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Presence of Metallic Microfragments on Dentinal Walls and Instrument Defects following Root Canal Preparation

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ABSTRACT

Aim: To determine the presence of metallic microfragments and their elemental composition in the dentinal walls of root canals following preparation using different endodontic instruments and to assess the active cutting edges of instruments with regard to structural defects.

Materials and methods: A total of 108 molar teeth were selected and prepared using different endodontic instruments. Teeth were randomly divided into nine groups of 12 teeth each, according to the instruments employed: Manual systems – K-FlexoFile, K-File, and Hedstroem; rotary systems – ProTaper Next, Mtwo, BioRaCe; and reciprocating systems – Reciproc, Unicone, and WaveOne. Both root canals and instruments were assessed using scanning electron microscopy, and the elemental composition of metallic microfragments was determined using energy-dispersive X-ray spectroscopy.

Results: Metallic microfragments were found in the groups prepared with both manual and reciprocating instruments, with no statistically significant differences between groups, thirds, or presence of metallic microfragments ($p \geq 0.05$). Moreover, all groups presented structural defects in both new and used instruments; however, rotary instruments (ProTaper Next, Mtwo 702, BioRaCe) were the ones with the lowest number of defects, at statistically significant differences in comparison with other instruments ($p < 0.05$).

Conclusion: The presence of metallic microfragments on dentinal walls following root canal preparation was associated with manual and reciprocating instrumentation. Furthermore, rotary instruments were the ones with the lowest number of defects. Considering the outcomes measured in this study, rotary instruments performed better than the other two groups, as they were associated with the lowest number of metallic microfragments and structural defects.

Clinical significance: During root canal preparation, operative procedures may induce changes to the root canal shape, as well as the release of metallic fragments resulting from the action of instruments on dentinal walls. Therefore, it is important to determine, among the different techniques used for this purpose, which ones are least susceptible to this occurrence.

Keywords: Endodontic instruments, Instrument defects, Laboratory research, Reciprocating instruments.

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INTRODUCTION

Adequate shaping of the root canal, combined with effective cleaning, is key to the success of root canal treatment.[1] Several instrumentation techniques, with different kinematics and types of instruments, have been introduced into the market with this goal in mind.[2,3] Traditional stainless steel files and nickel–titanium (NiTi) files used in rotary and reciprocating systems are universally employed. Investigating the implications, clinical conditions, and limitations of each instrument and technique, used according to the manufacturer's instructions, is essential to improve clinical practice.

Root canal preparation can change endodontic instruments, causing wear and deformation.[4] Regardless of the type of instrument selected, prolonged use results in

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decreased cutting action and cutting efficiency.[5] Excessive stress promotes cumulative microstructural defects that induce the nucleation, growth, and merging of fatigue cracks, which propagate and may ultimately lead to instrument fracture.[6,7] Moreover, structural irregularities on the file surface may compromise instrument integrity during its use in clinical practice, making the instrument more susceptible to fracture.[8]

Wear on cutting edges and the presence of microstructural defects in endodontic instruments can be assessed using scanning electron microscopy (SEM),[9] a technology, i.e., able to produce high-definition and high-magnification images.[8,10,11] The use of SEM has been combined with energy-dispersive X-ray (EDX) spectroscopy, a method, i.e., useful in analyzing the elemental composition of different materials. More specifically, EDX allows to identify and precisely measure the concentration of the chemical elements present in different materials and types of samples.[12-14]

Most stainless steel files present high concentrations of iron, chrome, and nickel in their chemical composition.[13] The NiTi instruments, in turn, are comprised of approximately 54.2–57% of nickel and 44–45% of titanium.[14-16] Despite the large number of investigations about the use of these instruments, few studies have assessed the presence of metallic chemical elements on dentinal walls following root canal preparation. These chemical elements could impair the adhesion of endodontic sealers to dentinal walls and obliterate dentinal tubules, in addition to eventually reaching periapical tissues.

The objectives of this study were to determine the presence of metallic microfragments on dentinal walls following root canal preparation with different types of endodontic instruments using SEM and characterize their elemental composition using EDX. Moreover, the active cutting edges of instruments were assessed with regard to the presence of structural defects, also using SEM.

MATERIALS AND METHODS

In this study, 108 extracted human mandibular molars were used, following approval by the Research Ethics Committee of Universidade Luterana do Brasil, under protocol no. 967055. Sample size was calculated considering a margin error of 5% and a confidence interval of 95%, as determined in a pilot study conducted using the proposed methodology and three teeth.

Baseline digital radiographs (Spectro II, Dabi Atlante, Ribeirão Preto, Brazil) and cone-beam computed tomography scans (I-CAT; Imaging Sciences International, Hatfield, USA) were obtained to measure pulp chamber space and the diameter of distal canals. The following inclusion criteria were taken into consideration during tooth selection: The presence of fully formed, intact roots and full or partial crowns. Moreover, the distal canals of mandibular molars should have a diameter compatible with a K-File #20 (Dentsply/Maillefer®, Ballaigues, Switzerland).

To avoid interference with the study outcome, teeth showing previous root canal treatment, a second canal in the distal root, intraradicular posts, resorption, calcifications, root fractures, or amalgam restorations were discarded. Specimens were kept refrigerated and stored in plastic containers containing 0.2% thymol solution (Natufarma®, Passo Fundo, Brazil) until the beginning of study procedures.

Coronal Access and Group Distribution

For coronal access and root canal preparation, teeth were held in a vise. Following complete removal of the pulp chamber root, the distal canals of mandibular molars were located with the aid of a Rhein probe (SS White Duflex®, Pennsylvania, USA). Then, the distal canals were explored using K-FlexoFiles #10 and 15 (Dentsply/Maillefer®), introduced into the root canal by negotiation movement, using 2.5% sodium hypochlorite as irrigant (Natufarma®). Working length was determined using a #15 file passing through the exit of the apical foramen and established 1 mm short of that measure.

Subsequently, root canals were numbered 1–108, and randomly assigned to one of nine experimental groups, of 12 teeth each. In each group, root canals were prepared using a different endodontic instrument, as follows: Three manual instruments, namely, K-FlexoFile (Dentsply/Maillefer®), K-File (Dentsply/Maillefer®), and Hedstroem (Dentsply/Maillefer®); three rotary instruments, namely, ProTaper Next (Dentsply/Maillefer®), Mtwo 702 (VDW, Germany), and BioRaCe (FKG Dentaire, Switzerland); and three reciprocating instruments, namely, Reciproc (VDW), Unicone (Medin, Czech Republic), and WaveOne (Dentsply/Maillefer®). A single distal root of a mandibular molar not subjected to any type of preparation was used as control.

Root Canal Preparation

Root canal preparation was performed using 2.5% sodium hypochlorite as irrigant (2 mL at each instrument change). Following preparation, canals were irrigated with 5 mL of 17% ethylenediaminetetraacetic acid (Natufarma®) for 3 minutes to remove the smear layer, followed by a final flush with 2.5% sodium hypochlorite.

In the groups where manual instruments were employed (K-FlexoFile, K-File, Hedstroem), the cervical third (first 5 mm) of the canals was prepared using Gates-Glidden drills #2 and 3 (Dentsply/Maillefer®), and irrigated with 2.5% sodium hypochlorite at each instrument change. Subsequently, root canals were prepared using stainless steel files according to each group, using the step-back technique, with instrument sizes #15 to 40.

In the other groups (both rotary and reciprocating instrumentation), instruments were coupled to an X-Smart Plus motor (Dentsply/Maillefer®), previously set to either rotary or reciprocating mode, according to each group.

In the groups employing rotary instruments (ProTaper Next, Mtwo, BioRaCe), root canal preparation was conducted according to manufacturer's instructions, in the following sequence: ProTaper Next, X1 (17/0.04), X2 (25/0.06), X3 (30/0.07), X4 (40/0.06); Mtwo 702, 5* (25/0.07), 5 (30/0.05), 6 (35/0.04), 7 (40/0.04); BioRaCe, BR0 (25/0.08), BR1 (15/0.05), BR2 (25/0.04), BR3 (25/0.06), BR4 (35/0.04), and BR5 (40/0.04).

Finally, in the reciprocating groups (Reciproc, Unicone, WaveOne), instruments were slowly introduced into the canals using in-and-out movements and removed after three cutting cycles (3–4 mm of amplitude), with increasing pressure toward the apex, to the established working length. The following instrument sizes were used: Reciproc R#40 (#40/0.06), Unicone #40/0.06, and WaveOne Large (#40/0.08).

All steps of root canal preparation, in all teeth, were performed by a single endodontist. Each instrument was used a maximum of three times. Following preparation, tooth crowns were sectioned below the cementoenamel junction, standardizing the length of distal roots at 13 mm; distal roots were separated from the other roots using a carborundum disk (Labordental, São Paulo, Brazil).

Specimen Preparation for SEM and EDX Analysis

A longitudinal groove was made in the roots of each specimen using a metallic disk (KG Sorensen, São Paulo, Brazil) under refrigeration. With the aid of a #1 Ochsenbein periodontal chisel (SS White Duflex, Pennsylvania, USA), the root was sectioned in the buccolingual direction so as to expose the entire extent of the canal. Fragments were fixed in buffered formalin solution for 1 week. Then, fragments were dehydrated using sequential 70, 95, and 99.5% ethanol solutions (each solution was changed twice), at a total of 30 min in each solution. Specimens were critical-point dried (Autosamdri-815, Tousimis Research Corporation, Rockville, USA) and then metallized for SEM and EDX.

Specimens were examined using a Leo Stereoscan 420i SEM (Leica Electron Optics, Cambridge, UK) at 8-10 kV and a resolution of 2 nm. Images were captured and processed in the digital image tool freeware (Bruce McArthur) and initially analyzed by navigation at 100× magnification in the cervical, middle, and apical thirds to identify the presence or absence of metallic microfragments (chemical elements). Whenever present, fragments were identified by their generally irregular shape and bright surface (the brighter the microfragment, the lower is its molecular weight).

The chemical composition of elements found was assessed using the EDX NSS Spectral Analysis System 2.3 (Thermo Fisher Scientific, Suwanee, USA), with an electronic beam <50 nm, a voltage of 25 kV, and a current of 110 mA, determined according to manufacturer's specifications. Spectra were obtained for 100 s (measurement time). The same software was used to build elemental maps (spectral peaks) using the net counts method (Microsoft) at high resolution.

Instrument Preparation for SEM Analysis

After three uses, the last instrument employed to prepare each canal was stored in a flask for subsequent assessment. A total of 36 instruments, i.e., 4 from each group, were subjected to SEM analysis, as follows: FlexoFile, #40; K-File, #40; Hedstroem, #40; ProTaper Next, X4; Mtwo, 7; BioRaCe, BR5; Reciproc, R40; Unicone #40/.06; and WaveOne, Large. New (not used) instruments, one of each system, were also analyzed for comparison purposes.

The instruments selected for analysis in each group were disinfected, cleaned, and placed in plastic microtubes containing alcohol 70%. Then, they were subjected to ultrasonic cleaning to remove any contaminants adhering to the surface. Two cycles of 15 min were performed (alcohol was changed once). Instruments were mounted onto stubs using specific metallic tape and forwarded to SEM analysis.

A total of 288 SEM images of active cutting edges (16 mm) were obtained for each instrument. These images of 16 mm were divided into eight parts of 2 mm each (n = 32 areas per group). All SEM images were obtained from the convex surface (side A) of the fixation device (mandrel).

For the identification of defects on the active cutting edges of instruments, SEM images were obtained at 200× magnification. The same protocol was followed in the control group (new instruments). All images were analyzed by a single examiner (physicist) previously trained and calibrated.

Instrument surface defects were classified according to the study by Pirani et al,[14] as follows: Absence of changes, the presence of metal strips, presence of microcracks, and flattening.

Statistical Analysis

Descriptive statistical analysis (qualitative variable) was used to determine the outcome of interest. Results on instrument defects were transformed into scores as follows: 0 = absence of changes, 1 = presence of metal strips, 2 = presence of microcracks, and 3 = flattening. Data were subjected to normality testing, which resulted in a nonnormal distribution. Results were statistically analyzed using the Kruskal–Wallis test ($p \leq 0.05$) and compared using the Statistical Package for the Social Sciences version 13.0.

RESULTS

In relation to the primary outcome of interest, of the 324 areas analyzed, corresponding to the cervical, middle, and apical thirds of each canal in each group (n = 36), metallic chemical elements were found on the dentinal walls of canals prepared using manual systems (K-FlexoFile, K-File, Hedstroem) and in one canal prepared using reciprocating instrumentation (Unicone), as shown in Table 1.

The manual instrumentation group was the one with the highest presence of metallic chemical elements on the dentinal walls of instrumented root canals (Figs 1A and B). Graph 1 shows the chemical elements found in K-FlexoFile group.

Table 2 shows the results obtained for instrument defects following root canal preparation. Rotary instruments were the ones with the lowest number of defects, at a statistically significant difference in relation to the two other types of instruments ($p < 0.05$). Manual and reciprocating instruments, in turn, showed statistically similar results for this outcome ($p > 0.05$). The distribution of defects in the different file areas analyzed was statistically similar throughout the surface ($p > 0.05$). Figure 2 shows examples of defects found in two instruments.

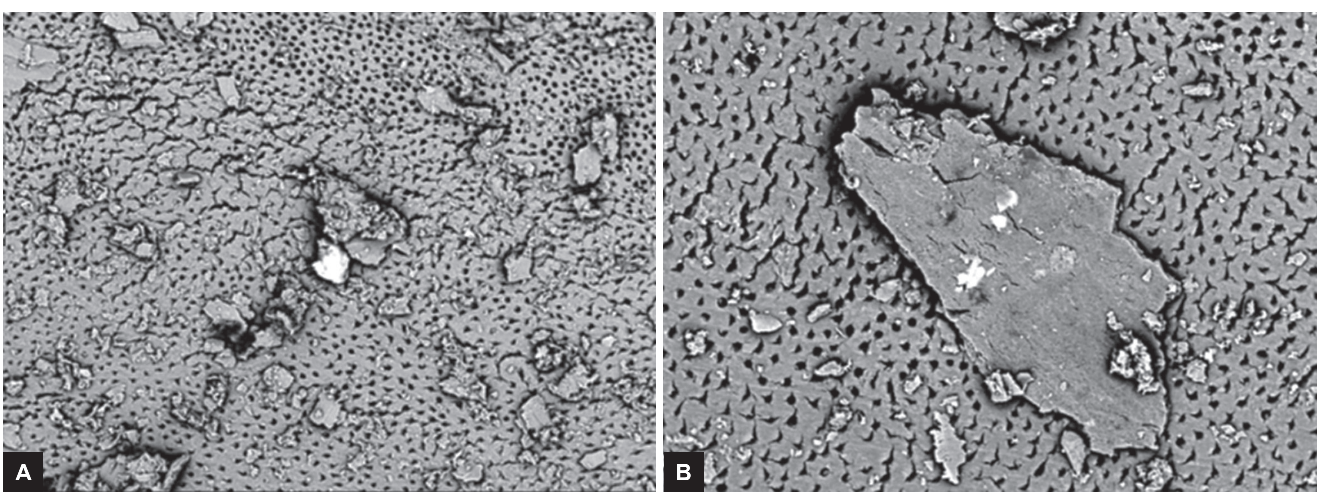
Table 1: Presence of metallic microfragments on the dentinal walls of root canals prepared using different instruments (n = 36 each group; total = 324)

Group	*Microfragments n (%)*	*No microfragments n (%)*
Manual instrumentation		
K-FlexoFile	6 (16.7)	30 (83.3)
K-File	3 (8.3)	33 (91.7)
Hedstroem	1 (2.8)	35 (97.2)
Rotary instrumentation		
ProTaper Next	0 (0)	36 (100)
Mtwo	0 (0)	36 (100)
BioRaCe	0 (0)	36 (100)
Reciprocating instrumentation		
Reciproc	0 (0)	36 (100)
Unicone	1 (2.8)	35 (97.2)
WaveOne	0 (0)	36 (100)
Total	11 (3.4)	313 (96.6)

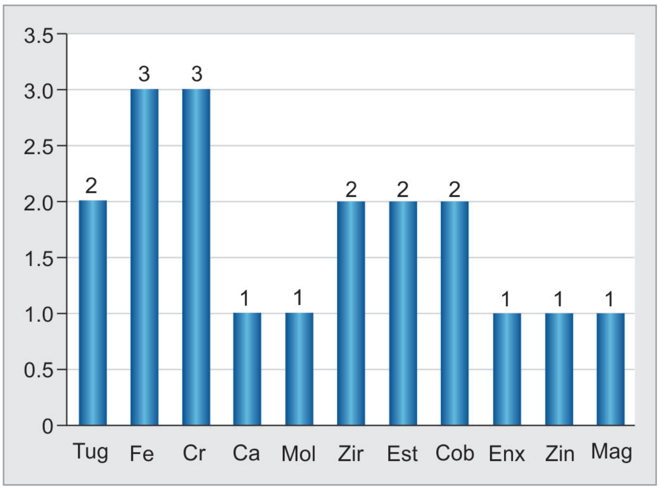
DISCUSSION

The presence of metallic microfragments on dentinal walls following root canal preparation with three different techniques (manual, rotary, and reciprocating instrumentation) was observed only in the groups employing manual and reciprocating systems (Table 1). The strongest presence of chemical elements found in association with stainless steel instruments (in our study, K-FlexoFile, K-File, Hedstroem) was probably due to the type of alloy used in fabrication, i.e., different from the NiTi alloy found in the other two types of instruments. Even though the rotary (ProTaper Next, Mtwo, BioRaCe) and reciprocating (Reciproc, Unicone, WaveOne) instruments showed a similar chemical composition, only one canal in the group instrumented with Unicone files showed metallic elements on dentinal walls. In relation to this outcome, no statistically significant differences were found between groups, canal thirds, or in regard to the chemical elements found ($p \geq 0.05$).

Zinelis et al[15] observed that the elemental composition of most NiTi instruments ranged from 54.5 to 57%



Figs 1A and B: The SEM images showing the presence of metallic fragments on dentinal walls: 400× (A) and 700× (B) magnification



Graph 1: Chemical characterization of metallic fragments found on the surface of the dentinal walls of root canals in the K-FlexoFile groups

Table 2: Instrument surface defects after use (n = 32; total = 288)

	Type of defect			
Group	*Absent*	*Metal strips*	*Microcracks*	*Flattening*
Manual instrumentation				
K-FlexoFile	18	0	1	13
K-File	21	0	0	11
Hedstroem	27	0	0	5
Rotary instrumentation				
ProTaper Next*	30	0	0	2
Mtwo*	31	0	1	0
BioRaCe*	29	2	0	1
Reciprocating instrumentation				
Reciproc	24	8	0	0
Unicone	17	11	0	4
WaveOne	18	8	1	5
Total	215	29	3	41

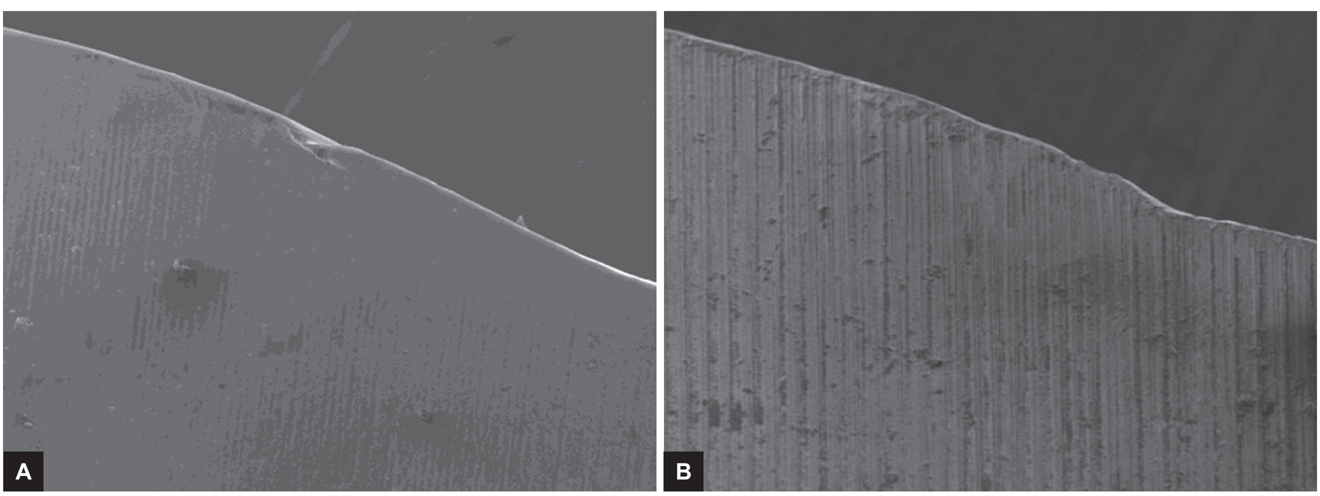
*Kruskal–Wallis test, $p < 0.05$

for nickel weight, which is within limits established for NiTi alloys used for medical applications.[17]

The defects found in the instruments used in this study are probably due to fabrication defects that are inherent to NiTi[17] and stainless steel files.[18] According to Walia et al,[19] NiTi instruments are subjected to grinding during fabrication, eventually causing structural defects or the presence of metal strips on their cutting edges. These defects could detach from the files and adhere to root canal walls, potentially impairing the adhesion of endodontic sealers, obliterating dentinal tubules, in addition to adhering to the smear layer and potentially being extruded from the apical foramen into periapical tissues. Despite the improved finishing of new-generation endodontic instruments, they have still been shown to present surface defects.[17]

During root canal preparation, a smear layer is produced, resulting from the action of the instruments on root canal walls. This layer is present to a greater or lesser extent, depending on the type of instrument employed. The smear layer comprises both organic and inorganic components[20,21] and it adheres to root canal walls, obliterating the entry of dentinal tubules and, therefore, reducing dentin permeability.[22] In fact, the results of this study suggest that the concept of smear layer should be revised, as metallic microfragments were found to be adhered to it in samples from different groups. It could be speculated, then, that the smear layer can also have a metallic component.

The EDX allows to determine the composition and distribution of chemical elements in different materials and has been increasingly used in endodontics.[12,14,15,23] In our sample, the presence of chemical elements was relatively low. One explanation for this could be that only the distal canals of mandibular molars were analyzed, and these canals are usually wide and proximally



Figs 2A and B: The SEM showing metal strips on a BioRaCe file: (A) Flattening on a ProTaper Next file; and (B) 200× magnification flattened.[24] Previous studies[25,26] had already reported that endodontic instruments usually do not touch all dentinal walls of wide, flattened canals during the shaping process. We chose to use mandibular molars so as to replicate a common clinical situation.

The SEM analysis is regarded in the literature as a well-documented method for the precise assessment of morphological characteristics[11,27] and defects of endodontic instruments. The criteria used to assess instrument defects following root canal preparation in this study (metal strips, microcracks, and flattening) were based on Pirani et al.[14] In our sample, rotary instruments showed a significantly lower number of defects when compared with their manual and reciprocating counterparts ($p \geq 0.05$) (Table 2).

Conversely, considering only the first 2 mm of the file tip, a statistically significant difference was also found between the different reciprocating instruments employed, namely, Reciproc showed a lower number of defects than Unicone and WaveOne ($p < 0.05$). These data are in line with the study by Pirani et al,[14] in which the most frequent defect was associated with wear at the tip of Reciproc and WaveOne instruments – the part of the file that most commonly deforms. Considering all the file areas assessed in the different groups, no statistically significant differences were found ($p \geq 0.05$).

The mechanical stress imposed on instruments is not uniformly distributed over the extent of the file.[28,29] During the laboratory phase of this study, none of the instruments fractured, and no macroscopic signs of deformation or spiral distortion could be found in any of the groups. This absence of fractures may be explained by the professional experience of the operator and by the small number of microcracks found – only three instruments showed this defect (FlexoFile, Mtwo, and WaveOne). Moreover, there is evidence in the literature suggesting that microcracks may increase the occurrence of endodontic instrument fracture during root canal preparation.[6,7]

Overall, root canal preparation protocols always follow the same sequence: Exploration, preflaring, patency/measurement with manual files, apical enlargement to file #15, and instrumentation with manual and/or rotary files. However, when reciprocating systems are chosen, the use of a single file is advocated[2,30]; this is why a different preparation protocol was followed in the groups employing reciprocating instruments. Despite the existence of several publications on the use of endodontic systems and instruments, these should be selected after careful consideration of their chemical composition, regardless of the instrumentation technique, fabrication method, or type of alloy employed, as fractures and deformation are frequent in endodontic practice. Moreover, the importance of starting and finishing chemical–mechanical preparation with manual instruments should be highlighted, so as to ensure the elimination of interferences, the establishment of patency, and a larger area of contact between instruments and root canal walls. The primary goal of these different methods available is to congregate the best technical qualities of each system and instrument available and use them to maximize results.

CONCLUSION

The presence of metallic microfragments on dentinal walls following root canal preparation was observed only in the groups where manual and reciprocating instruments were used. Furthermore, rotary systems were the ones with the lowest number of defects, at a statistically significant difference in relation to the other two types of instruments. Considering the outcomes measured in this study, rotary instruments performed better than the other two groups, as they were associated with the lowest number of metallic microfragments and structural defects.

CLINICAL SIGNIFICANCE

Root canal preparation is key to endodontic success. During instrumentation, operative procedures may induce changes to the root canal shape, as well as the release of metallic fragments resulting from the action of instruments on dentinal walls. Therefore, it is important to determine, among the different techniques used for this purpose, which ones are least susceptible to this occurrence.

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