The effect of endodontic instrumentation on fatigue, fracture load, and dentin crack formation in restored uniradicular teeth: in vitro study

Efeito da instrumentação endodôntica na fadiga, na carga de fratura e na formação de fissuras dentárias em dentes não-radiculares restaurados: estudo in vitro

El efecto de la instrumentación endodóntica sobre la fatiga, la carga de fractura y la formación de grietas de dentina en dientes uniradiculares restaurados: estudio in vitro

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ABSTRACT
Objective(s): The aim of this study was to evaluate the effect of manual, rotatory, and reciprocating endodontic instrumentation for uniradicular teeth on fatigue, load to failure, and dentin crack formation. Materials and Methods: Sixty-two human uniradicular teeth were selected. Root samples were standsdized at 14 mm (t0). Teeth were divided into three groups according to endodontic instrumentation: Manual (M), Rotatory (RT), or Reciprocating (RC) and filled with passive technique (t1). All teeth received the cementation of a glass fiber post and were restored with composite resin core (t2) and metallic crown. Samples were subjected to mechanical cycling (177 N, 2x106 cycles, 4 Hz) (t3), followed by a load to failure test. Failure analysis was performed and dentin crack analysis was conducted in two samples each time t0, t1, t2, and t3. Results: Load to failure was not different between groups (p=0.716). However, the M group presented more irreparable failures. M and RC groups presented a high percentage of root sections with defects, and t3 was the evaluation time which presented more dentin crack formation. Conclusion(s): Endodontic instrumentation system did not affect load to failure of uniradicular teeth. Still, it affected the failure mode, with manual and reciprocating instrumentations presenting more irreparable failures and high root dentin crack formation.

Keywords: dental pulp cavity, fiberglass, fractures.

RESUMO
Objetivo(s): O objetivo deste estudo foi avaliar o efeito da instrumentação endodôntica manual, rotativa e recíproca para dentes não-irradiculares na fadiga, carga até a falha e formação de rachaduras dentinárias. Materiais e Métodos: Sessenta e dois dentes unirradiculares humanos foram selecionados. As amostras de raiz foram padronizadas em 14 mm (t0). Os dentes foram divididos em três grupos de acordo com a instrumentação endodôntica: Manual (M), Rotatória (RT) ou Recíproca (RC) e preenchidos com técnica passiva (t1). Todos os dentes receberam a cimentação de um poste de fibra de vidro e foram restaurados com núcleo de resina composta (t2) e coroa metálica. As amostras foram submetidas a ciclos mecânicos (177 N, 2x106 ciclos, 4 Hz) (t3), seguidos de um teste de carga até falha. Realizou-se análise de falha e análise de rachaduras dentinárias em duas amostras cada vez t0, t1, t2 e t3. Resultados: A carga até a falha não foi diferente entre os grupos (p=0,716). No entanto, o grupo M apresentou falhas mais irreparáveis. Grupos M e RC apresentaram uma alta porcentagem de seções de raiz com defeitos, e t3 foi o tempo de avaliação que apresentou mais formação de rachaduras de dentina. Conclusão(ões): O sistema de instrumentação endodôntica não afetou a carga até a falha dos dentes não-radiculares. Ainda assim, afetou o modo de falha, com instrumentações manuais e recíprocas apresentando falhas mais irreparáveis e formação de rachaduras de dentina de raiz alta.

Palavras-chave: cavidade da polpa dentária, fibra de vidro, fraturas.

RESUMEN
Objetivo(s): El objetivo de este estudio fue evaluar el efecto de la instrumentación endodóntica manual, rotatoria y recíproca para los dientes uniradiculares sobre la fatiga, la carga a la falla y la formación de grietas dentales. Materiales y Métodos: Se seleccionaron 62 dientes humanos

unirradiculares. Las muestras de raíz se estandarizaron a 14 mm (t0). Los dientes se dividieron en tres grupos de acuerdo con la instrumentación endodóntica: Manual (M), Rotatorio (RT) o Reciprocante (RC) y se rellenaron con técnica pasiva (t1). Todos los dientes recibieron la cementación de un poste de fibra de vidrio y fueron restaurados con núcleo de resina compuesta (t2) y corona metálica. Las muestras fueron sometidas a ciclos mecánicos (177 N, 2x106 ciclos, 4 Hz) (t3), seguidos de una prueba de carga a falla. Se realizó análisis de falla y análisis de grieta de dentina en dos muestras cada vez t0, t1, t2 y t3. Resultados: La carga de falla no fue diferente entre los grupos (p=0,716). Sin embargo, el grupo M presentó fallas más irreparables. Los grupos M y RC presentaron un alto porcentaje de secciones radiculares con defectos, y t3 fue el tiempo de evaluación que presentó más formación de grietas de dentina. Conclusión(es): El sistema de instrumentación endodóntica no afectó la carga a la falla de los dientes unirradiculares. Aún así, afectó el modo de falla, con instrumentaciones manuales y recíprocas que presentaban fallas más irreparables y una alta formación de grietas de dentina radicular.

Palabras clave: cavidad de la pulpa dental, fibra de vidrio, fracturas.

1 INTRODUCTION

The rehabilitation of endodontic-treated teeth is frequently under investigation due to the clinical failure of these elements. Endodontic instrumentation is one factor contributing to the formation of dentin defects, which could weaken the tooth. Rotatory systems may lead to a greater incidence and propagation of dentin cracks compared to manual instrumentation [22], and the reciprocating system creates more coronal and medium root defects thirds, decreasing the load to fracture of teeth [15]. The effect of such root dentin defects, under chewing cyclic loads, if they would propagate and decrease the tooth's maximum supported load is slightly addressed in the literature [12].

Endodontically treated teeth usually present a high loss of coronal structure, having little or no coronal remaining, which requires using intraradicular posts as intracanal anchorage for the core build-up and prosthetic crowns [14]. Glass fiber posts are an option for restoring such teeth, which represent a common time-consuming treatment [14], with a high clinical survival rate of the restored tooth [3,8]. However, the absence of remaining crown walls – no ferrule effect – increases the risk of clinical failure [7]. From the literature, when considering teeth with remaining walls, the use of glass fiber posts did not affect the clinical survival rate of endodontically treated teeth restored with full crowns after three [25] and five years [6], or even with direct restorations [24].

The simulation/characterization of the possible problems in several clinical situations of dental rehabilitation is a complex goal for clinical trials. In vitro tests may simulate the clinical situation and should ideally reproduce relevant clinical failures. Clinical failures are usually due to the fatigue of material and structures. This intermittent cyclical loading may lead to the growth of small cracks and defects failing to mechanical fatigue [4]. Considering those presupposes, a relevant point must be raised: Does the distinct endodontic instrumentation affect the fatigue behavior of uniradicular teeth?

Thus, the aim of this study was to evaluate the effect of manual, rotatory and reciprocating endodontic instrumentation of uniradicular teeth on load to failure and dentin crack formation when subjected to a mechanical fatigue loading regime. The null hypothesis was that the instrumentation does not affect the evaluated parameters of endodotically treated teeth restored with glass fiber posts and metal full crowns.

2 MATERIAL AND METHODS

The manuscript of this laboratory study has been written according to Preferred Reporting Items for Laboratory studies in Endodontology (PRILE) 2021 guidelines. The local ethics committee approved the present research (protocol # 4.276.089).

2.1 STUDY DESIGN

Uniradicular teeth (N=62, incisors, canines, and pre-molars) were obtained from the university's human teeth bank. They were randomly divided into three groups according to endodontic instrumentation: Manual (M), Rotatory (RT), or Reciprocating (RC), filled and restored with glass fiber post ad metallic full crown. The concept of the study was to compare the load to failure and dentin crack formation after cyclic load application to restored teeth.

2.2 RANDOMIZATION OF SAMPLES

Teeth had their buccal face marked on the root portion and sized into 14 mm with the sectioning of the coronal portion. First, five roots were randomly separated for the dentin crack analysis in 't0'. Afterward, all roots were measured in the buccolingual and mesiodistal dimensions and separated into three groups (small, medium, and large section area). Each group was randomized into three new groups (n=19, https://sorteador.com.br/), providing an equal number of samples from each section area size to each testing group. The samples were allocated according to endodontic instrumentation: manual, rotatory, or reciprocating.

2.3 ENDODONTIC INSTRUMENTATION

The working length was set at 14 mm and roots were subjected to canal preparation as described below:

A size 10 manual K-file (TDK-Files, Curitiba, PR, Brazil) was introduced into each canal until the working length set, and the canal was prepared until a size 15 manual K-file reach the working length.

Manual instrumentation (M): roots were manually instrumented with K-files from #15 to #40 performing ¼ turn with in-and-out motion. Between each file size, canals were irrigated with 3 mL of 2.5% sodium hypochlorite (NaOCl).

Rotatory instrumentation (RT): roots were instrumented with rotatory files (U-File, TDK-Files), using a gentle in-and-out motion at 300 rpm and 3 Ncm torque (Silver Reciproc, VDW, München, DBY, Germany). Root canal orifices were flared with a T-file glide path, followed by instrumentation with #25.08 file until reach the working length. A 3 mL 2.5% NaOCl irrigation was performed between each file introduction into the root canal.

Reciprocating instrumentation (RC): a single file system (#25.08 V-File, TDK Files) was used to instrument the roots in this group. Files were used in packing motion at 300 rpm and 3 Ncm torque (Silver Reciproc, VDW, München, DBY, Germany) until the working length was reached. A 3 mL 2.5% NaOCl irrigation was performed every three insertion movements.

Final irrigation was performed with 5 mL 17% EDTA by ultrasonic agitation (Easyclean Easy, Belo Horizonte, MG, Brazil) for 20 s, followed by irrigation with 5 mL 2.5% NaOCl. This protocol was performed three times, followed by final irrigation with 5 mL distilled water.

2.4 ROOT CANAL FILLING

Root canals were dried with absorbent paper points (Dentsply Maillefer, São Paulo, SP, Brazil) and filled using the passive technique. An endodontic sealer (AHPlus, Dentsply, São Paulo, SP, Brazil) was inserted into the root canal with a lentulo file #25. A single master Gutta-percha cone, consistent with each system used, was immediately inserted into the root canal. The excess gutta-percha in the coronal portion was removed with a heated instrument, and the root canal openings were sealed with composite resin (Opallis, FGM, Joinville, SC, Brazil). A single operator performed root canal instrumentation, irrigation, and filling procedures to avoid operator bias. Roots were stored in a humid environment for one week for the complete setting of the sealer. Two roots (n=2) from each group were randomly separated for the dentin crack analysis in ‘t1.’

2.5 FIBER POST CEMENTATION

Roots were then prepared for the cementation of the glass fiber post. Root filling was progressively removed with largo and gates drills from #1 to #4, followed by the specific fiber post preparation drill (White post drill #2, FGM) to a length of 10 mm. after preparation, the root canal was irrigated with 3 mL 2.5% NaOCl. Prepared teeth were then embedded into acrylic resin using the prepared root canal, in which the preparation drill was inserted. Roots were first involved with aluminum paper foil. Then, the preparation drill was coupled to a paralelometer, and the root was inserted into a PVC matrix (25 mm x 15 mm) filled with acrylic resin (JET, Clássico, Cotia, SP, Brazil), and the roots were inserted 12 mm into acrylic resin, having 2 mm that remained up. After the resin cure, roots were removed, and the aluminum foil was removed and replaced by silicone impression material (Perfil, Coltene, São Paulo, SP, Brazil) for periodontal ligament simulation [9].

The following step of preparation of the samples was the cementation of glass fiber posts (White post-DC #2, FGM). Posts were sectioned into 15 mm at their coronal part, cleaned with isopropyl alcohol, and received the application of a layer of silane bonding agent (Prosil, FGM). Root canal dentin was treated with universal adhesive in self-etch mode (Ambar Universal, FGM), and applied in two consecutive layers. The excess adhesive was removed with absorbent paper points before light cure (20 s, Bluephase, Ivoclar, Schann, Liechtenstein). A dual cure resin cement (AllCem, FGM) was manipulated and inserted into the root canal with a specific mixing-needle point. The fiber post was immediately placed inside the root canal, the excess resin cement was removed, and the assembly was light cured for 60 s (Bluephase N, Ivoclar) on the occlusal surface.

The core build-up (in the shape of preparation for a full metallic crown) was performed with composite resin (Opalis, FGM), using a shaped standardized acetate matrix. The core matrix was filled with the composite resin and placed on the post and occlusal surface of the root. The assembly was light-activated during 20 s (Bluephase N) per side and carefully removed. After this step, two roots from each group were randomly separated for the dentin crack analysis in ‘t2.’

2.6 METAL FULL CROWN FABRICATION AND CEMENTATION

The remaining samples (n=15) were waxed for a full metallic crown. A sectioned silicon matrix (Zetalabor, Zhermack, Badia Polesine, RO, Italy) with a crown shape was used for waxing all crowns on their respective preparations. Waxing patterns were invested and fused into a cobalt-chromium alloy. Each crown was cemented to the respective prepared tooth with zinc phosphate cement (SS White, Hulmeville, PA, USA), simulating the tooth rehabilitation.

2.7 MECHANICAL FATIGUE

Samples were subjected to cyclic mechanical load. Samples (n=15) were positioned into a fatigue machine (BioCycle V2, BioPDI, São Carlos, SP, Brazil) in a 45º angulated base. They received the application of 177 N load, for 2x106 cycles, at 4 Hz frequency, on the palatal side, with a 4 mm diameter round metallic tip. Root fractures and loss of crown-core-post were considered failures, but the loss of retention of the metallic crown was not. After fatigue, all samples were inspected for failure, and two samples from each group were randomly separated for the dentin crack analysis in 't3'. The remaining samples (n=13) were subjected to load to failure test (MBio 500, BioPDI). Samples were likewise positioned into a 45° angulated base, and a 4 mm diameter round metallic tip was applied in increasing load at the palatal surface of the sample until failure. The maximum value reached (N) was recorded. Data were subjected to the Kolmogorov-Smirnov test for data distribution analysis and then to Kruskal-Wallis statistical analysis for group comparison.

All samples were inspected, and failures were classified according to the clinical outcome as (1) repairable, with fracture or loss of retention of the assembly crown-resin core-fiber post, or (2) irreparable, with dentin root fracture.

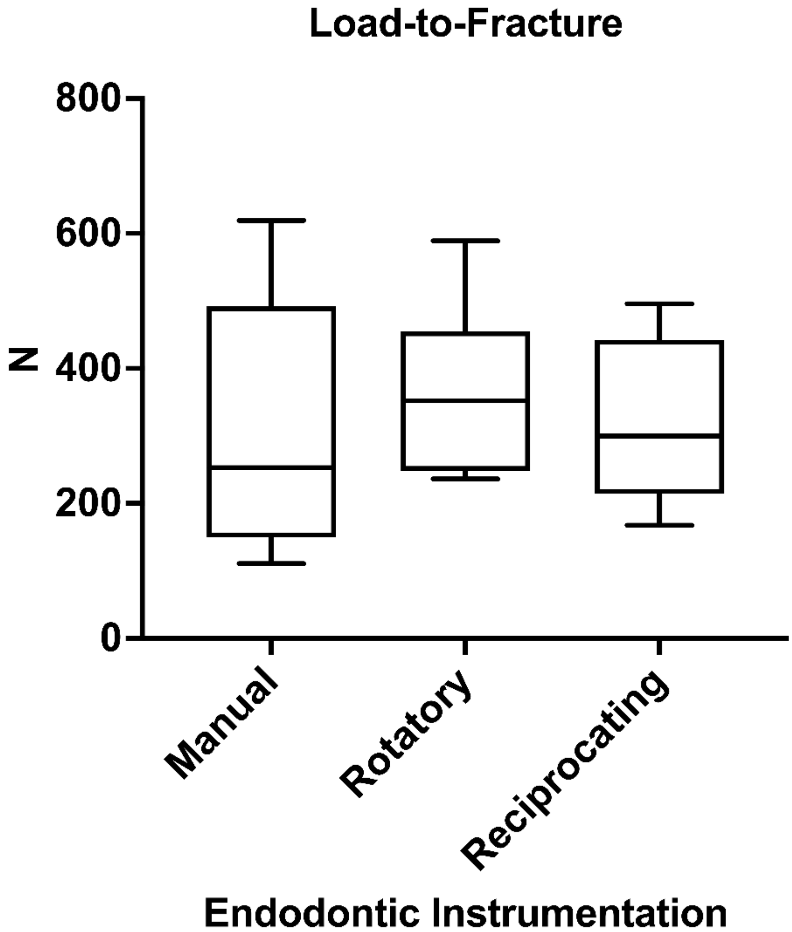
2.8 DENTIN CRACK ANALYSIS

For this analysis, samples stored from each step were used: t0 (control, after root size standardization, before any treatment); t1 (after endodontic treatment); t2 (after fiber post cementation); and t3 (after mechanical fatigue). Samples were embedded into a chemically cured acrylic resin cylinder and attached to a precision sectioning machine (ISOMET, Buehler, Lake Buff, IL, USA). The first section was discarded, and four other sections were performed at 3, 6, 9, and 12 mm.1 Each section was evaluated in both sides, by transillumination, and images were taken with photograph equipment (D3000, Nikon, Tokyo, Japan). Images were evaluated by two independent researchers and classified as "with defects" and "without defects" [1,13,14]. When there was a disagreement between researchers, a discussion about the specific image was carried out, and both attributed a final classification.

3 RESULTS

Two samples showed failures after the cyclic fatigue: one sample from the M group (irreparable – vertical root fracture), and another sample from RC group, with loss of retention of the assembly crown-resin core-fiber post. Data obtained from the failure load test presented no statistically significant difference (p=0.716) (Figure 1).

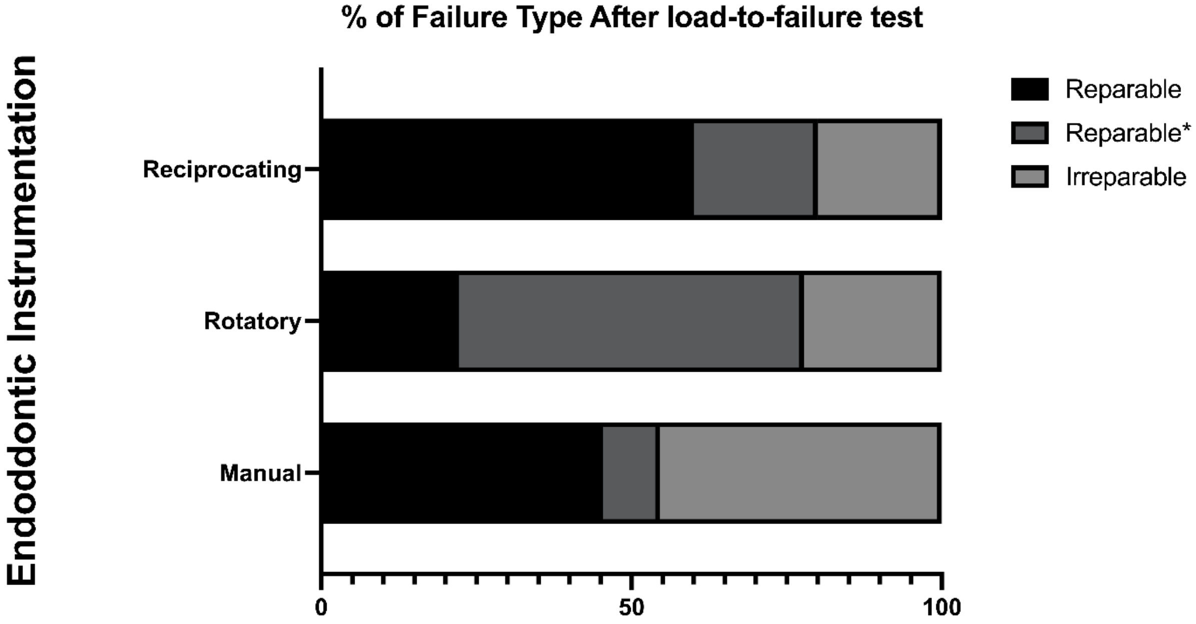
Figure 1. Failure load results, where the endodontic instrumentation did not affect the maximum load supported by samples in each tested group.



Source: Own authorship

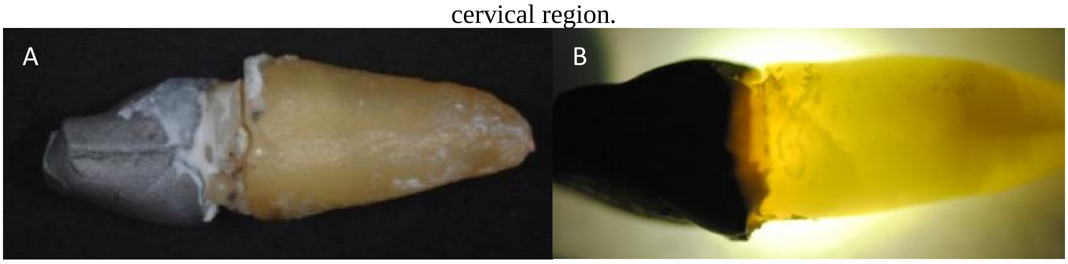
Regarding failure analysis after the failure load test, failures were mostly classified as reparable in all groups (Figure 2), with loss of retention of the assembly crown-resin core-fiber post (Figure 3A). However, after removing roots from the acrylic resin base, several samples presented cracks in dentin (Figure 3B). The classification of such failures was kept as reparable since, clinically, it would not be possible to make a such observation. Group M presented the greatest number of samples with irreparable failures (Figure 4).

Figure 2. Amount (%) of reparable and irreparable failures recorded after load to failure test. Failures indicated at the image as “reparable* were visually classified as reparable, but after removal from acrylic resin base, root dentin cracks were observed).



Source: Own authorship.

Figure 3. (A) Reparable failure, with loss of retention of the assembly crown-core-post. (B) But after removal of the sample from acrylic resin base and observation with transillumination, dentin cracks may be observed at cervical region.



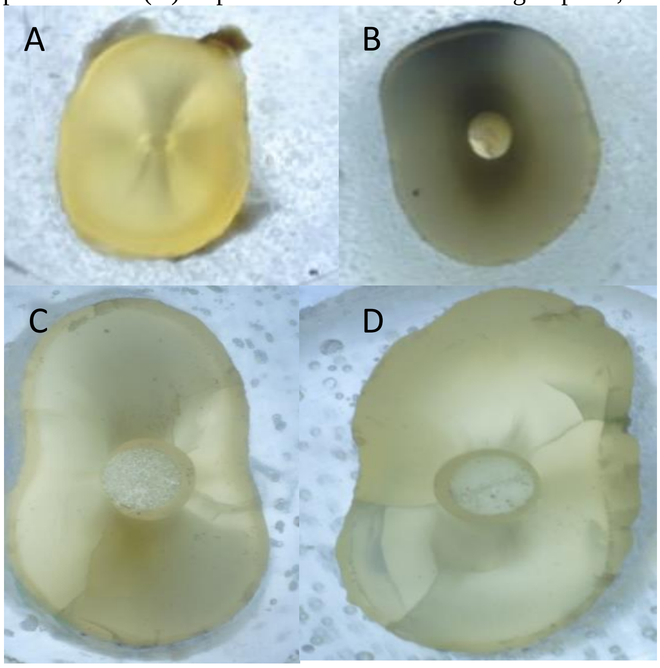
Source: Own authorship.

Figure 4. Irreparable failure – vertical root fracture on cervical portion.

Source: Own authorship.

The dentin crack analysis showed that at t0 (Figure 5A and B), no root section presented defects. Group M presented 29.9% of the root sections classified as "with defects" (Figure 5C), group RC presented cracks in 25% of the sections (Figure 5D), while group RT presented cracks in 8.3% of the sections. The evaluation at the time t3 (after mechanical fatigue) demonstrated the greatest amount of root sections with cracks (33.3%) compared to the evaluations at times t1 (20.8%) and t2 (8.3%).

Figure 5. (A and B) Root sections from t0, classified as "no defects". (C) Representative root section of group M, with partial and complete cracks. (D) Representative root section of group RC, with several dentin cracks.



Source: Own authorship

4 DISCUSSION

Fatigue and load to failure were not affected by endodontic instrumentation. Thus, the null hypothesis was accepted, but the different instrumentation techniques lead to different failures and root dentin crack formation patterns. Group M presented the greatest number of irreparable failures after the loading to failure test and was the only group to present irreparable failure after fatigue (only one sample). This fact may be explained by the irregularities created in the root canal walls after manual instrumentation [17]. The highest amount of dentin cracks was also observed for manual instrumented samples, where almost 30% of the root sections were classified as “with defects.” Both facts – irreparable failures at load to failure test and a high percentage of dentin cracks – are probably related. Even though no effect of endodontic instrumentation on fatigue outcome has been detected, it is crucial to depict that the differences in dentin cracks’ introduction might be a source of progressive crack, propagation, and ultimate failure when occurring more intense forces and stresses than rather applied by this current study – the presence of defects at the surface dentin means a potential fact for the ongoing and progressive failure of the restored system.

According to the literature [23], the reciprocating instrumentation system creates defects in coronal and medium root dentin thirds, resulting in the lowest load to failure of treated teeth.2 In the present study, manual and reciprocating instrumented groups lead to more cracks in root dentin than rotatory systems. And despite the load to failure being similar between groups, in Figure 1, it is possible to observe a higher standard deviation in data from the M group, followed by the RC group, suggesting the lack of standardization. Such irregularities may remain even after canal preparation and cementation of glass fiber posts [17].

The defects caused in dentin by the rotatory instrumentation system may be considered small and mostly incomplete compared to the defects of root dentin instrumented with the reciprocating system [5,10,13]. In the rotatory instrumentation technique, a root canal is gradually enlarged by a sequence of instruments, leading to lower stress to root dentin walls [18] when compared to the reciprocating system, which is used only one instrument for the entire process. In the present study, only 8.3% of root sections from group RT were classified as “with defects” (Figure 5D).

According to literature, the mechanized instrumentation may lead to root fracture due to the stress caused to root canal dentin walls or excessive dentin removal [20]. The amount of removed dentin, the crack formation, and the excessive enlargement of the root canal are predictors of root fracture when a tooth is in function [1,18,20]. However, in the present study, it was possible to observe that the preparation provided by the rotatory system is much more standardized and controlled than manual and reciprocating systems (by the spread of standard deviation values, Figure 1), improving the prognosis of tooth survival under fatigue or after load to failure test. The alternating dentin wear caused by the reciprocating system was supposed to release stress from root dentin walls during preparation [20]. Still, it led to more root sections presenting cracks (Figure 5D) and a worse failure pattern (irreparable) (Figure 4) after loading to the failure test than the RT group.

The instruments used in the present study were fabricated in NiTi (manual files), and the mechanized instruments were flexible and thermal treated, according to the manufacturer. These flexible and thermally treated instruments effectively reduce dentin crack formation [16], which may have collaborated to the similar load to failure presented by groups.

Regarding the time of dentin crack analysis, t3 (after mechanical cycling) was the evaluation time that presented the highest frequency (33.3%) of root sections with defects. The cyclic load was applied to the palatal surface of teeth at 45° inclination, simulating the load received by anterior teeth. This test set leads to the formation of stress in the cervical region [11]. Despite few samples after mechanical fatigue, it is possible that samples were affected by cracks, which favored the irreparable failures or the reparable failure with posterior crack observation (Reparable*, Figure 3A) after load to failure test. The presence of dentin cracks before any procedure was almost discarded by the absence of cracks in root sections from t0 (Figure 5Aand 5B), and the crack formation by post space preparation and cementation (t2) in a root canal is also not likely (8.3% of root sections with defects).

In any situation, endodontically treated teeth, restored or not with glass fiber posts, do not reach the load to failure supported by sound teeth [2]. The load to failure of the samples tested in the present study varied from 325.36 to 366.75 N, which are superior to clinically applied loads. The fatigue effect might be intensified by applying loads higher than the present study during mechanical cycling, which inducts its consequences (crack propagation, crack nucleation, failure). Implementing a fatigue method as such step-stress/stepwise depicts more accurate results in terms of the load-bearing capacity of fatigue behavior of the restored system. The present study used roots without any remaining crown walls. Thus, results may be different for different clinical situations.

5 CONCLUSIONS

Considering the limitations of the present study, it can be concluded that (1) the endodontic instrumentation system did not affect load to failure of uniradicular teeth, but (2) it affected the failure mode, with manual instrumentation presenting more irreparable failures and manual and reciprocating systems presenting high root dentin crack formation. Thus, rotatory instrumentation seems to be a more controlled technique, favoring the prognosis of endodontically treated and restored uniradicular teeth.

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