical and middle preflaring did not increase the resistance to cyclic fatigue of the instruments tested.

Conflict of Interest:

The authors have no conflicts of interest to declare.

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